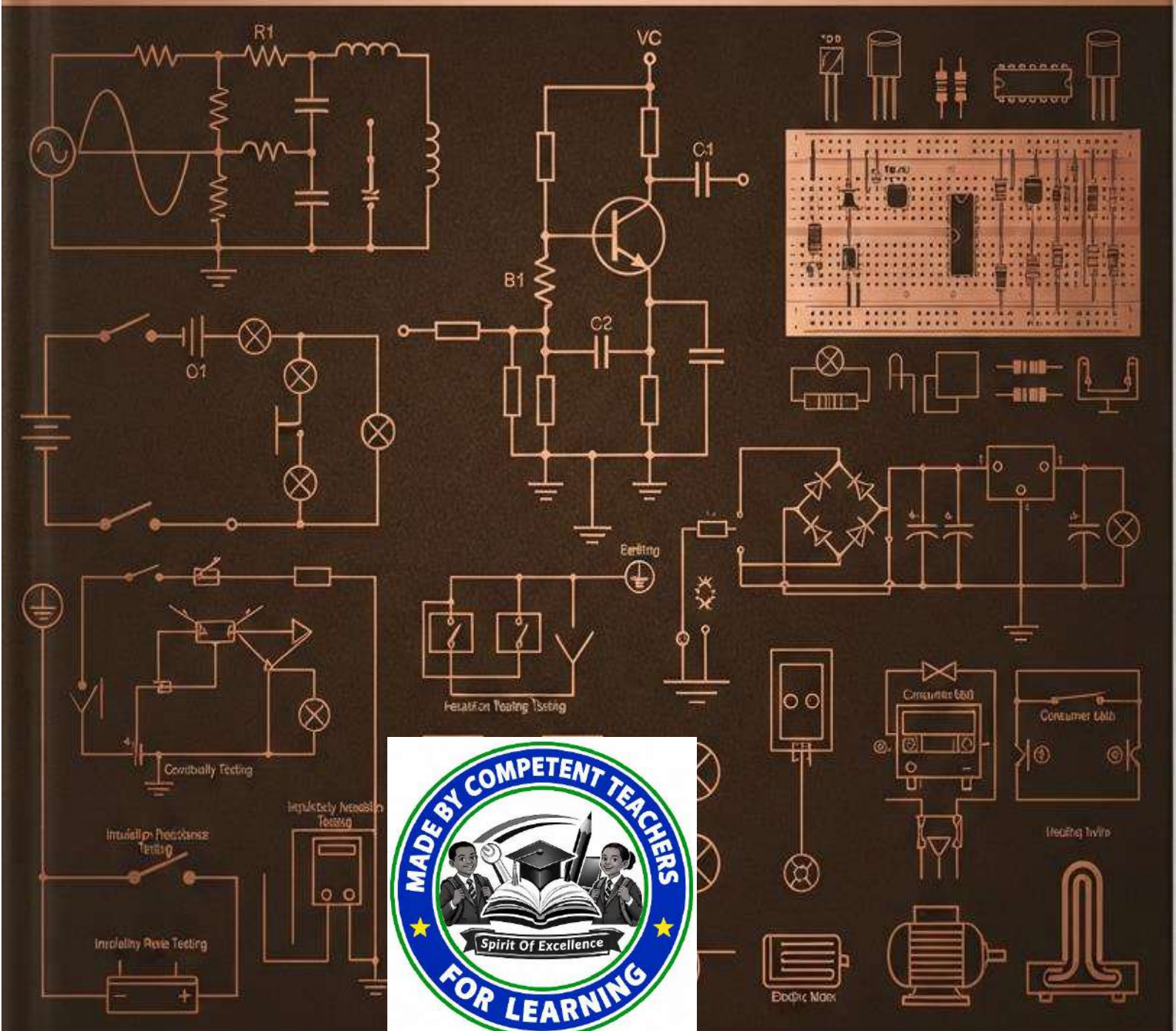
CERTIFICATE OF BASIC EDUCATION
SENIOR SCHOOL CURRICULUM
GRADE 11 ELECTRICITY TECHNOLOGY NOTES
COMPETENCY-BASED EDUCATION



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Spirit Of Excellence

STRAND 1.0: FUNDAMENTALS OF ELECTRICITY I

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SUB-STRAND 1.1: SINGLE-PHASE AC CIRCUITS

1.0 STRAND: FUNDAMENTALS OF ELECTRICITY

1.1 Sub-strand: Single-Phase AC Circuits

INTRODUCTION

Electricity is an essential form of energy used in homes, schools, industries, hospitals, businesses and other institutions.

It provides energy for operating:

- Lighting systems.
- Computers and electronic equipment.
- Refrigerators and freezers.
- Electric motors.
- Communication equipment.
- Industrial machines.
- Water pumps.
- Cooking appliances.

In Kenya, most electricity supplied to homes, schools and commercial buildings is alternating current (AC).

Understanding single-phase AC circuits enables learners to understand how electrical energy is generated, transmitted, distributed and used safely.

This sub-strand covers:

1. Generation of single-phase alternating current.
2. Characteristics of sinusoidal waveforms.
3. Behaviour of resistors in AC circuits.
4. Behaviour of inductors in AC circuits.
5. Behaviour of capacitors in AC circuits.
6. Analysis of resistor-inductor-capacitor (RLC) circuits.
7. Construction and testing of AC circuits.
8. Measurement of AC quantities using electrical instruments.
9. Applications of AC electricity in everyday life.
10. Electrical safety and troubleshooting.

1.1.1 INTRODUCTION TO ALTERNATING CURRENT (AC)

A. Meaning of Electricity

Electricity is a form of energy associated with the presence and movement of electric charges, particularly electrons.

Uses of electricity

Electricity is used to:

1. Produce light in lamps and bulbs.
2. Generate heat in electric cookers and irons.
3. Operate electric motors.
4. Power electronic equipment.
5. Operate communication devices.

6. Run industrial machines.
7. Charge batteries and other energy-storage devices.

B. Meaning of Electric Current

Electric current is the rate of flow of electric charge through a conductor.

- Symbol: I
- SI unit: Ampere (A)

The mathematical relationship is:

$$I = \frac{Q}{t}$$

Where:

- I = Electric current in amperes (A).
- Q = Electric charge in coulombs (C).
- t = Time in seconds (s).

Worked Example 1

A charge of 60 coulombs flows through a conductor in 10 seconds. Calculate the current.

Solution

Given:

$$Q = 60C, \quad t = 10s$$

Formula:

$$I = \frac{Q}{t}$$

Substitution:

$$I = \frac{60}{10}$$

$$\boxed{I = 6A}$$

Therefore, the current flowing through the conductor is 6 amperes.

C. Types of Electric Current

Electric current is broadly classified into two main types:

1. Direct Current (DC).
2. Alternating Current (AC).

1. Direct Current (DC)

Direct current is an electric current that flows continuously in one direction through a conductor.

Characteristics of DC

1. Flows in one direction.
2. Has fixed polarity.
3. Its magnitude may be constant or may vary with time.
4. It is commonly supplied by batteries and DC power supplies.
5. It is used in electronic circuits and battery-powered equipment.

Examples of DC sources

- Dry cells.
- Rechargeable batteries.
- Solar photovoltaic panels.
- DC generators.
- Battery packs.

Applications of DC

- Mobile phones.
- Laptop computers.
- Torches.
- Solar battery-storage systems.
- Electronic equipment.
- Battery-operated toys.

2. Alternating Current (AC)

Alternating current is an electric current that periodically changes both its magnitude and direction.

Unlike DC, alternating current reverses its direction at regular intervals.

Characteristics of AC

1. Changes direction periodically.
2. Its magnitude varies with time.
3. It is commonly represented by a sinusoidal waveform.
4. Its voltage can be changed using transformers.
5. It is widely used in electricity generation, transmission and distribution.
6. It is suitable for supplying homes, schools and industries.

Examples of AC sources

- Alternators.
- Electrical power stations.
- AC generators.
- AC mains electricity supply.

Applications of AC

- Lighting systems.
- Electric cookers.
- Refrigerators.
- Washing machines.
- Water pumps.
- Air conditioners.
- Industrial motors.
- Electric fans.

D. Differences Between AC and DC

Alternating Current (AC)	Direct Current (DC)
Changes direction periodically.	Flows in one direction.
Its magnitude varies with time in a sinusoidal sup-	May have constant or varying magnitude.

Alternating Current (AC)	Direct Current (DC)
ply.	
Has frequency.	Steady DC has zero frequency.
Can easily be transformed using transformers.	Requires electronic conversion to change voltage levels.
Used in mains electricity supply.	Used in batteries and electronic circuits.
Commonly generated by alternators.	Commonly supplied by batteries and solar panels.

1.1.2 GENERATION OF SINGLE-PHASE ALTERNATING CURRENT

A. Meaning of Electromagnetic Induction

Electromagnetic induction is the process through which an electromotive force (EMF) is produced in a conductor when the magnetic flux linking the conductor changes.

The induced EMF can cause current to flow when the conductor forms part of a closed circuit.

Electromagnetic induction is the basic principle used in AC generators and alternators.

B. Faraday's Laws of Electromagnetic Induction

Michael Faraday established the laws of electromagnetic induction.

First Law

Whenever the magnetic flux linking a conductor or circuit changes, an electromotive force is induced in that conductor or circuit.

If the circuit is closed, an electric current flows.

Second Law

The magnitude of the induced electromotive force is directly proportional to the rate of change of magnetic flux linkage.

Mathematically:

$$E = -N\frac{\Delta\Phi}{\Delta t}$$

Where:

- E = Induced electromotive force (V).
- N = Number of turns in the coil.
- $\Delta\Phi$ = Change in magnetic flux (Wb).
- Δt = Time taken for the change (s).

The negative sign represents Lenz's law.

C. Lenz's Law

Lenz's law states that the direction of an induced current is such that its magnetic effect opposes the change in magnetic flux that produces it.

Importance of Lenz's law

1. Explains the direction of induced current.

2. Demonstrates the conservation of energy.
3. Helps determine the direction of induced EMF.
4. Explains the opposing torque experienced by a generator coil.

D. Principle of Operation of an AC Generator

An AC generator works on the principle of electromagnetic induction.

It converts mechanical energy into electrical energy.

When a coil rotates in a magnetic field, the magnetic flux linking the coil continuously changes. Consequently, an alternating EMF is induced in the coil.

When the coil is connected to an external circuit, alternating current flows.

E. Main Parts of a Simple AC Generator

1. **Field magnets:** Produce the magnetic field in which the coil rotates.
2. **Armature coil:** A coil of insulated copper wire in which EMF is induced.
3. **Shaft:** Supports the rotating coil and transfers mechanical motion.
4. **Slip rings:** Two separate conducting rings connected to the ends of the rotating coil.
5. **Carbon brushes:** Maintain electrical contact between the rotating slip rings and the external circuit.
6. **External load:** The electrical device or circuit supplied by the generator.
7. **Prime mover:** Supplies the mechanical energy needed to rotate the generator.

F. How an AC Generator Works

1. Mechanical energy is supplied to the generator by a prime mover.
2. The shaft rotates the armature coil between the magnetic poles.
3. As the coil rotates, it cuts through magnetic field lines.
4. The magnetic flux linking the coil changes continuously.
5. An EMF is induced in the coil through electromagnetic induction.
6. The direction of induced EMF changes after every half rotation.
7. Slip rings transfer the induced alternating voltage to the external circuit through carbon brushes.
8. Alternating current flows through the connected load.

G. Position of the Coil During One Complete Rotation

A rotating coil passes through five important positions.

Position 1: 0°

- The plane of the coil is perpendicular to the magnetic field.
- The rate of change of magnetic flux linkage is zero.
- The induced EMF is zero.

Position 2: 90°

- The plane of the coil is parallel to the magnetic field.
- The rate of change of magnetic flux linkage is maximum.
- The induced EMF is maximum.

Position 3: 180°

- The coil completes half a revolution.
- The induced EMF becomes zero.
- The direction of the induced EMF reverses after this position.

Position 4: 270°

- The induced EMF reaches its maximum value in the opposite direction.

Position 5: 360°

- The coil completes one revolution.
- The induced EMF returns to zero.
- One complete AC cycle has been generated.

H. Factors Affecting the Magnitude of Induced EMF

The induced EMF in an AC generator depends on:

1. **Number of turns in the coil:** Increasing the number of turns increases the induced EMF.
2. **Strength of the magnetic field:** A stronger magnetic field produces a greater induced EMF.
3. **Speed of rotation:** Increasing rotational speed increases the rate of change of magnetic flux.
4. **Area of the coil:** A larger coil area increases the magnetic flux linkage.
5. **Orientation of the coil:** The induced EMF varies according to the position of the rotating coil.

I. Types of Electrical Generators

1. AC Generator (Alternator)

An alternator converts mechanical energy into alternating electrical energy.

Applications:

- Electricity generation stations.
- Standby generators.
- Vehicle charging systems.
- Wind turbines.
- Small hydroelectric generating systems.

2. DC Generator

A DC generator converts mechanical energy into direct electrical energy.

It uses a split-ring commutator instead of two separate slip rings.

Applications:

- Specialised industrial DC supplies.
- Battery-charging systems.
- Laboratory DC power systems.

J. Sources of Mechanical Energy Used in Electricity Generation in Kenya

Mechanical energy used to rotate generators can come from different sources.

1. **Hydroelectric power:** Flowing or falling water rotates turbines connected to generators.
2. **Geothermal energy:** Steam from underground geothermal reservoirs drives turbines.
3. **Wind energy:** Wind rotates turbine blades connected to generators.
4. **Thermal power:** Steam produced by heating water drives turbines.
5. **Diesel generators:** Diesel engines rotate alternators.
6. **Biomass power:** Energy from organic materials can be used to produce heat or mechanical power for electricity generation.

Examples of Kenyan electricity generation facilities

- Olkaria geothermal power stations.
- Turkwel hydroelectric power station.
- Kiambere hydroelectric power station.
- Gitaru hydroelectric power station.
- Lake Turkana Wind Power project.

K. Importance of AC Generators

1. Generate electrical power for domestic use.
2. Supply electricity to schools and hospitals.
3. Support industrial production.
4. Provide standby electricity during power interruptions.
5. Support electricity generation from renewable energy sources.
6. Supply power to commercial buildings.
7. Support economic development.

1.1.3 SINGLE-PHASE ALTERNATING CURRENT

A. Meaning of Single-Phase AC

Single-phase alternating current is an AC electrical supply consisting of one alternating voltage wave-form.

It is commonly used for domestic and light commercial electrical installations.

In a typical single-phase system, the supply has:

1. One live conductor.
2. One neutral conductor.
3. A protective earth conductor for safety.

The protective earth conductor is not normally a current-carrying conductor during normal operation.

B. Characteristics of Single-Phase AC Supply

1. Has one alternating voltage waveform.
2. Voltage changes periodically.
3. Current reverses direction periodically.
4. Has a measurable frequency.
5. Commonly used in domestic electrical installations.
6. Can supply lighting, socket outlets and household appliances.

Kenyan application

Domestic electricity supply in Kenya is nominally 230 V, 50 Hz single-phase AC. Actual voltage may vary within permitted supply limits.

C. Difference Between Single-Phase and Three-Phase AC

Single-phase AC	Three-phase AC
Has one alternating voltage waveform.	Has three alternating voltage waveforms.
Commonly used in homes.	Commonly used in larger commercial and industrial installations.
Suitable for light electrical loads.	Suitable for heavy electrical loads and large motors.
Uses one phase and neutral in a typical supply.	Uses three phase conductors, with or without neutral.
Power delivery to a resistive load is pulsating.	Balanced three-phase power delivery is approximately constant.

1.1.4 SINUSOIDAL WAVEFORMS IN AC CIRCUITS

A. Meaning of a Waveform

A waveform is a graphical representation showing how an electrical quantity, such as voltage or current, changes with time.

Waveforms help electrical technicians understand the behaviour of AC circuits.

Common types of waveforms

1. Sinusoidal waveform.
2. Square waveform.
3. Triangular waveform.
4. Sawtooth waveform.
5. Pulse waveform.

B. Meaning of a Sinusoidal Waveform

A sinusoidal waveform is a smooth, periodic waveform whose shape follows a sine or cosine mathematical function.

It is commonly produced by rotating AC generators.

The instantaneous voltage of a sinusoidal AC supply is given by:

$$v = V_m \sin\omega t$$

Where:

- v = Instantaneous voltage (V).
- V_m = Maximum or peak voltage (V).
- ω = Angular frequency (rad/s).
- t = Time (s).

For a sinusoidal current:

$$i = I_m \sin\omega t$$

Where:

- i = Instantaneous current (A).
- I_m = Maximum or peak current (A).

C. Important Quantities of a Sinusoidal Waveform

1. Cycle

A cycle is one complete sequence of positive and negative alternations of an AC waveform.

A complete cycle represents 360 electrical degrees.

For a sinusoidal waveform:

- Positive half-cycle = 180°.
- Negative half-cycle = 180°.
- Complete cycle = 360°.

2. Frequency

Frequency is the number of complete cycles produced per second.

- Symbol: f
- SI unit: Hertz (Hz).

Formula:

$$f = \frac{1}{T}$$

Where:

- f = Frequency in hertz.
- T = Period in seconds.

Worked Example 2

An AC supply completes 50 cycles in one second. Determine its frequency.

Formula:

$$f = \frac{\text{Number of cycles}}{\text{Time}}$$

Substitution:

$$f = \frac{50}{1}$$

$$\boxed{f = 50Hz}$$

3. Periodic Time

Period is the time taken by an AC waveform to complete one full cycle.

- Symbol: T
- SI unit: Seconds (s).

Formula:

$$T = \frac{1}{f}$$

Worked Example 3

Calculate the period of a 50 Hz AC supply.

$$T = \frac{1}{50}$$

$$\boxed{T = 0.02s}$$

Therefore, the supply takes 0.02 seconds to complete one cycle.

4. Amplitude

Amplitude is the maximum displacement of a waveform from its zero reference position.

For an AC voltage waveform, amplitude is the maximum voltage measured from zero to the positive or negative peak.

It is also called the peak value.

5. Peak Value

Peak value is the maximum instantaneous value reached by an alternating voltage or current.

It is represented by:

- V_m for peak voltage.
- I_m for peak current.

6. Peak-to-Peak Value

Peak-to-peak value is the total difference between the maximum positive peak and maximum negative peak of an AC waveform.

For a symmetrical sinusoidal waveform:

$$V_{pp} = 2V_m$$

Similarly:

$$I_{pp} = 2I_m$$

Worked Example 4

An AC voltage has a peak value of 100 V. Determine its peak-to-peak voltage.

$$V_{pp} = 2V_m$$

$$V_{pp} = 2 \times 100$$

$$\boxed{V_{pp} = 200V}$$

7. Instantaneous Value

Instantaneous value is the value of an alternating voltage or current at a particular moment in time.

It changes continuously during each cycle.

For voltage:

$$v = V_m \sin\omega t$$

For current:

$$i = I_m \sin\omega t$$

Worked Example 5

An AC voltage has a peak value of 100 V. Calculate its instantaneous value at an electrical angle of 30°.

Formula:

$$v = V_m \sin\theta$$

Substitution:

$$v = 100\sin 30°$$

Since:

$$\sin 30° = 0.5$$

Therefore:

$$v = 100 \times 0.5$$

$$\boxed{v = 50V}$$

8. Root Mean Square (RMS) Value

RMS value is the effective value of an alternating voltage or current that produces the same heating effect in a resistor as an equivalent DC voltage or current.

It is the most commonly used value when specifying AC voltage and current.

For a sinusoidal voltage:

$$V_{rms} = \frac{V_m}{\sqrt{2}}$$

Or:

$$V_{rms} = 0.707 V_m$$

For a sinusoidal current:

$$I_{rms} = \frac{I_m}{\sqrt{2}}$$

Or:

$$I_{rms} = 0.707 I_m$$

Worked Example 6

Calculate the RMS voltage of an AC supply whose peak voltage is 325 V.

$$V_{rms} = 0.707 V_m$$

$$V_{rms} = 0.707 \times 325$$

$$\boxed{V_{rms} = 229.8V}$$

This is approximately 230 V.

9. Average Value

The average value of an AC waveform is the arithmetic mean of its instantaneous values over a specified interval.

For a symmetrical sinusoidal waveform over one complete cycle:

$$V_{avg} = 0$$

This is because the positive and negative half-cycles cancel each other.

For one positive half-cycle:

$$V_{avg} = \frac{2V_m}{\pi}$$

Or:

$$V_{avg} = 0.637V_m$$

Similarly, for current:

$$I_{avg} = 0.637I_m$$

The average value over a complete cycle of a symmetrical sine wave is zero, while the average over a rectified waveform is different.

10. Angular Frequency

Angular frequency is the rate at which the electrical angle of a sinusoidal waveform changes with time.

- Symbol: ω
- Unit: Radians per second (rad/s).

Formula:

$$\omega = 2\pi f$$

Worked Example 7

Calculate the angular frequency of a 50 Hz AC supply.

$$\omega = 2\pi f$$

$$\omega = 2 \times 3.142 \times 50$$

11. Phase Angle

Phase angle is the angular difference between two alternating waveforms of the same frequency.

It is measured in degrees or radians.

Two waveforms may be:

- In phase.
- Leading.
- Lagging.

12. Phase Difference

Phase difference is the amount by which one alternating waveform leads or lags another waveform.

It is important when analysing AC circuits containing resistors, inductors and capacitors.

1.1.5 RELATIONSHIP BETWEEN AC WAVEFORM QUANTITIES

The following relationships are important when analysing sinusoidal AC waveforms.

Quantity	Formula
Frequency	$f = \frac{1}{T}$
Period	$T = \frac{1}{f}$
Angular frequency	$\omega = 2\pi f$
Peak voltage	$V_m = \sqrt{2}V_{rms}$
RMS voltage	$V_{rms} = 0.707V_m$
Peak current	$I_m = \sqrt{2}I_{rms}$
RMS current	$I_{rms} = 0.707I_m$
Peak-to-peak voltage	$V_{pp} = 2V_m$
Average half-cycle voltage	$V_{avg} = 0.637V_m$

Worked Example 8: AC Waveform Calculations

An AC voltage has an RMS value of 230 V and a frequency of 50 Hz. Determine:

a) Peak voltage.

b) Peak-to-peak voltage.

c) Period.

d) Angular frequency.

Solution

a) Peak voltage

$$V_m = \sqrt{2} \times 230$$

$$\boxed{V_m = 325.3V}$$

b) Peak-to-peak voltage

$$V_{pp} = 2 \times 325.3$$

$$\boxed{V_{pp} = 650.6V}$$

c) Period

$$T = \frac{1}{50}$$

$$\boxed{T = 0.02s}$$

d) Angular frequency

$$\omega = 2\pi \times 50$$

1.1.6 RESISTORS IN AC CIRCUITS

A. Meaning of a Resistor

A resistor is an electrical component designed to oppose the flow of electric current in an electrical circuit.

The opposition offered by a resistor is called resistance.

- Symbol: R
- SI unit: Ohm (Ω).

B. Electrical Symbol of a Resistor

In circuit diagrams, a resistor is commonly represented by a rectangular or zigzag symbol, depending on the drawing convention used.

C. Characteristics of a Resistor in an AC Circuit

When a pure resistor is connected to an AC supply:

1. It opposes the flow of alternating current.
2. The current increases and decreases as the applied voltage changes.
3. Voltage and current reach their maximum values at the same time.
4. Voltage and current are said to be in phase.
5. The phase difference between voltage and current is zero degrees.
6. Electrical energy is converted mainly into heat.
7. The resistor consumes real electrical power.

D. Relationship Between Voltage, Current and Resistance

Ohm's law applies to a pure resistive AC circuit when voltage and current are expressed using RMS values.

$$V = IR$$

Where:

- V = RMS voltage (V).
- I = RMS current (A).
- R = Resistance (Ω).

Rearranging the formula:

$$I = \frac{V}{R}$$

$$R = \frac{V}{I}$$

Worked Example 9

A 50 Ω resistor is connected to a 230 V AC supply. Calculate the current flowing through the resistor.

Solution

Given:

$$R = 50\Omega$$

$$V = 230V$$

Using Ohm's law:

$$I = \frac{V}{R}$$

Substitution:

$$I = \frac{230}{50}$$

$$\boxed{I = 4.6A}$$

Therefore, the current flowing through the resistor is 4.6 A.

E. Power in a Resistive AC Circuit

Electrical power is the rate at which electrical energy is converted into another form of energy.

For a pure resistive AC circuit:

$$P = VI$$

Other useful formulae are:

$$P = I^2R$$

$$P = \frac{V^2}{R}$$

Where:

- P = Real power (W).
- V = RMS voltage (V).
- I = RMS current (A).
- R = Resistance (Ω).

Worked Example 10

A 100 Ω resistor is connected to a 200 V AC supply. Calculate the power consumed.

Solution

Given:

$$V = 200V, \quad R = 100\Omega$$

Formula:

$$P = \frac{V^2}{R}$$

Substitution:

$$P = \frac{200^2}{100}$$

$$P = \frac{40000}{100}$$

$$\boxed{P = 400W}$$

F. Applications of Resistors

Resistors are used in:

1. Electric heaters.
2. Electric irons.
3. Incandescent lamps.
4. Electronic circuits.
5. Current-limiting circuits.
6. Voltage-dividing circuits.
7. Testing and measuring equipment.

1.1.7 INDUCTORS IN AC CIRCUITS

A. Meaning of an Inductor

An inductor is a passive electrical component consisting of a coil of insulated conducting wire designed to store energy in a magnetic field when current flows through it.

An inductor opposes changes in electric current.

The ability of an inductor to oppose changes in current is called inductance.

- Symbol: L
- SI unit: Henry (H).

B. Principle of Operation of an Inductor

An inductor operates on the principle of electromagnetic induction.

When alternating current flows through the coil:

1. A magnetic field is produced around the coil.
2. The magnetic field changes as the current changes.
3. The changing magnetic field induces a back EMF in the coil.
4. The induced EMF opposes the change in current.
5. The inductor stores and releases energy in its magnetic field.

C. Inductive Reactance

Inductive reactance is the opposition offered by an inductor to the flow of alternating current.

- Symbol: X_L
- SI unit: Ohm (Ω).

Formula:

$$X_L = 2\pi f L$$

Where:

- X_L = Inductive reactance (Ω).
- f = Frequency (Hz).
- L = Inductance (H).
- $\pi = 3.142$.

D. Factors Affecting Inductive Reactance

1. **Frequency:** Inductive reactance increases when frequency increases.
2. **Inductance:** Inductive reactance increases when inductance increases.

This means that an inductor offers greater opposition to high-frequency alternating current than to low-frequency alternating current.

Worked Example 11: Calculating Inductive Reactance

An inductor of 0.2 H is connected to a 50 Hz AC supply. Calculate its inductive reactance.

Given:

$$L = 0.2H$$

$$f = 50Hz$$

Formula:

$$X_L = 2\pi fL$$

Substitution:

$$X_L = 2 \times 3.142 \times 50 \times 0.2$$

$$\boxed{X_L = 62.84\Omega}$$

E. Current in a Pure Inductive Circuit

For a pure inductive AC circuit:

$$I = \frac{V}{X_L}$$

Where:

- I = RMS current (A).
- V = RMS voltage (V).
- X_L = Inductive reactance (Ω).

Worked Example 12

A 0.1 H inductor is connected to a 230 V, 50 Hz AC supply. Calculate:

a) Inductive reactance.

b) Current flowing through the inductor.

Solution

a) Inductive reactance

$$X_L = 2\pi fL$$

$$X_L = 2 \times 3.142 \times 50 \times 0.1$$

$$\boxed{X_L = 31.42\Omega}$$

b) Current

$$I = \frac{V}{X_L}$$

$$I = \frac{230}{31.42}$$

$$\boxed{I = 7.32A}$$

F. Phase Relationship in a Pure Inductive Circuit

In a pure inductive AC circuit:

1. Current lags behind voltage by 90°.
2. Voltage leads current by 90°.
3. The circuit does not consume average real power in an ideal inductor.
4. Energy is temporarily stored in the magnetic field and returned to the supply.

G. Applications of Inductors

Inductors are used in:

1. Transformers.
2. Electric motors.
3. Generators.
4. Chokes.
5. Radio-frequency circuits.
6. Power supply filtering.
7. Electromagnetic devices.
8. Electrical energy conversion systems.

1.1.8 CAPACITORS IN AC CIRCUITS

A. Meaning of a Capacitor

A capacitor is a passive electrical component that stores electrical energy in an electric field between two conducting plates separated by an insulating material called a dielectric.

The ability of a capacitor to store electric charge is called capacitance.

- Symbol: C
- SI unit: Farad (F).

B. Main Parts of a Capacitor

1. First conducting plate.
2. Second conducting plate.
3. Dielectric material.
4. Connecting terminals.

C. Principle of Operation of a Capacitor

When a capacitor is connected to a voltage source:

1. Electric charges accumulate on the two conducting plates.
2. One plate becomes positively charged.
3. The other plate becomes negatively charged.
4. An electric field develops between the plates.
5. Electrical energy is stored in the electric field.
6. When the capacitor is connected to a suitable discharge path, it releases its stored energy.

D. Types of Capacitors

1. Ceramic Capacitors

- Use ceramic material as the dielectric.
- Commonly used in electronic circuits.
- Often suitable for high-frequency applications.

2. Electrolytic Capacitors

- Commonly used for relatively large capacitance values.
- Usually polarised.
- Must be connected with correct polarity in DC circuits.
- Commonly found in power supply circuits.

3. Film Capacitors

- Use plastic film as the dielectric.
- Commonly used in electronic and electrical circuits.
- Available in different capacitance values.

4. Variable Capacitors

- Their capacitance can be adjusted.
- Used in tuning circuits.
- Commonly associated with radio-frequency applications.

E. Capacitive Reactance

Capacitive reactance is the opposition offered by a capacitor to the flow of alternating current.

- Symbol: X_C
- SI unit: Ohm (Ω).

Formula:

$$X_C = \frac{1}{2\pi f C}$$

Where:

- X_C = Capacitive reactance (Ω).
- f = Frequency (Hz).
- C = Capacitance (F).

F. Factors Affecting Capacitive Reactance

1. **Frequency:** Capacitive reactance decreases as frequency increases.
2. **Capacitance:** Capacitive reactance decreases as capacitance increases.

A capacitor therefore offers greater opposition to low-frequency AC than to high-frequency AC.

Worked Example 13: Calculating Capacitive Reactance

A capacitor of 100 μF is connected to a 50 Hz AC supply. Calculate its capacitive reactance.

Given:

$$C = 100\mu F$$

$$f = 50Hz$$

First, convert microfarads into farads.

$$100\mu F = 100 \times 10^{-6} F$$

$$C = 0.0001F$$

Formula:

$$X_C = \frac{1}{2\pi f C}$$

Substitution:

$$X_C = \frac{1}{2 \times 3.142 \times 50 \times 0.0001}$$

$$X_C = \frac{1}{0.03142}$$

$$\boxed{X_C = 31.83\Omega}$$

G. Current in a Pure Capacitive Circuit

$$I = \frac{V}{X_C}$$

Where:

- I = RMS current (A).
- V = RMS voltage (V).
- X_C = Capacitive reactance (Ω).

Worked Example 14

A capacitor has a reactance of 40 Ω and is connected to a 200 V AC supply. Calculate the current.

Solution

$$I = \frac{V}{X_C}$$

$$I = \frac{200}{40}$$

$$\boxed{I = 5A}$$

H. Phase Relationship in a Pure Capacitive Circuit

In a pure capacitive AC circuit:

1. Current leads voltage by 90°.
2. Voltage lags current by 90°.
3. Energy is stored temporarily in the electric field.
4. The capacitor returns stored energy to the supply.
5. An ideal capacitor does not consume average real power.

I. Applications of Capacitors

Capacitors are used in:

1. Ceiling fan circuits.
2. Electric motor starting circuits.

3. Power supply filtering.
4. Radio tuning circuits.
5. Electronic devices.
6. Power factor correction.
7. Energy-storage systems.
8. Electrical noise suppression.

1.1.9 COMPARISON OF RESISTORS, INDUCTORS AND CAPACITORS IN AC CIRCUITS

Property	Resistor	Inductor	Capacitor
Main quantity	Resistance	Inductance	Capacitance
Symbol	R	L	C
Unit	Ohm (Ω)	Henry (H)	Farad (F)
Opposition	Resistance	Inductive reactance	Capacitive reactance
Opposition formula	R	$2\pi fL$	$\frac{1}{2\pi fC}$
Energy behaviour	Dissipates energy	Stores magnetic energy	Stores electric energy
Current and voltage	In phase	Current lags	Current leads
Ideal phase angle	0°	90°	90°

Summary of Phase Relationships

1. **Pure resistor:** Voltage and current are in phase.
2. **Pure inductor:** Current lags voltage by 90°.
3. **Pure capacitor:** Current leads voltage by 90°.

1.1.10 IMPEDANCE IN AC CIRCUITS

A. Meaning of Impedance

Impedance is the total opposition offered by an AC circuit to the flow of alternating current.

It combines resistance and reactance.

- Symbol: Z
- SI unit: Ohm (Ω).

In an AC circuit, impedance determines the amount of current that flows for a given applied voltage.

B. Impedance in a Series RL Circuit

An RL circuit consists of a resistor and an inductor connected in series.

The impedance is calculated using:

$$Z = \sqrt{R^2 + X_L^2}$$

Where:

- Z = Impedance (Ω).
- R = Resistance (Ω).
- X_L = Inductive reactance (Ω).

Worked Example 15

A 30 Ω resistor is connected in series with an inductor having an inductive reactance of 40 Ω. Calculate the impedance.

Solution

$$Z = \sqrt{R^2 + X_L^2}$$

$$Z = \sqrt{30^2 + 40^2}$$

$$Z = \sqrt{900 + 1600}$$

$$Z = \sqrt{2500}$$

$$\boxed{Z = 50\Omega}$$

C. Impedance in a Series RC Circuit

An RC circuit consists of a resistor and capacitor connected in series.

The impedance is:

$$Z = \sqrt{R^2 + X_C^2}$$

Worked Example 16

A 60 Ω resistor is connected in series with a capacitor having a reactance of 80 Ω. Calculate the impedance.

Solution

$$Z = \sqrt{60^2 + 80^2}$$

$$Z = \sqrt{3600 + 6400}$$

$$Z = \sqrt{10000}$$

$$\boxed{Z = 100\Omega}$$

D. Impedance in a Series RLC Circuit

An RLC circuit consists of a resistor, an inductor and a capacitor connected in series.

The total reactance is determined by the difference between inductive reactance and capacitive reactance.

$$X = X_L - X_C$$

The impedance is:

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

Where:

- Z = Total impedance (Ω).
- R = Resistance (Ω).
- X_L = Inductive reactance (Ω).
- X_C = Capacitive reactance (Ω).

Worked Example 17: Calculating Impedance in an RLC Circuit

A series RLC circuit has the following values:

- Resistance = 30 Ω.
- Inductive reactance = 80 Ω.
- Capacitive reactance = 40 Ω.

Calculate the impedance.

Solution

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

Substitution:

$$Z = \sqrt{30^2 + (80 - 40)^2}$$

$$Z = \sqrt{900 + 40^2}$$

$$Z = \sqrt{900 + 1600}$$

$$Z = \sqrt{2500}$$

$$\boxed{Z = 50\Omega}$$

1.1.11 CURRENT AND VOLTAGE IN SERIES RLC CIRCUITS

A. Current in a Series RLC Circuit

In a series circuit, the same current flows through the resistor, inductor and capacitor.

The current is calculated using:

$$I = \frac{V}{Z}$$

Where:

- I = Circuit current (A).
- V = Supply RMS voltage (V).
- Z = Impedance (Ω).

B. Voltage Drop Across the Resistor

The voltage across a resistor is calculated using:

$$V_R = IR$$

C. Voltage Drop Across the Inductor

The voltage across an inductor is calculated using:

$$V_L = IX_L$$

D. Voltage Drop Across the Capacitor

The voltage across a capacitor is calculated using:

$$V_C = IX_C$$

The supply voltage is not generally the arithmetic sum of the individual voltage drops because the voltages have different phase angles.

For a series RLC circuit:

$$V = \sqrt{V_R^2 + (V_L - V_C)^2}$$

Worked Example 18: Complete RLC Circuit Calculation

A series RLC circuit has the following values:

- Supply voltage = 200 V.
- Resistance = 30 Ω.
- Inductive reactance = 80 Ω.
- Capacitive reactance = 40 Ω.

Calculate:

a) Total impedance.

b) Circuit current.

c) Voltage across the resistor.

d) Voltage across the inductor.

e) Voltage across the capacitor.

Solution

a) Impedance

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

$$Z = \sqrt{30^2 + (80 - 40)^2}$$

$$Z = \sqrt{900 + 1600}$$

$$\boxed{Z = 50\Omega}$$

b) Current

$$I = \frac{V}{Z}$$

$$I = \frac{200}{50}$$

$$\boxed{I = 4A}$$

c) Resistor voltage

$$V_R = IR$$

$$V_R = 4 \times 30$$

$$\boxed{V_R = 120V}$$

d) Inductor voltage

$$V_L = IX_L$$

$$V_L = 4 \times 80$$

$$\boxed{V_L = 320V}$$

e) Capacitor voltage

$$V_C = IX_C$$

$$V_C = 4 \times 40$$

$$\boxed{V_C = 160V}$$

Verification

Notice that the supply voltage is not equal to:

$$120 + 320 + 160$$

The correct relationship is:

$$V = \sqrt{120^2 + (320 - 160)^2}$$

$$V = \sqrt{14400 + 25600}$$

$$V = \sqrt{40000}$$

$$\boxed{V = 200V}$$

1.1.12 PHASE ANGLE AND POWER FACTOR

A. Meaning of Power Factor

Power factor is the ratio of real power consumed by an AC circuit to the apparent power supplied to the circuit.

It indicates how effectively electrical power is being converted into useful work.

It is represented by:

$$PF = \cos\phi$$

Where:

- PF = Power factor.
- ϕ = Phase angle between voltage and current.

Power factor has no unit.

B. Power Factor in Different AC Circuits

1. Pure resistive circuit: Power factor = 1.
2. Pure inductive circuit: Power factor = 0 lagging.
3. Pure capacitive circuit: Power factor = 0 leading.
4. Practical inductive circuit: Usually has a lagging power factor.
5. Practical capacitive circuit: May have a leading power factor.

C. Calculating Power Factor in a Series RLC Circuit

$$PF = \frac{R}{Z}$$

For the previous example:

$$PF = \frac{30}{50}$$

$$\boxed{PF = 0.6}$$

Since inductive reactance is greater than capacitive reactance, the power factor is lagging.

D. Types of Electrical Power

1. Real Power

Real power is the electrical power actually converted into useful work, heat, light or other forms of energy.

- Symbol: P
- Unit: Watts (W).

Formula:

$$P = VI\cos\phi$$

2. Reactive Power

Reactive power is the power that moves back and forth between the AC source and reactive components such as inductors and capacitors.

- Symbol: Q
- Unit: Volt-amperes reactive (VAR).

Formula:

$$Q = VI\sin\phi$$

3. Apparent Power

Apparent power is the product of RMS voltage and RMS current in an AC circuit.

- Symbol: S
- Unit: Volt-amperes (VA).

Formula:

$$S = VI$$

E. Relationship Between the Three Types of Power

$$S^2 = P^2 + Q^2$$

This relationship is represented by the power triangle.

1.1.13 RESONANCE IN SERIES RLC CIRCUITS

A. Meaning of Resonance

Resonance is the condition in an RLC circuit where inductive reactance is equal to capacitive reactance.

At resonance:

$$X_L = X_C$$

Therefore:

$$X_L - X_C = 0$$

The impedance of a series RLC circuit becomes equal to its resistance.

$$Z = R$$

B. Resonant Frequency

Resonant frequency is the frequency at which inductive reactance equals capacitive reactance.

- Symbol: f_r
- Unit: Hertz (Hz).

Formula:

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

Where:

- f_r = Resonant frequency (Hz).
- L = Inductance (H).
- C = Capacitance (F).

C. Characteristics of a Series RLC Circuit at Resonance

1. Inductive reactance equals capacitive reactance.
2. Net reactance is zero.
3. Impedance is at its minimum value.
4. Impedance equals the resistance.
5. Circuit current reaches its maximum value.
6. Voltage and current are in phase.
7. Power factor is unity.
8. The circuit behaves like a pure resistive circuit.

D. Applications of Resonance

1. Radio tuning circuits.
2. Communication equipment.
3. Frequency selection circuits.
4. Electronic oscillators.
5. Signal processing circuits.

1.1.14 CONSTRUCTION OF SINGLE-PHASE AC CIRCUITS

A. Meaning of an Electrical Circuit

An electrical circuit is a complete conducting path through which electric current can flow from a source, through connected components and back to the source.

An AC circuit is an electrical circuit supplied by alternating voltage.

B. Components Required When Constructing AC Circuits

The following materials and equipment are required:

1. AC power source or approved low-voltage AC supply.
2. Resistors.
3. Inductors.
4. Capacitors.
5. Connecting wires.
6. Switches.
7. Breadboard or suitable circuit construction board.
8. Multimeter.
9. Protective equipment.
10. Appropriate circuit diagrams.

C. Basic Procedure for Constructing an AC Circuit

1. Study the circuit diagram carefully.
2. Identify the components required.
3. Check the ratings of all components.
4. Ensure the power supply is switched off.
5. Connect the components according to the circuit diagram.
6. Check that connections are secure.
7. Check for short circuits.
8. Connect the approved AC source.
9. Switch on the supply under supervision.
10. Measure voltage and current.
11. Record the readings.
12. Compare the results with theoretical calculations.
13. Switch off the power supply before making any changes.

D. Constructing a Resistive AC Circuit

Materials required

- AC supply.
- Resistor.
- Connecting wires.
- Switch.
- AC voltmeter.
- AC ammeter.

Procedure

1. Connect the resistor in series with the AC supply and ammeter.
2. Connect the voltmeter in parallel across the resistor.
3. Check the connections.

4. Apply a suitable approved AC voltage.
5. Record the voltage and current.
6. Calculate resistance using Ohm's law.

E. Constructing an RL Circuit

Materials required

- AC source.
- Resistor.
- Inductor.
- Ammeter.
- Voltmeter.
- Connecting wires.

Procedure

1. Connect the resistor and inductor in series.
2. Connect an ammeter in series with the circuit.
3. Connect a voltmeter across the supply.
4. Switch on the approved supply.
5. Record the current and voltage.
6. Calculate inductive reactance and impedance where the component values are known.

F. Constructing an RC Circuit

Materials required

- AC source.
- Resistor.
- Capacitor suitable for AC operation.
- Ammeter.
- Voltmeter.
- Connecting wires.

Procedure

1. Connect the resistor and capacitor in series.
2. Connect the ammeter in series.
3. Connect the voltmeter across the supply.
4. Check all connections.
5. Apply an approved low-voltage AC supply.
6. Record the readings.
7. Calculate capacitive reactance and impedance.

G. Constructing an RLC Circuit

Materials required

- AC supply.
- Resistor.
- Inductor.
- Capacitor.
- Ammeter.
- Voltmeter.

- Connecting wires.

Procedure

1. Identify the required components.
2. Connect the resistor, inductor and capacitor in series.
3. Connect the ammeter in series.
4. Connect the voltmeter across the supply.
5. Confirm that all component ratings are suitable.
6. Apply a suitable low-voltage AC supply.
7. Measure the current and voltage.
8. Calculate total impedance.
9. Compare theoretical and experimental results.

1.1.15 MEASURING INSTRUMENTS USED IN AC CIRCUITS

Electrical measuring instruments are devices used to measure different electrical quantities such as voltage, current, resistance, frequency and waveform characteristics.

1. Digital Multimeter

A digital multimeter is an electrical measuring instrument used to measure different electrical quantities.

It can measure:

1. AC voltage.
2. DC voltage.
3. AC current (on suitable models).
4. DC current.
5. Resistance.
6. Continuity.
7. Frequency (on suitable models).
8. Capacitance (on suitable models).

Uses

- Testing electrical circuits.
- Measuring supply voltage.
- Checking continuity of conductors.
- Measuring resistance.
- Identifying faulty components.

2. Cathode Ray Oscilloscope (CRO)

A cathode ray oscilloscope is an electronic measuring instrument used to display electrical signals as waveforms on a screen.

It enables learners and technicians to observe how voltage changes with time.

Uses of a CRO

1. Observing sinusoidal waveforms.
2. Measuring peak voltage.
3. Determining peak-to-peak voltage.
4. Measuring time period.

5. Determining frequency.
6. Comparing the phase difference between two signals.

3. Frequency Meter

A frequency meter is an instrument used to measure the frequency of an alternating electrical signal.

It measures frequency in hertz (Hz).

Uses

1. Checking the frequency of AC supplies.
2. Testing generators.
3. Monitoring electrical systems.
4. Checking the operating frequency of electronic equipment.

4. Signal Generator

A signal generator is an electronic instrument used to produce electrical signals of known frequency, amplitude and waveform.

It can generate:

- Sine waves.
- Square waves.
- Triangular waves.
- Other selectable waveforms, depending on the model.

Uses

1. Testing electronic circuits.
2. Demonstrating AC waveforms.
3. Testing amplifiers.
4. Studying frequency response.
5. Carrying out laboratory experiments.

5. AC Voltmeter

An AC voltmeter measures the voltage between two points in an AC circuit.

Connection: It is connected in parallel with the component or supply being measured.

6. AC Ammeter

An AC ammeter measures the alternating current flowing through a circuit.

Connection: It is connected in series with the circuit.

Comparison of Measuring Instruments

Instrument	Main quantity measured or displayed
Multimeter	Voltage, current, resistance and other supported quantities
CRO	Waveform, voltage and time characteristics
Frequency meter	Frequency
Signal generator	Produces test signals
AC voltmeter	AC voltage
AC ammeter	AC current

1.1.16 MEASUREMENT OF AC QUANTITIES USING A CRO

A CRO is particularly useful when studying sinusoidal waveforms.

A. Important CRO Controls

1. **Volts/division:** Determines the voltage represented by each vertical division.
2. **Time/division:** Determines the time represented by each horizontal division.
3. **Position control:** Moves the waveform vertically or horizontally.
4. **Trigger control:** Stabilises the waveform on the screen.
5. **Intensity control:** Adjusts the brightness of the waveform.
6. **Focus control:** Adjusts the sharpness of the displayed waveform.

B. Determining Voltage Using a CRO

The peak-to-peak voltage is calculated using:

Worked Example 19

A waveform occupies 6 vertical divisions. The CRO is set at 2 V/division. Determine the peak-to-peak voltage.

Solution

$$V_{pp} = 6 \times 2$$

$$\boxed{V_{pp} = 12V}$$

For a symmetrical sinusoidal waveform:

$$V_m = \frac{V_{pp}}{2}$$

$$V_m = \frac{12}{2}$$

$$\boxed{V_m = 6V}$$

C. Determining the Time Period Using a CRO

The time period is calculated using:

Worked Example 20

One complete cycle occupies 4 horizontal divisions. The time base is set at 5 ms/division. Calculate the period.

Solution

$$T = 4 \times 5ms$$

$$T = 20ms$$

Converting into seconds:

$$T = \frac{20}{1000}$$

$$\boxed{T = 0.02s}$$

D. Determining Frequency Using a CRO

Frequency is the reciprocal of the period.

$$f = \frac{1}{T}$$

Using the previous example:

$$f = \frac{1}{0.02}$$

$$\boxed{f = 50Hz}$$

1.1.17 APPLICATIONS OF SINGLE-PHASE AC IN EVERYDAY LIFE

Single-phase AC electricity is important in everyday life because it provides electrical energy to many domestic and commercial appliances.

A. Applications in Homes

1. **Lighting:** Powers lamps and lighting systems.
2. **Refrigeration:** Powers domestic refrigerators and freezers.
3. **Cooking:** Supplies energy to electric cookers and ovens.
4. **Entertainment:** Powers televisions and audio equipment.
5. **Cleaning:** Powers washing machines and vacuum cleaners.
6. **Cooling:** Powers fans and suitable air-conditioning equipment.
7. **Water supply:** Operates small water pumps.
8. **Ironing:** Powers electric irons.

B. Applications in Schools

Single-phase AC electricity is used for:

1. Lighting classrooms.
2. Powering computers.
3. Operating printers and photocopiers.
4. Running laboratory equipment.
5. Operating projectors.
6. Charging electronic devices.
7. Powering office equipment.

C. Applications in Commercial Establishments

Single-phase AC is commonly used in:

1. Shops.
2. Offices.
3. Hotels.
4. Restaurants.
5. Salons.
6. Workshops.
7. Small manufacturing businesses.

D. Importance of AC Electricity in Kenya

1. Supports domestic activities.
2. Promotes industrial development.
3. Supports education through electronic learning.
4. Improves healthcare through medical equipment.
5. Supports communication and information technology.
6. Creates employment opportunities.
7. Supports business operations.
8. Promotes agricultural processing and irrigation activities.

1.1.18 ELECTRICAL SAFETY WHEN WORKING WITH AC CIRCUITS

Electricity is useful but can cause serious injury, fire and damage to equipment if handled incorrectly.

Learners must observe electrical safety procedures during practical activities.

A. Electrical Hazards

1. Electric shock.
2. Electrical burns.
3. Short circuits.
4. Overloading.
5. Electrical fires.
6. Damage to electrical equipment.
7. Explosions caused by electrical sparks in hazardous environments.

B. Electrical Safety Precautions

1. Never handle electrical equipment with wet hands.
2. Switch off the power supply before making connections.
3. Use insulated tools.
4. Avoid damaged electrical cables.
5. Never overload socket outlets.
6. Use appropriate fuses and circuit breakers.
7. Ensure electrical equipment is properly earthed where required.
8. Use the correct measuring instrument and range.
9. Do not touch exposed conductors.
10. Work under the supervision of a qualified teacher or technician.
11. Use suitable personal protective equipment.
12. Keep water and liquids away from electrical equipment.
13. Never attempt to repair live electrical equipment.
14. Discharge capacitors safely using an appropriate method before handling them.
15. Use approved low-voltage training supplies for classroom experiments.

C. Important Safety Note

Learners should not construct or test circuits directly on Kenya's 230 V mains supply.

Practical activities should use appropriately rated, isolated, current-limited low-voltage AC training equipment under qualified supervision.

1.1.19 TROUBLESHOOTING AC CIRCUITS

A. Meaning of Troubleshooting

Troubleshooting is the systematic process of identifying, locating and correcting faults in an electrical circuit or system.

It helps technicians restore the proper functioning of electrical equipment.

B. Common Faults in AC Circuits

1. **Open circuit:** Occurs when the conducting path is broken, preventing current from flowing.
2. **Short circuit:** Occurs when current takes an unintended low-resistance path.
3. **Loose connections:** Poor connections may cause intermittent operation, overheating or sparking.
4. **Blown fuse:** A fuse melts and breaks the circuit when excessive current flows.
5. **Faulty resistor:** A resistor may become open-circuited, damaged or change its resistance value.
6. **Faulty capacitor:** A capacitor may become damaged, lose capacitance or develop leakage.
7. **Faulty inductor:** An inductor may develop an open winding or shorted turns.
8. **Overloading:** Occurs when the connected load demands more current than the circuit is designed to carry.
9. **Incorrect connections:** Components may be connected wrongly, resulting in improper operation.

C. Steps Followed When Troubleshooting AC Circuits

1. Identify the symptoms of the fault.
2. Switch off and isolate the power supply.
3. Observe the circuit for visible damage.
4. Check connecting wires and terminals.
5. Inspect fuses and protective devices.
6. Use a multimeter to test continuity and resistance where appropriate.
7. Check components for signs of damage.
8. Compare the circuit connections with the circuit diagram.
9. Identify the faulty component or connection.
10. Replace or repair the faulty component using an appropriate procedure.
11. Recheck the circuit connections.
12. Test the circuit using an approved low-voltage supply.
13. Record the fault and corrective action taken.

D. Importance of Troubleshooting

1. Helps identify faults in electrical systems.
2. Prevents further damage to equipment.
3. Improves the reliability of electrical installations.
4. Reduces unnecessary replacement of components.
5. Improves electrical safety.
6. Saves time and maintenance costs.
7. Ensures electrical equipment operates efficiently.

PART 2: TOPICAL REVISION QUESTIONS

GRADE 11 – ELECTRICITY TECHNOLOGY

STRAND 1.0: FUNDAMENTALS OF ELECTRICITY

SUB-STRAND 1.1: SINGLE-PHASE AC CIRCUITS

SECTION A: MULTIPLE-CHOICE QUESTIONS (30 MARKS)

Instructions: Answer all questions. Each question carries 1 mark. Choose the correct answer from alternatives A, B, C and D.

1. Which statement correctly describes alternating current?

A. It flows in one direction only.

B. It changes direction periodically.

C. It has a constant magnitude at all times.

D. It cannot be used in domestic appliances.

2. The SI unit of electric current is:

A. Volt

B. Ohm

C. Ampere

D. Coulomb

3. An electric current of 4 A flows for 5 seconds. What quantity of charge passes through the conductor?

A. 0.8 C

B. 9 C

C. 20 C

D. 25 C

4. The principle used in generating alternating current is:

A. Electrostatic attraction

B. Electromagnetic induction

C. Chemical reaction

D. Thermal expansion

5. Which component of an AC generator maintains electrical contact between the rotating coil and the external circuit?

A. Bearings

B. Shaft

C. Carbon brushes

D. Field magnets

6. The function of slip rings in an AC generator is to:

A. Increase the magnetic field strength.

B. Transfer induced current from the rotating coil to the external circuit.

C. Reduce the speed of rotation.

D. Convert AC into DC.

7. Which component is used in a DC generator instead of slip rings?

A. Capacitor

B. Split-ring commutator

C. Inductor

D. Fuse

8. The number of complete AC cycles produced in one second is called:

A. Amplitude

B. Period

C. Frequency

D. Reactance

9. An AC supply has a frequency of 50 Hz. What is its period?

A. 0.2 s

B. 0.02 s

C. 0.002 s

D. 2 s

10. The maximum value reached by an alternating voltage is called:

A. Average value

B. RMS value

C. Peak value

D. Instantaneous period

11. The peak-to-peak voltage of a sinusoidal waveform with a peak voltage of 150 V is:

A. 75 V

B. 150 V

C. 225 V

D. 300 V

12. The RMS value of a sinusoidal AC voltage is approximately:

A. 0.5 times the peak value.

B. 0.637 times the peak value.

C. 0.707 times the peak value.

D. 1.414 times the peak value.

13. The average value of a symmetrical sinusoidal voltage over one complete cycle is:

A. Zero

B. Equal to peak voltage

C. Half the peak voltage

D. 0.707 times peak voltage

14. Which formula is used to calculate angular frequency?

A.

B. $\omega = 2\pi f$

C.

D. $\omega = IR$

15. In a pure resistive AC circuit, the phase difference between voltage and current is:

A. 90°

B. 180°

C. 0°

D. 45°

16. Which of the following is the SI unit of inductance?

A. Farad

B. Henry

C. Ohm

D. Watt

17. Inductive reactance increases when:

A. Frequency decreases.

B. Inductance increases.

C. Resistance decreases.

D. Voltage decreases.

18. In a pure inductive AC circuit, current:

A. Leads voltage by 90°.

B. Lags voltage by 90°.

C. Is in phase with voltage.

D. Leads voltage by 180°.

19. Which formula is used to calculate inductive reactance?

A. $X_L = 2\pi f L$

B. $X_L = IR$

C.

D.

20. Which electrical component stores energy in a magnetic field?

A. Resistor

B. Capacitor

C. Inductor

D. Fuse

21. Which component stores energy in an electric field?

A. Resistor

B. Fuse

C. Capacitor

D. Inductor

22. The SI unit of capacitance is:

A. Henry

B. Farad

C. Ohm

D. Ampere

23. Capacitive reactance decreases when:

A. Frequency increases.

B. Capacitance decreases.

C. Frequency decreases.

D. Voltage increases.

24. In a pure capacitive AC circuit, current:

A. Lags voltage by 90°.

B. Leads voltage by 90°.

C. Is in phase with voltage.

D. Is always zero.

25. The total opposition offered by an AC circuit to current flow is called:

A. Conductance

B. Resistance

C. Impedance

D. Capacitance

26. A series RLC circuit is at resonance when:

A. Resistance equals inductance.

B. Inductive reactance equals capacitive reactance.

C. Voltage equals current.

D. Resistance is zero.

27. Which instrument is used to display an electrical waveform?

A. Frequency meter

B. CRO

C. Ohmmeter

D. Wattmeter

28. Which instrument is primarily used to measure the frequency of an AC supply?

A. Frequency meter

B. Voltmeter

C. Ammeter

D. Galvanometer

29. In an AC circuit, an ammeter should be connected:

A. In parallel.

B. In series.

C. Across the resistor only.

D. Across the supply terminals only.

30. Which of the following is the safest practice when constructing AC circuits in a school laboratory?

A. Using exposed live conductors.

B. Making connections while the supply is on.

C. Using an isolated, current-limited low-voltage AC supply.

D. Using damaged connecting wires.

SECTION A: ANSWER KEY

Question	Answer	Question	Answer
1	B	16	B
2	C	17	B
3	C	18	C
4	B	19	C
5	C	20	B
6	B	21	C
7	B	22	B
8	C	23	A
9	B	24	B
10	C	25	C

Question	Answer	Question	Answer
11	D	26	B
12	C	27	B
13	A	28	A
14	B	29	B
15	C	30	C

SECTION B: STRUCTURED QUESTIONS (50 MARKS)

Instructions: Answer all questions. Show all necessary working in calculation questions.

QUESTION 1: GENERATION OF ALTERNATING CURRENT (8 MARKS)

a) Define electromagnetic induction. (2 marks)

b) State two laws of electromagnetic induction. (2 marks)

c) Name four main components of a simple AC generator. (2 marks)

d) Explain how an AC generator produces alternating current. (2 marks)

QUESTION 2: AC WAVEFORM QUANTITIES (8 MARKS)

An AC supply has an RMS voltage of 230 V and a frequency of 50 Hz.

a) Define frequency. (1 mark)

b) Calculate the period of the AC supply. (2 marks)

c) Calculate the peak voltage. (2 marks)

d) Determine the peak-to-peak voltage. (1 mark)

e) Calculate the angular frequency of the supply. (2 marks)

QUESTION 3: RESISTORS AND INDUCTORS IN AC CIRCUITS (8 MARKS)

a) State two characteristics of a pure resistive AC circuit. (2 marks)

b) Explain the meaning of inductive reactance. (2 marks)

c) A coil having an inductance of 0.15 H is connected to a 50 Hz AC supply.

Calculate its inductive reactance. (2 marks)

d) State two factors that affect the inductive reactance of a coil. (2 marks)

QUESTION 4: CAPACITORS IN AC CIRCUITS (8 MARKS)

a) Define capacitance. (1 mark)

b) State two functions of a capacitor in electrical circuits. (2 marks)

c) A capacitor of 100 μF is connected to a 50 Hz AC supply.

Calculate its capacitive reactance. (3 marks)

d) State two characteristics of a pure capacitive AC circuit. (2 marks)

QUESTION 5: SERIES RLC CIRCUITS (10 MARKS)

A series RLC circuit has the following characteristics:

- Resistance = 40 Ω.
- Inductive reactance = 100 Ω.
- Capacitive reactance = 40 Ω.
- Supply voltage = 200 V.

Calculate:

a) The net reactance of the circuit. (2 marks)

b) The total impedance of the circuit. (2 marks)

c) The current flowing through the circuit. (2 marks)

d) The voltage drop across the resistor. (2 marks)

e) The power factor of the circuit and state whether it is leading or lagging. (2 marks)

QUESTION 6: MEASURING INSTRUMENTS AND SAFETY (8 MARKS)

a) State two uses of a digital multimeter in AC circuit testing. (2 marks)

b) Explain two functions of a cathode ray oscilloscope. (2 marks)

c) State two precautions to observe when constructing AC circuits in a school laboratory. (2 marks)

d) Differentiate between an AC ammeter and an AC voltmeter based on their connections in a circuit. (2 marks)

TOTAL: 50 MARKS

PART 3: TEACHER'S MARKING SCHEME – SECTION B

QUESTION 1: GENERATION OF ALTERNATING CURRENT (8 MARKS)

a) Define electromagnetic induction. (2 marks)

The process by which an electromotive force is induced in a conductor when the magnetic flux linking it changes. (2 marks)

b) State two laws of electromagnetic induction. (2 marks)

1. Whenever the magnetic flux linking a conductor changes, an EMF is induced in the conductor. (1 mark)
2. The magnitude of induced EMF is proportional to the rate of change of magnetic flux linkage. (1 mark)

c) Name four main components of a simple AC generator. (2 marks)

Award ½ mark each for any four:

- Field magnets.
- Armature coil.
- Slip rings.
- Carbon brushes.
- Shaft.
- External load.

d) Explain how an AC generator produces alternating current. (2 marks)

- Mechanical energy rotates a coil in a magnetic field. (1 mark)
- Changing magnetic flux induces an EMF whose direction reverses every half revolution, producing alternating current in a closed circuit. (1 mark)

QUESTION 2: AC WAVEFORM QUANTITIES (8 MARKS)

An AC supply has an RMS voltage of 230 V and a frequency of 50 Hz.

a) Define frequency. (1 mark)

Number of complete cycles produced per second. (1 mark)

b) Calculate the period. (2 marks)

Formula:

$$T = \frac{1}{f}$$

Substitution:

$$T = \frac{1}{50}$$

$$\boxed{T = 0.02s}$$

Award:

- Correct formula (1 mark).
- Correct answer (1 mark).

c) Calculate peak voltage. (2 marks)

$$V_m = \sqrt{2}V_{rms}$$

$$V_m = 1.414 \times 230$$

$$\boxed{V_m = 325.2V}$$

Award:

- Correct formula (1 mark).
- Correct answer (1 mark).

d) Determine peak-to-peak voltage. (1 mark)

$$V_{pp} = 2V_m$$

$$V_{pp} = 2 \times 325.2$$

$$\boxed{V_{pp} = 650.4V}$$

e) Calculate angular frequency. (2 marks)

$$\omega = 2\pi f$$

$$\omega = 2 \times 3.142 \times 50$$

Award:

- Correct formula (1 mark).
- Correct answer (1 mark).

QUESTION 3: RESISTORS AND INDUCTORS (8 MARKS)

a) Characteristics of a pure resistive AC circuit. (2 marks)

Any two:

1. Voltage and current are in phase.
2. Phase angle is zero degrees.
3. The resistor converts electrical energy into heat.
4. It consumes real power.
5. Resistance is independent of frequency for an ideal fixed resistor.

Award 1 mark each.

b) Meaning of inductive reactance. (2 marks)

Inductive reactance is the opposition offered by an inductor to the flow of alternating current.

Award 2 marks for the correct definition.

c) Calculate inductive reactance. (2 marks)

Given:

$$L = 0.15H$$

$$f = 50Hz$$

Formula:

$$X_L = 2\pi fL$$

Substitution:

$$X_L = 2 \times 3.142 \times 50 \times 0.15$$

$$\boxed{X_L = 47.13\Omega}$$

Award:

- Correct formula and substitution (1 mark).
- Correct answer (1 mark).

d) Factors affecting inductive reactance. (2 marks)

1. Frequency of the AC supply.
2. Inductance of the coil.

Award 1 mark each.

QUESTION 4: CAPACITORS IN AC CIRCUITS (8 MARKS)

a) Define capacitance. (1 mark)

Capacitance is the ability of a capacitor to store electric charge.

(1 mark)

b) State two functions of a capacitor in electrical circuits. (2 marks)

Any two:

1. Stores electrical energy.
2. Used in motor-starting circuits.
3. Used in power supply filtering.
4. Used in power factor correction.
5. Used in radio tuning circuits.

Award 1 mark each.

c) Calculate capacitive reactance. (3 marks)

Given:

$$C = 100\mu F$$

$$f = 50Hz$$

Convert microfarads into farads:

$$C = 100 \times 10^{-6}$$

$$C = 0.0001F$$

Formula:

$$X_C = \frac{1}{2\pi fC}$$

Substitution:

$$X_C = \frac{1}{2 \times 3.142 \times 50 \times 0.0001}$$

$$X_C = \frac{1}{0.03142}$$

$$\boxed{X_C = 31.83\Omega}$$

Award:

- Correct conversion and formula (1 mark).
- Correct substitution (1 mark).
- Correct answer (1 mark).

d) Characteristics of a pure capacitive AC circuit. (2 marks)

Any two:

1. Current leads voltage by 90°.
2. Voltage lags current by 90°.
3. Energy is stored in the electric field.

4. An ideal capacitor does not consume average real power.

Award 1 mark each.

QUESTION 5: SERIES RLC CIRCUITS (10 MARKS)

Given:

- Resistance = 40 Ω.
- Inductive reactance = 100 Ω.
- Capacitive reactance = 40 Ω.
- Supply voltage = 200 V.

a) Calculate net reactance. (2 marks)

$$X = X_L - X_C$$

$$X = 100 - 40$$

$$\boxed{X = 60\Omega}$$

Award:

- Correct formula (1 mark).
- Correct answer (1 mark).

b) Calculate impedance. (2 marks)

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

$$Z = \sqrt{40^2 + 60^2}$$

$$Z = \sqrt{1600 + 3600}$$

$$Z = \sqrt{5200}$$

$$\boxed{Z = 72.11\Omega}$$

Award:

- Correct formula and substitution (1 mark).
- Correct answer (1 mark).

c) Calculate current. (2 marks)

$$I = \frac{V}{Z}$$

$$I = \frac{200}{72.11}$$

$$\boxed{I = 2.77A}$$

Award:

- Correct formula (1 mark).
- Correct answer (1 mark).

d) Voltage across the resistor. (2 marks)

$$V_R = IR$$

$$V_R = 2.77 \times 40$$

$$\boxed{V_R = 110.8V}$$

Award:

- Correct formula (1 mark).
- Correct answer (1 mark).

e) Power factor and its type. (2 marks)

$$PF = \frac{R}{Z}$$

$$PF = \frac{40}{72.11}$$

$$\boxed{PF = 0.555}$$

Since:

$$X_L > X_C$$

The circuit has a **lagging power factor**.

Award:

- Correct calculation (1 mark).
- Correct identification as lagging (1 mark).

QUESTION 6: MEASURING INSTRUMENTS AND SAFETY (8 MARKS)

a) Uses of a digital multimeter. (2 marks)

Any two:

1. Measuring AC voltage.
2. Measuring DC voltage.
3. Measuring AC current on suitable models.
4. Measuring resistance.
5. Testing continuity.
6. Measuring capacitance on suitable models.
7. Measuring frequency on suitable models.

Award 1 mark each.

b) Functions of a CRO. (2 marks)

Any two:

1. Displays electrical waveforms.
2. Measures peak voltage.
3. Measures peak-to-peak voltage.
4. Determines time period.
5. Determines frequency.
6. Compares phase differences between signals.

Award 1 mark each.

c) Safety precautions. (2 marks)

Any two:

1. Switch off the power supply before making connections.
2. Use insulated connecting wires.
3. Use low-voltage isolated AC supplies.
4. Avoid touching exposed conductors.
5. Use appropriate measuring instruments.
6. Work under teacher supervision.
7. Avoid damaged equipment.

Award 1 mark each.

d) Difference between AC ammeter and AC voltmeter. (2 marks)

- AC ammeter is connected in series with the circuit to measure current. (1 mark)
- AC voltmeter is connected in parallel across a component or supply to measure voltage. (1 mark)

TOTAL: 50 MARKS

PART 4: SUMMARY OF IMPORTANT FORMULAE

Quantity	Formula
Electric current	$I = \frac{Q}{t}$
Faraday's law	$E = -N\frac{\Delta\Phi}{\Delta t}$
Instantaneous voltage	$v = V_m \sin\omega t$
Instantaneous current	$i = I_m \sin\omega t$
Frequency	$f = \frac{1}{T}$
Period	$T = \frac{1}{f}$
Angular frequency	$\omega = 2\pi f$
Peak voltage	$V_m = \sqrt{2}V_{rms}$
RMS voltage	$V_{rms} = 0.707V_m$
Peak current	$I_m = \sqrt{2}I_{rms}$
RMS current	$I_{rms} = 0.707I_m$
Peak-to-peak voltage	$V_{pp} = 2V_m$
Average half-cycle voltage	$V_{avg} = 0.637V_m$
Ohm's law	$V = IR$
Resistive power	$P = VI$
Inductive reactance	$X_L = 2\pi fL$
Capacitive reactance	$X_C = \frac{1}{2\pi fC}$
RL impedance	$Z = \sqrt{R^2 + X_L^2}$
RC impedance	$Z = \sqrt{R^2 + X_C^2}$
RLC impedance	$Z = \sqrt{R^2 + (X_L - X_C)^2}$

Quantity	Formula
Circuit current	$I = \frac{V}{Z}$
Resistor voltage	$V_R = IR$
Inductor voltage	$V_L = IX_L$
Capacitor voltage	$V_C = IX_C$
Real power	$P = VI\cos\phi$
Apparent power	$S = VI$
Reactive power	$Q = VI\sin\phi$
Power factor	$PF = \cos\phi = \frac{R}{Z}$
Resonant frequency	$f_r = \frac{1}{2\pi\sqrt{LC}}$

IMPORTANT UNIT CONVERSIONS

Unit	Conversion
1 kΩ	1,000 Ω
1 MΩ	1,000,000 Ω
1 mH	0.001 H
1 µH	0.000001 H
1 mF	0.001 F
1 µF	0.000001 F
1 nF	0.000000001 F
1 ms	0.001 s
1 kHz	1,000 Hz

STRAND 1.0: FUNDAMENTALS OF ELECTRICITY

SUB-STRAND 1.2: ORTHOGRAPHIC PROJECTION

1.2.1 Introduction to Orthographic Projection

Orthographic projection is an important method of technical drawing used in engineering, construction, manufacturing and electrical technology.

In electrical technology, technicians and engineers use orthographic drawings to represent electrical components, equipment, installations and structures accurately.

For example, when an electrician is required to install a distribution board in a building, an orthographic drawing can show:

- The front appearance of the distribution board.
- Its height and width.
- Its depth.
- The position of switches, circuit breakers and other components.

- The location of mounting holes and cable entry points.

Orthographic projection enables different people involved in an engineering project to understand the exact shape, size and arrangement of an object without physically seeing it.

1.2.2 Definition of Orthographic Projection

Orthographic projection is a technical drawing method used to represent a three-dimensional object on two-dimensional planes by projecting its features at right angles (90°) onto imaginary projection planes.

It produces different views of an object, commonly:

1. Front elevation.
2. Plan (top view).
3. End elevation (side view).

These views provide sufficient information about the shape, size and features of an object.

1.2.3 Meaning of Important Terms Used in Orthographic Projection

1. Object

An object is the component, structure or item being represented in a technical drawing.

Examples:

- Electrical distribution board.
- Junction box.
- Electrical enclosure.
- Transformer casing.
- Cable trunking.
- Motor housing.

2. Projection

Projection is the process of transferring the visible features of an object onto a drawing plane using imaginary straight lines called projectors.

3. Projectors

Projectors are imaginary straight lines drawn from points on an object towards a projection plane.

In orthographic projection, projectors are perpendicular to the projection plane.

4. Projection plane

A projection plane is an imaginary flat surface onto which the image of an object is projected.

The main projection planes are:

- Vertical Plane (VP).
- Horizontal Plane (HP).
- Profile Plane (PP).

5. Front elevation

This is the view obtained when an object is observed directly from the front.

It normally shows:

- Height.
- Width.
- Front features.
- Position of components on the front surface.

6. Plan

A plan is the view obtained when an object is observed directly from above.

It shows:

- Length or width of the object.
- Depth.
- Arrangement of features on the upper surface.

7. End elevation

An end elevation is the view obtained when an object is observed from either the left-hand side or right-hand side.

It shows:

- Height.
- Depth.
- Features on the side of the object.

8. Hidden detail

Hidden detail refers to features of an object that cannot be seen directly from a particular viewing direction.

It is represented using short-dashed lines.

9. Visible outline

A visible outline represents the edges and boundaries of an object that can be seen from a particular viewing direction.

It is represented using continuous thick lines.

10. Centre line

A centre line indicates the centre of circular features, holes, cylinders or symmetrical objects.

It is usually represented by a thin chain line consisting of alternating long and short dashes.

1.2.4 Characteristics of Orthographic Projection

Orthographic projection has the following characteristics:

1. It represents three-dimensional objects using two-dimensional views.
2. Projectors are drawn perpendicular to the projection plane.
3. The views are aligned correctly with one another.
4. The actual dimensions of the object are maintained when drawn to full scale.
5. It uses standard engineering drawing conventions.
6. It can represent both external and internal features.

7. It allows accurate measurement and manufacture of components.
8. It uses standard symbols, lines and dimensioning techniques.
9. It provides a clear and systematic representation of complex objects.
10. It can be produced manually or using computer-aided design (CAD) software.

1.2.5 Importance of Orthographic Projection in Engineering

Orthographic projection is important in engineering for the following reasons:

1. **Accurate representation:** It shows the actual dimensions and shape of an object through different views.

2. **Communication:** It provides a common technical language for engineers, technicians, electricians and manufacturers.

3. **Manufacturing:** It provides the information needed to manufacture machine parts and electrical components.

4. **Installation:** It guides technicians when installing electrical equipment and accessories.

5. **Planning:** It helps engineers plan the arrangement of electrical equipment before installation.

6. **Maintenance:** It assists technicians in identifying components and understanding equipment construction during repairs.

7. **Cost reduction:** Accurate drawings reduce material wastage and mistakes during construction.

8. **Safety:** It assists in planning safe electrical installations and suitable equipment clearances.

9. **Quality control:** It enables manufactured components to be checked against specified dimensions.

10. **Documentation:** It provides permanent technical records for future reference.

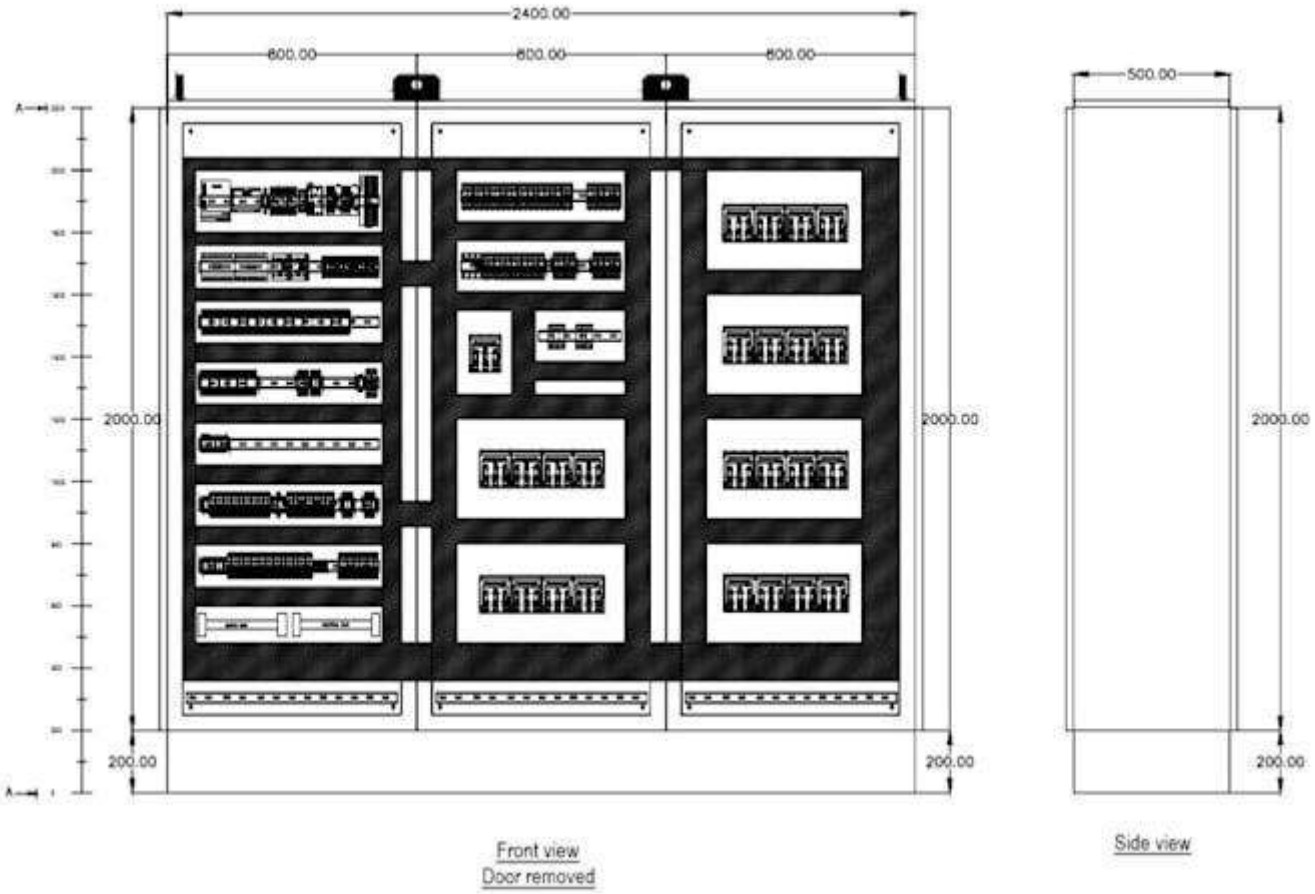
1.2.6 Applications of Orthographic Projection in Electrical Technology

Orthographic projection is widely applied in electrical technology.

Examples include:

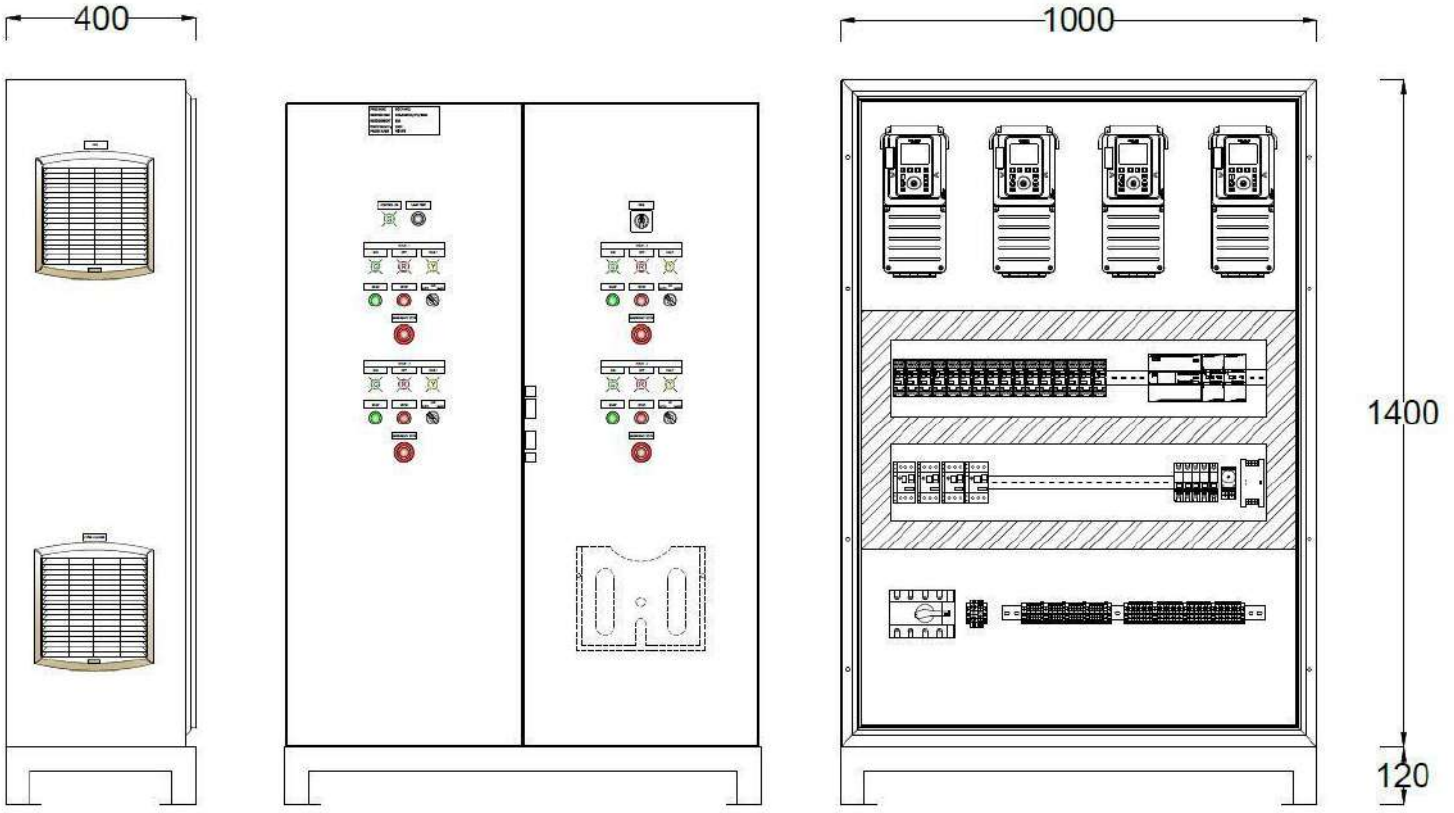
Application	How orthographic projection is used
Distribution boards	Showing the front, side and top dimensions and component arrangement.
Control panels	Representing the location of switches, meters, indicators and push buttons.
Junction boxes	Showing enclosure dimensions, openings and cable entry points.
Electrical installations	Planning the position of electrical accessories and equipment.
Transformers	Showing the external shape, dimensions and mounting arrangements.
Electric motors	Representing the casing, shaft and mounting holes.
Cable trays	Showing their dimensions and arrangement.

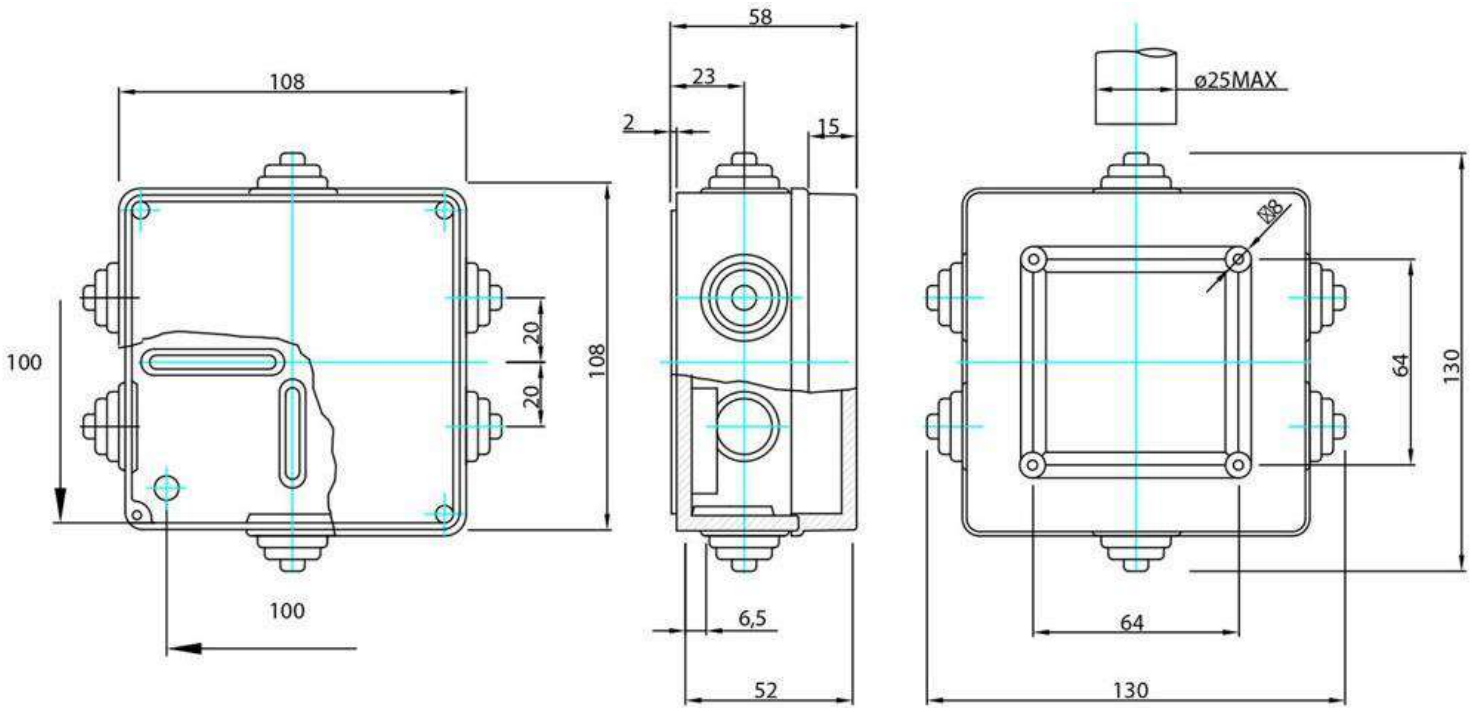
Lighting fittings	Representing the shape, mounting features and dimensions.
Generator enclosures	Showing the overall dimensions and ventilation openings.
Switchgear	Showing the arrangement and physical dimensions of switching equipment.



Front view
Door removed

Side view





1.2.7 Principles of Orthographic Projection

Orthographic projection is based on the principle of viewing an object from different directions and transferring its features onto projection planes.

The three principal views are obtained as follows:

A. Front elevation

- The observer looks at the object from the front.

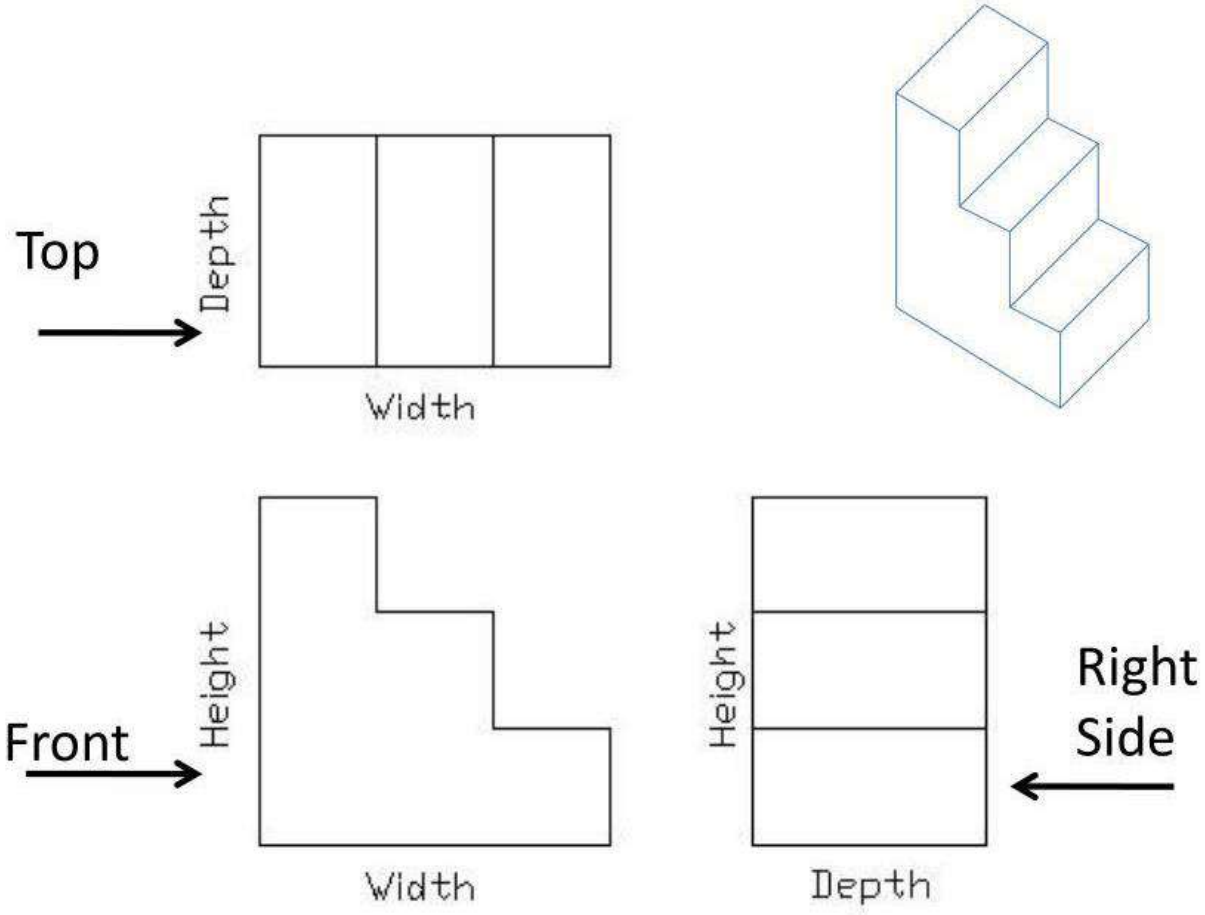
- The image is projected onto the vertical plane.
- It shows the height and width of the object.

B. Plan (top view)

- The observer looks at the object from above.
- The image is projected onto the horizontal plane.
- It shows the width and depth of the object.

C. End elevation (side view)

- The observer looks at the object from the left or right.
- The image is projected onto the profile plane.
- It shows the height and depth of the object.



1.2.8 Main Views Used in Orthographic Projection

1. Front elevation

The front elevation is the view of an object obtained by looking directly at its front face.

Features:

- It normally shows the height and width.
- It is usually selected as the principal view.
- It should show as many important features as possible.
- It provides the main reference for positioning other views.

Example: In a distribution board, the front elevation shows the arrangement of circuit breakers, indicator lamps, meters and the enclosure door.

2. Plan (top view)

The plan is the view obtained by looking vertically downwards onto an object.

Features:

- It shows the length and width or depth, depending on the object's orientation.
- It reveals the arrangement of features on the top surface.
- It is projected in alignment with the front elevation.

Example: A plan of an electrical control cabinet can show the top ventilation openings and cable entry positions.

3. End elevation

An end elevation shows the appearance of an object when viewed from either end.

There are two types:

- Left-hand end elevation: obtained by viewing the object from the left.
- Right-hand end elevation: obtained by viewing the object from the right.

Features:

- It shows height and depth.
- It reveals side features.
- It helps in understanding the thickness and overall shape of an object.

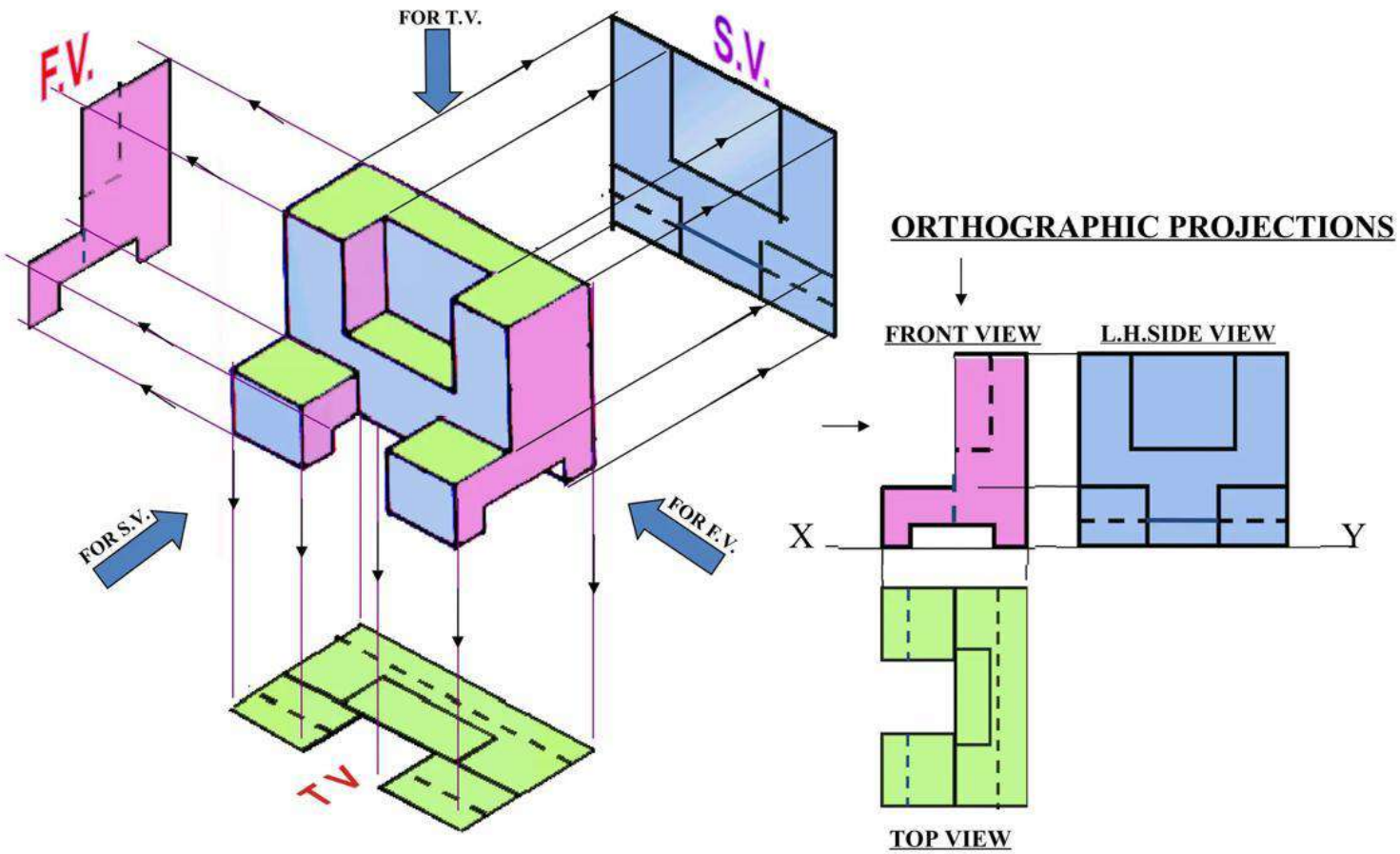
4. Sectional view

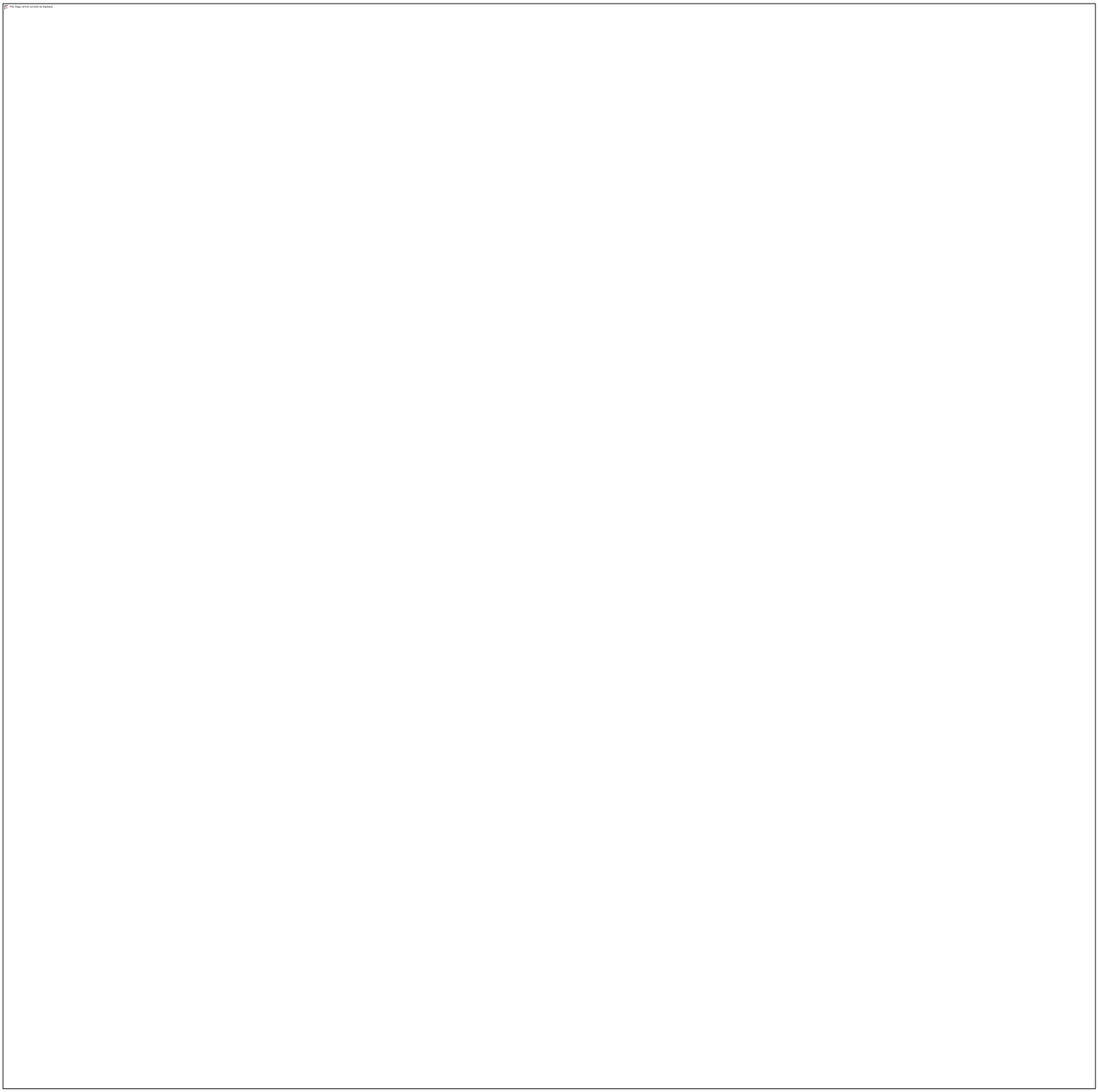
A sectional view is a drawing that shows the internal details of an object as though it has been cut through by an imaginary cutting plane.

It is useful when internal features cannot be clearly represented using ordinary external views.

Examples of applications:

- Showing internal parts of an electrical motor.
- Showing the internal arrangement of a switchgear enclosure.
- Showing the internal construction of a transformer.
- Showing the internal arrangement of an electrical connector.


FOR T.V.
F.V.
S.V.
FOR S.V.
FOR F.V.
T.V
ORTHOGRAPHIC PROJECTIONS
FRONT VIEW
L.H.SIDE VIEW
X
Y
TOP VIEW



5. Auxiliary view

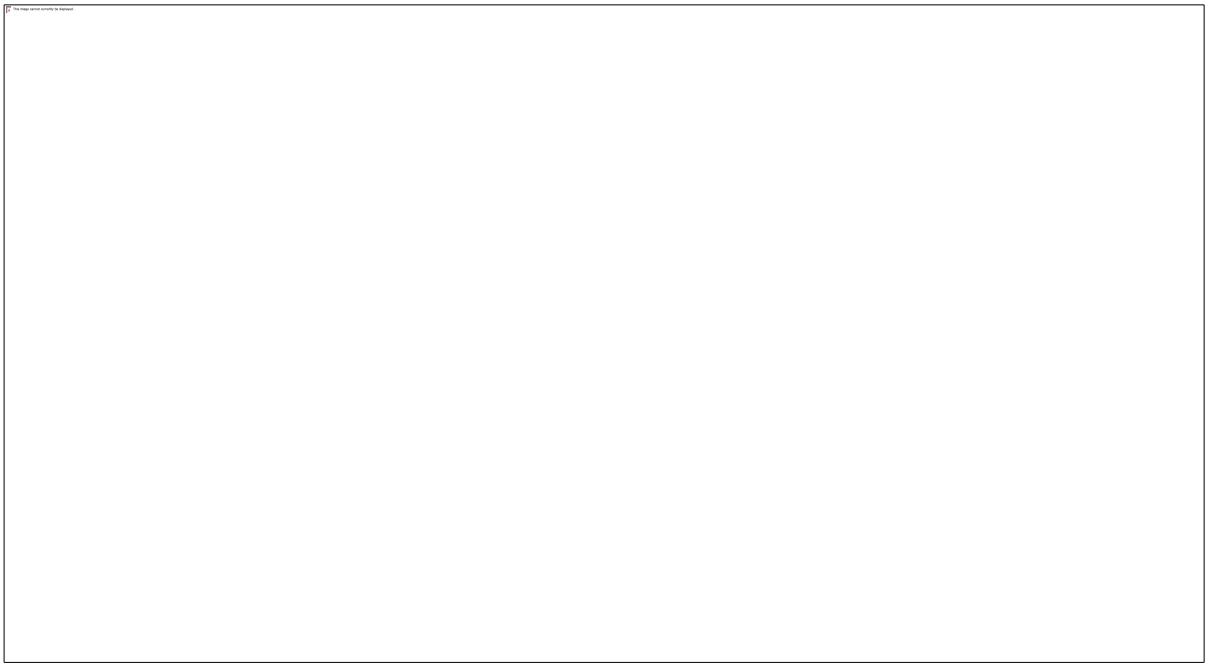
An auxiliary view is a view projected onto an additional plane to show the true shape and size of an inclined surface.

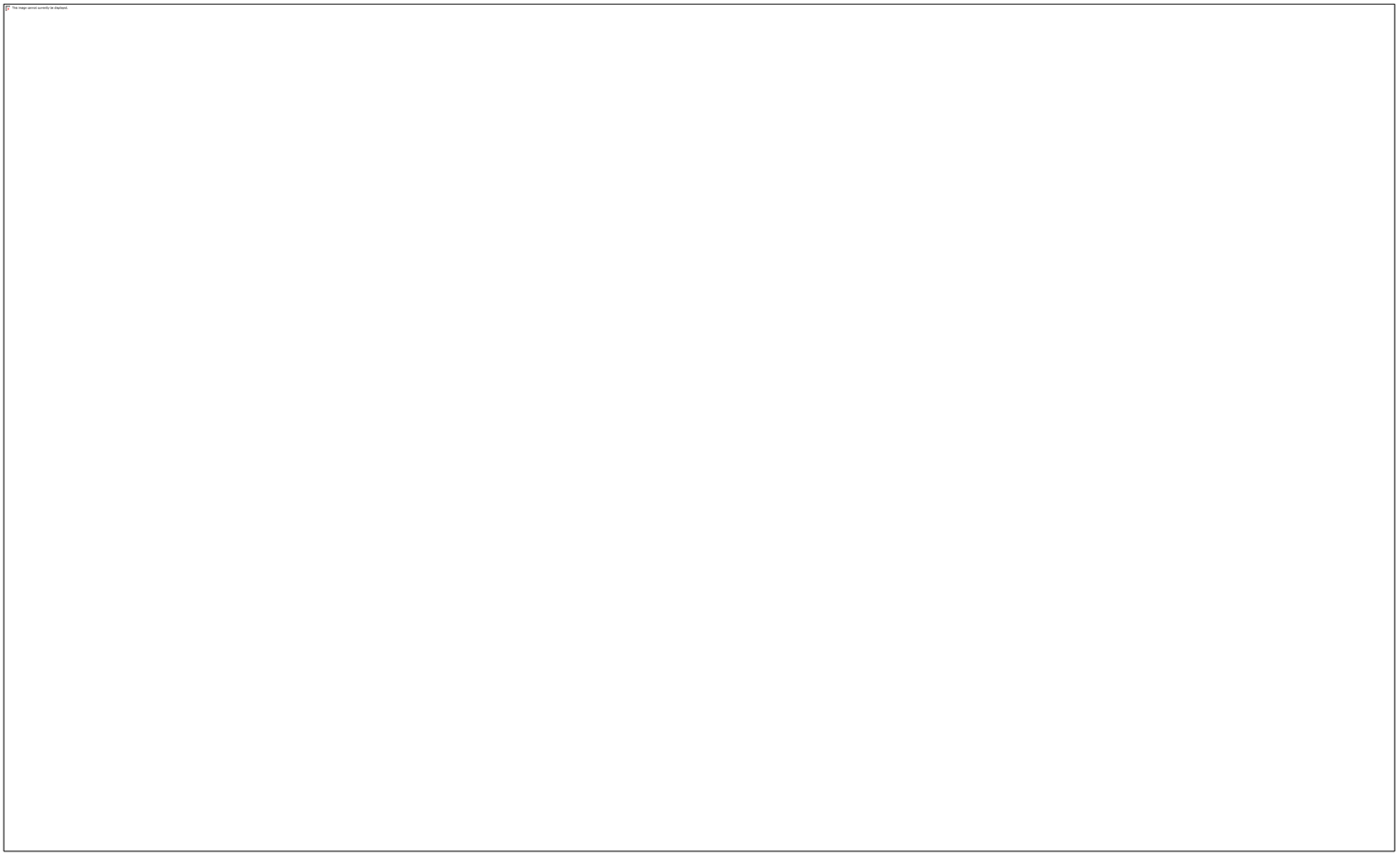
It is used when an inclined surface appears distorted in the principal orthographic views.

1.2.9 Drawing Instruments and Materials Used in Orthographic Projection

Orthographic drawings can be prepared using traditional drawing instruments or computer-aided design software.

A. Traditional drawing instruments







1. Drawing board

- Provides a flat surface for preparing drawings.
- Supports the drawing paper.
- Helps maintain accuracy during drawing.

2. T-square

- Used to draw horizontal lines.
- Used as a guide when using set squares.
- Helps maintain parallel lines.

3. Set squares

Common types include:

- 45° set square.
- 30°/60° set square.

Uses:

- Drawing vertical lines.
- Drawing perpendicular lines.
- Drawing lines at standard angles.
- Constructing geometrical shapes.

4. Scale ruler

- Used to measure lengths.
- Used to draw objects to a specified scale.
- Helps transfer dimensions accurately.

5. Drawing pencils

Different grades are used for different purposes.

Pencil grade	**Common application**
2H	Thin construction and projection lines
H	Light technical drawing lines
HB	General drawing and lettering
B	Darker freehand lines and shading

6. Compass

- Used to draw circles and arcs.
- Used to construct curved features of objects.

7. Protractor

- Used to measure and construct angles.
- Helps in drawing inclined features.

8. Eraser

- Used to remove unwanted pencil marks.
- Helps maintain neatness.

9. Drawing paper

- Provides the surface on which drawings are prepared.
- It should be clean, smooth and suitable for technical drawing.

10. Drawing clips or masking tape

- Used to hold drawing paper firmly on the drawing board.

B. Digital drawing tools

Computer-aided design (CAD) software can be used to prepare accurate orthographic drawings.

Examples include:

- AutoCAD.
- Autodesk Fusion.
- FreeCAD.
- SolidWorks.

Advantages of digital drawing:

1. High drawing accuracy.
2. Easy modification of drawings.
3. Ability to store drawings electronically.
4. Easy duplication and sharing.
5. Faster production of complex drawings.
6. Easy application of dimensions and annotations.
7. Ability to produce three-dimensional models from which two-dimensional views can be generated.

1.2.10 The Quadrant Method in Orthographic Projection

Meaning of the quadrant method

The quadrant method is a system of dividing the space around the intersection of the vertical plane and horizontal plane into four sections called quadrants.

It is used to determine the position of an object in relation to the horizontal and vertical projection planes.

The two principal planes are:

1. Vertical Plane (VP)

- It is an imaginary vertical surface.
- It receives the front elevation.
- It is used to project the front view of an object.

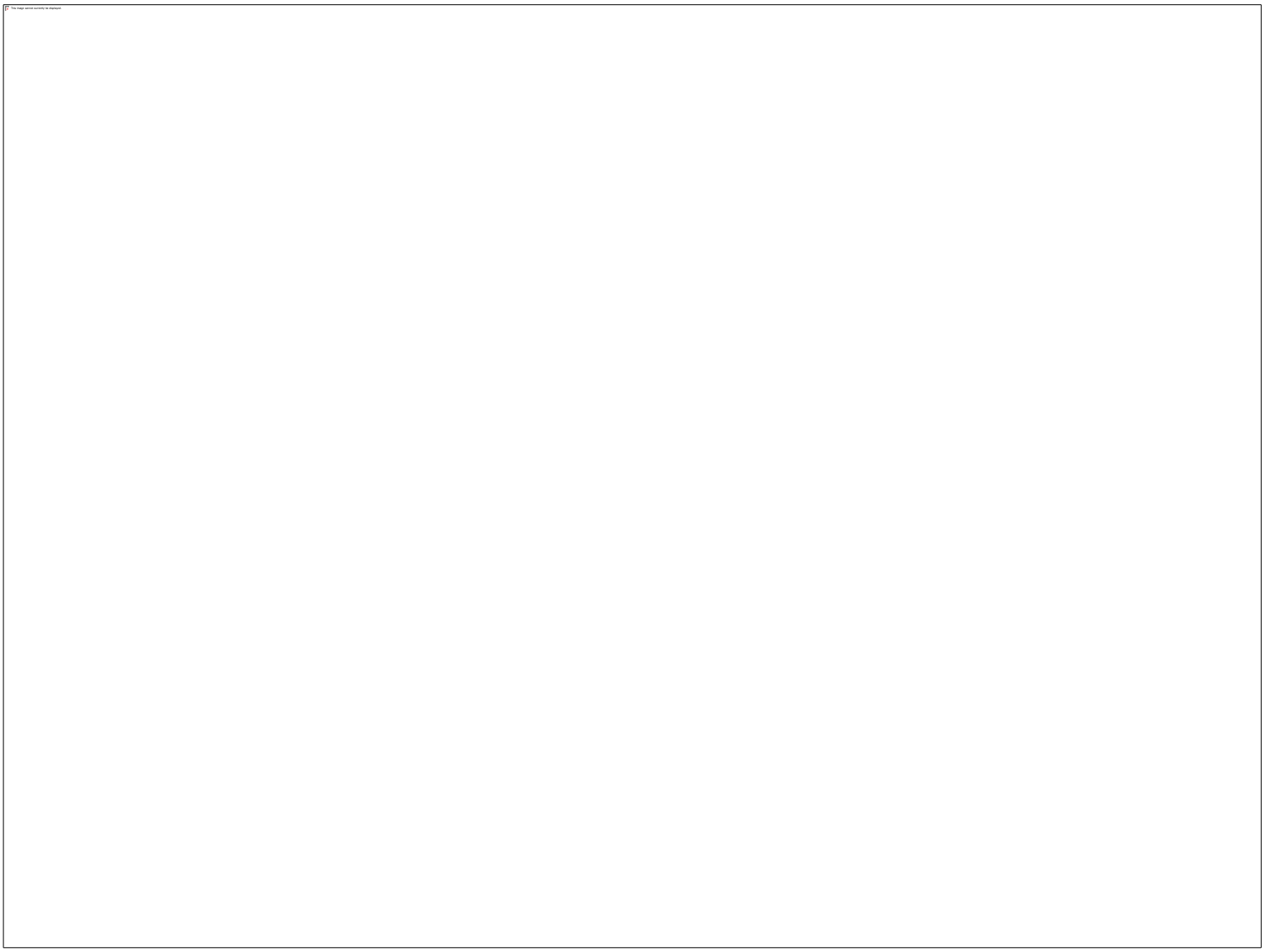
2. Horizontal Plane (HP)

- It is an imaginary horizontal surface.
- It receives the plan or top view.
- It is used to project the top view of an object.

The intersection of the vertical plane and horizontal plane is called the **XY reference line**.

A. The four quadrants

The vertical plane and horizontal plane divide the space into four quadrants.



First quadrant

- Located above the horizontal plane.
- Located in front of the vertical plane.
- Objects placed here are used in first-angle projection.
- This is the standard position for first-angle projection.

Second quadrant

- Located above the horizontal plane.
- Located behind the vertical plane.
- The object is above HP and behind VP.

Third quadrant

- Located below the horizontal plane.
- Located behind the vertical plane.
- Objects placed here are used in third-angle projection.

- This is the standard position for third-angle projection.

Fourth quadrant

- Located below the horizontal plane.
- Located in front of the vertical plane.
- The object is below HP and in front of VP.

B. Summary of the four quadrants

Quadrant	Position above/below HP	Position in front/behind VP
First	Above HP	In front of VP
Second	Above HP	Behind VP
Third	Below HP	Behind VP
Fourth	Below HP	In front of VP

C. Importance of the quadrant method

1. It helps determine the position of objects relative to projection planes.
2. It forms the foundation of first-angle and third-angle projection.
3. It helps learners understand the arrangement of views.
4. It provides a systematic method of representing three-dimensional objects.
5. It helps avoid errors when constructing orthographic drawings.
6. It assists in interpreting engineering drawings.

1.2.11 First-Angle Projection

Definition

First-angle projection is a method of orthographic projection in which an object is positioned in the first quadrant, that is, above the horizontal plane and in front of the vertical plane.

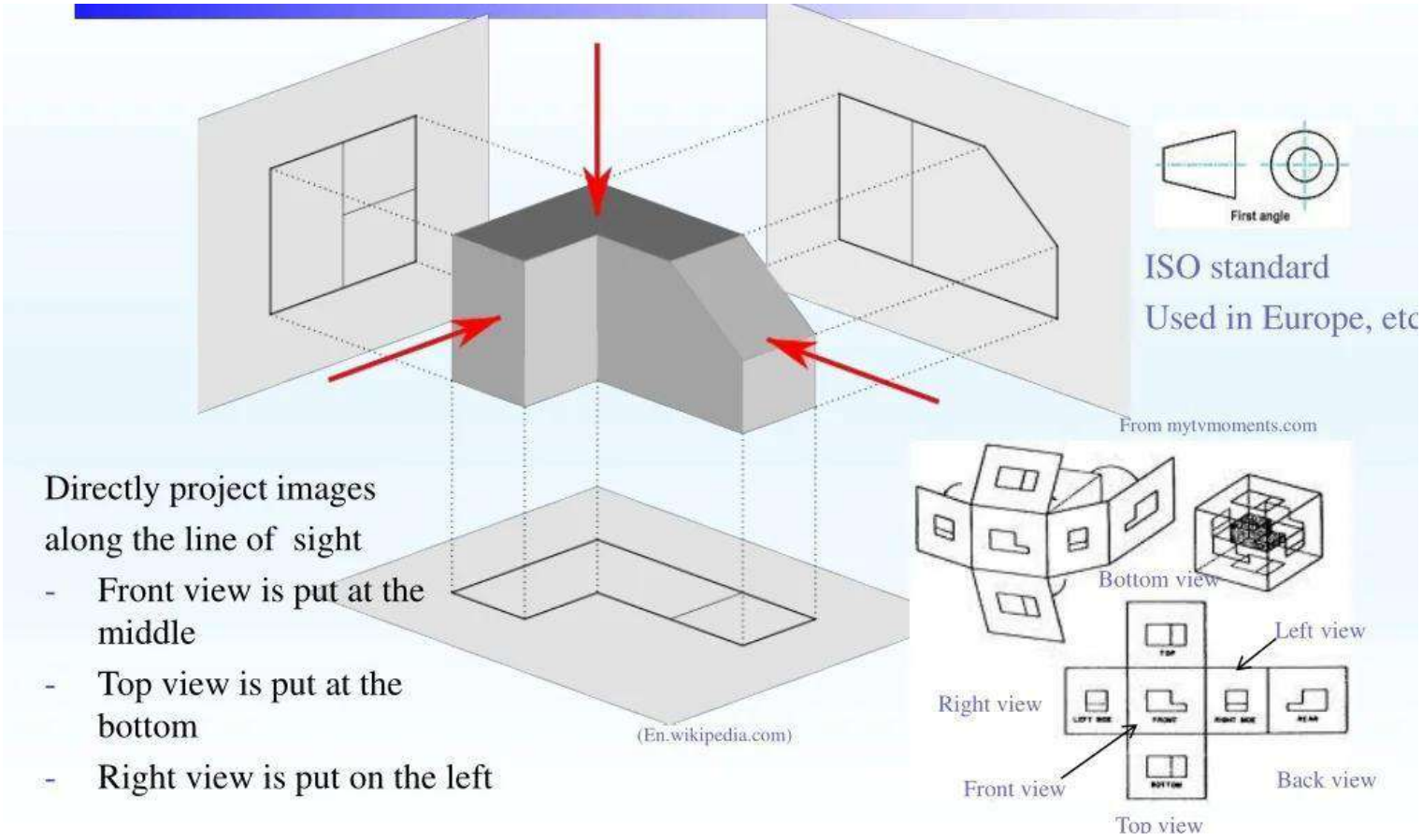
In this method, the object is positioned between the observer and the projection plane.

The views are arranged according to the principle that each view is placed on the opposite side of the object from the direction from which it is observed.

Arrangement of views in first-angle projection

The arrangement is as follows:

1. The front elevation is the principal view.
2. The plan is placed below the front elevation.
3. The right-hand end elevation is placed on the left of the front elevation.
4. The left-hand end elevation is placed on the right of the front elevation.



Explanation of the arrangement

1. Front elevation

- Drawn in the centre of the drawing.
- Provides the principal reference for other views.

2. Plan

- Placed below the front elevation.
- Obtained by projecting the object from above.

3. Right-hand end elevation

- Placed to the left of the front elevation.
- Obtained by viewing the object from the right-hand side.

4. Left-hand end elevation

- Placed to the right of the front elevation.
- Obtained by viewing the object from the left-hand side.

Advantages of first-angle projection

1. It is widely used in many engineering drawing systems.
2. It provides a systematic arrangement of views.
3. It enables accurate interpretation of object dimensions.
4. It is suitable for manufacturing and engineering work.
5. It reduces misunderstanding when drawings follow standard conventions.

Disadvantages of first-angle projection

1. Beginners may find the arrangement of views confusing.
2. The plan appears below the front elevation, which may initially seem counterintuitive.
3. Incorrect placement of side views can lead to errors in interpreting drawings.

1.2.12 Third-Angle Projection

Definition

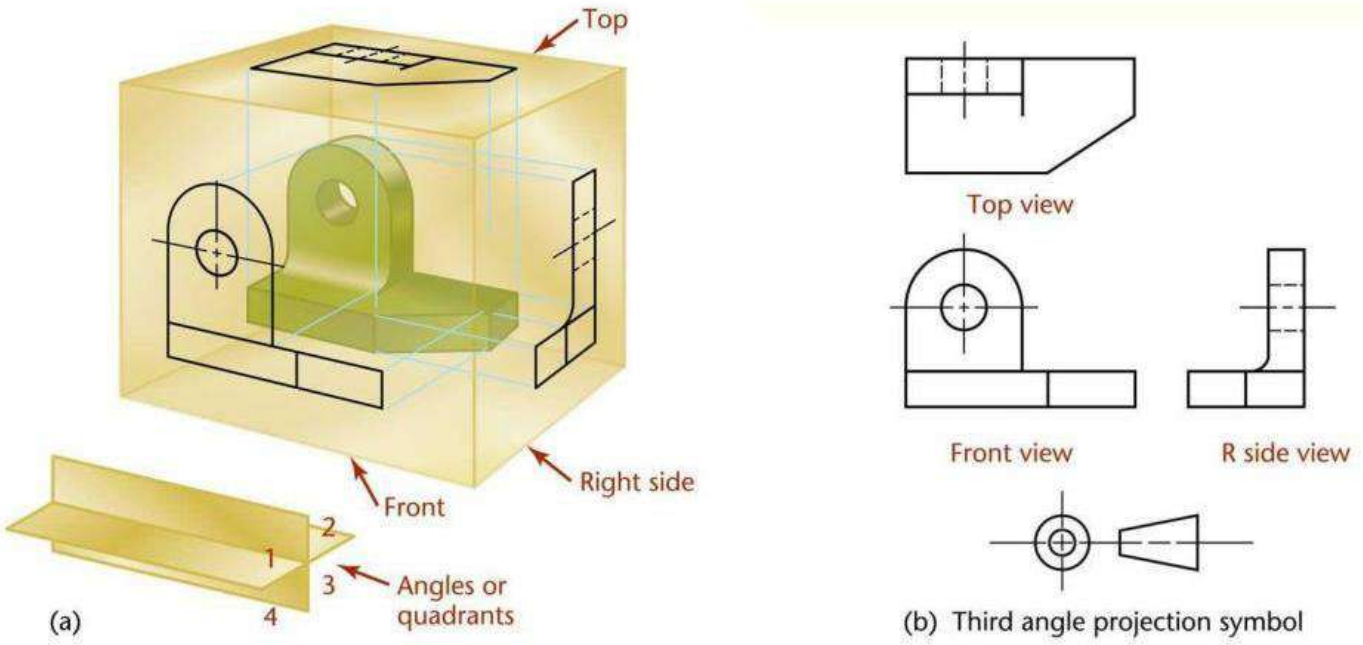
Third-angle projection is a method of orthographic projection in which an object is positioned in the third quadrant, that is, below the horizontal plane and behind the vertical plane.

In this method, the projection plane is positioned between the observer and the object.

Arrangement of views in third-angle projection

The arrangement is as follows:

1. The front elevation is the principal view.
2. The plan is placed above the front elevation.
3. The right-hand end elevation is placed on the right of the front elevation.
4. The left-hand end elevation is placed on the left of the front elevation.



Explanation of the arrangement

1. Front elevation

- Placed at the centre.
- Shows the front features of the object.

2. Plan

- Placed above the front elevation.
- Shows the top features.

3. Right-hand end elevation

- Placed to the right of the front elevation.
- Shows the right side of the object.

4. Left-hand end elevation

- Placed to the left of the front elevation.
- Shows the left side of the object.

Advantages of third-angle projection

1. The views are arranged on the same side as the direction from which they are observed.
2. It is easy for many learners to understand.
3. It provides a clear representation of the object's features.
4. It is commonly used in engineering drawings in countries such as the United States and Canada.
5. It simplifies the identification of the different views.

Disadvantages of third-angle projection

1. It may be unfamiliar to technicians trained in first-angle projection.
2. It can cause confusion when interpreted using first-angle conventions.
3. Drawings must clearly indicate the projection method used.

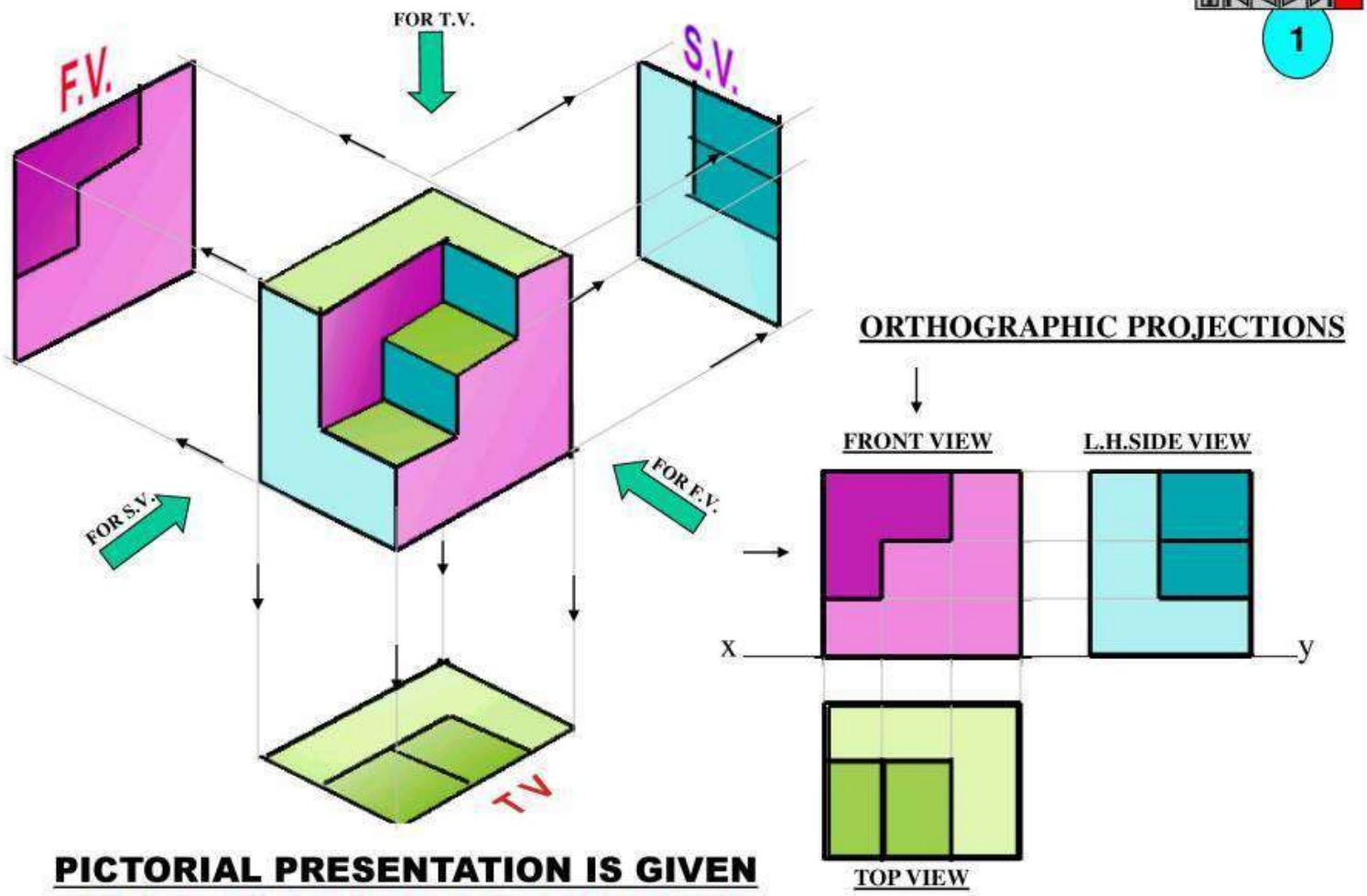
1.2.13 Differences Between First-Angle and Third-Angle Projection

The two methods are used to represent three-dimensional objects using two-dimensional drawings. However, they differ in the positioning of the object and the arrangement of views.

Feature	First-angle projection	Third-angle projection
Position of object	First quadrant	Third quadrant
Object position	Above HP and in front of VP	Below HP and behind VP
Position of plan	Below front elevation	Above front elevation
Right-hand end elevation	Left of front elevation	Right of front elevation
Left-hand end elevation	Right of front elevation	Left of front elevation
Projection plane	Behind the object	Between observer and object
Common use	Widely used in Kenya and many other countries	Commonly used in the USA and Canada

An easy way to remember

First-angle projection



Plan below; right view on left.

Third-angle projection

Plan above; right view on right.

1.2.14 Standard Symbols for First-Angle and Third-Angle Projection

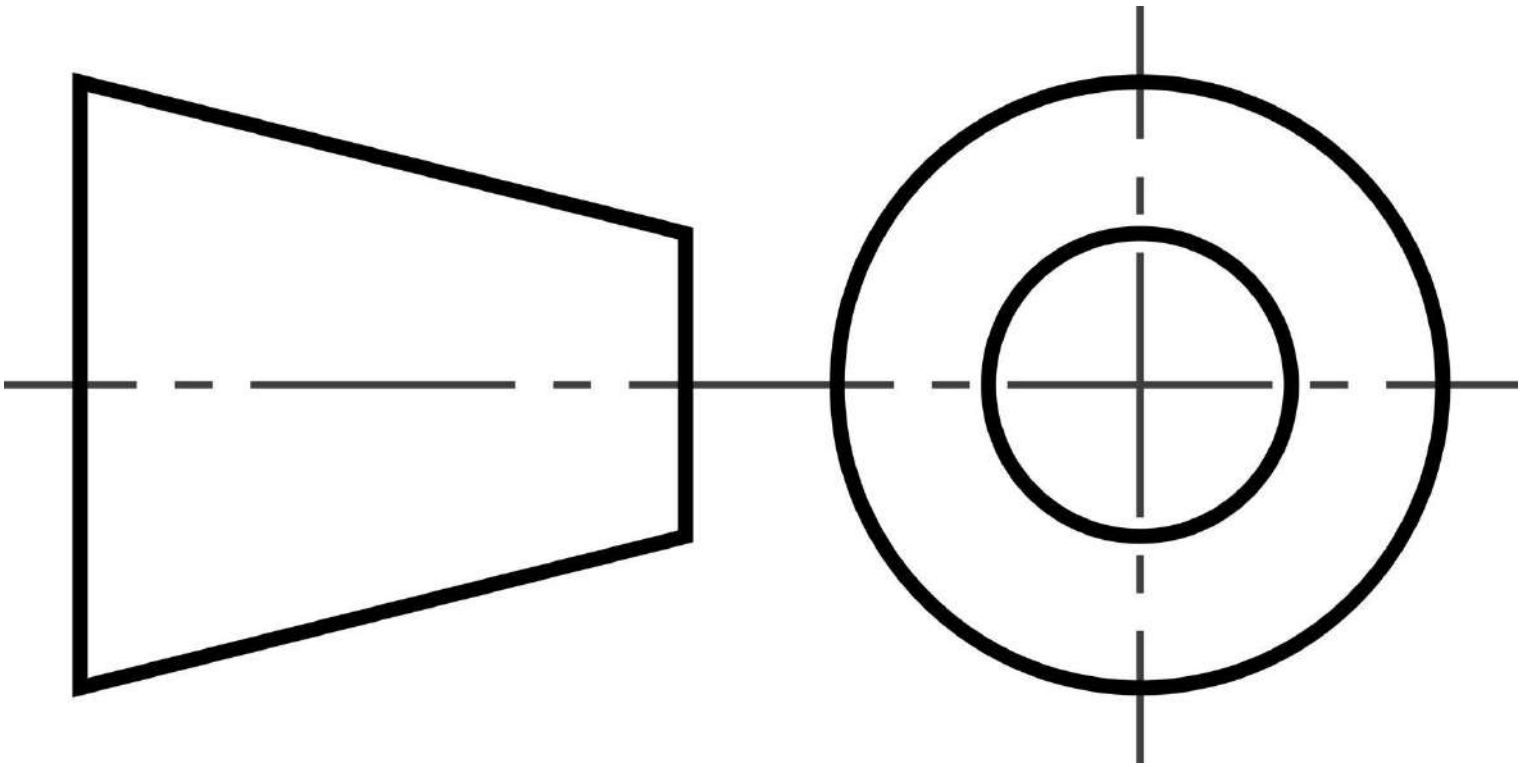
Engineering drawings use standard symbols to identify the projection method applied.

The symbols are based on the front and end views of a truncated cone.

1. First-angle projection symbol



2. Third-angle projection symbol



Importance of projection symbols

1. They identify the projection method used.
2. They prevent confusion when interpreting engineering drawings.

3. They guide the correct arrangement of views.
4. They promote uniformity in technical drawings.
5. They improve communication between designers and technicians.

Important: A drawing should clearly indicate whether first-angle or third-angle projection has been used, especially when the drawing is shared between people using different conventions.

1.2.15 Construction of Orthographic Drawings

Orthographic drawings should be constructed systematically to achieve accuracy, neatness and correct alignment.

A. General procedure for constructing orthographic views

Step 1: Study the object

- Examine the shape and features of the object.
- Identify the front, top and side surfaces.
- Identify holes, slots, steps, curves and other details.

Step 2: Select the front view

- Choose the view that reveals the most important features.
- Ensure the selected view gives a clear understanding of the object.

Step 3: Determine the projection method

- Decide whether to use first-angle or third-angle projection.
- Follow the required drawing convention.

Step 4: Draw the reference lines

- Draw the XY reference line where necessary.
- Establish the positions of the projection views.

Step 5: Construct the front elevation

- Use suitable drawing instruments.
- Draw light construction lines.
- Transfer the correct dimensions.

Step 6: Project the plan

- Project vertical construction lines from the front elevation.
- Transfer the depth dimensions.
- Draw the plan in its correct position.

Step 7: Construct the end elevation

- Transfer the height from the front elevation.
- Transfer the depth from the plan.
- Use a 45° mitre line where appropriate to transfer dimensions between plan and side view.

Step 8: Add details

- Draw holes, slots and other features.

- Include hidden details where necessary.
- Add centre lines for circular features.

Step 9: Apply line conventions

- Darken visible outlines.
- Use dashed lines for hidden details.
- Use thin chain lines for centres.

Step 10: Add dimensions

- Insert dimension lines.
- Add extension lines.
- Insert arrowheads and numerical dimensions.

Step 11: Add the projection symbol

- Indicate the method used.

Step 12: Check the drawing

- Confirm that all views are correctly aligned.
- Check dimensions and line types.
- Erase unnecessary construction lines.
- Ensure the drawing is neat and legible.

B. Example of a simple orthographic drawing

Consider a rectangular electrical enclosure with the following dimensions:

- Width = 120 mm.
- Height = 80 mm.
- Depth = 50 mm.

The object is represented using three principal views.



Interpretation of the views:

1. Front elevation: 120 mm wide and 80 mm high.
2. Plan: 120 mm wide and 50 mm deep.
3. End elevation: 50 mm deep and 80 mm high.

This example demonstrates how three views provide complete dimensional information about a simple electrical enclosure.

1.2.16 Dimensioning in Orthographic Drawings

Definition of dimensioning

Dimensioning is the process of indicating the measurements of an object on a technical drawing using numerical values, dimension lines, extension lines, arrowheads and other standard symbols.

Dimensioning communicates the actual size and position of the features of an object.

In electrical technology, dimensioning is important when manufacturing or installing equipment such as:

- Distribution boards.
- Electrical control panels.
- Junction boxes.
- Cable trays.
- Mounting brackets.
- Switchgear enclosures.

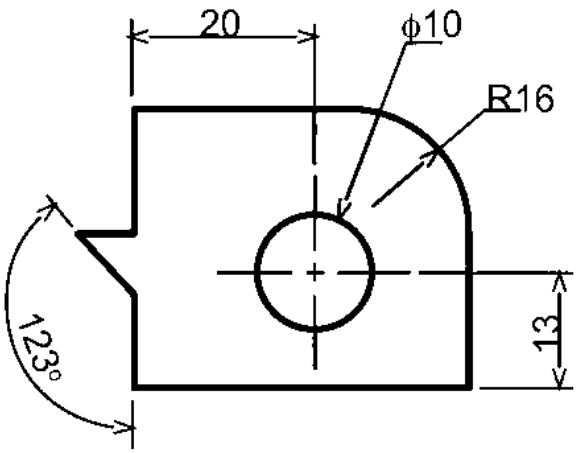
A. Importance of dimensioning

1. It communicates the exact size of an object.
2. It guides the manufacturing of components.
3. It assists in planning installation work.
4. It prevents measurement errors.
5. It helps determine the amount of material required.
6. It ensures components fit together correctly.
7. It reduces material wastage.
8. It improves quality control.
9. It supports maintenance and replacement of equipment.
10. It promotes standardisation in engineering drawings.

B. Main elements of dimensioning

- **Extension lines**
  - indicate the location on the object's features that are dimensioned.
- **Dimension lines** (with arrowheads)
  - indicate the direction and extent of a dimension, and inscribe
- **Dimension numbers**
  (or dimension figures)
- **Leader lines**
  - indicate details of the feature with a note.
- **Notes**
  - local or general note

Example



1. Dimension line

A dimension line is a thin continuous line that indicates the distance between two points or features.

Characteristics:

- It is usually drawn parallel to the dimension being indicated.
- It has arrowheads at both ends.
- It carries the numerical dimension.

2. Extension line

An extension line is a thin continuous line that extends from the feature being measured towards the dimension line.

Uses:

- Indicates the limits of the measurement.
- Shows the exact points between which a dimension applies.

3. Arrowheads

Arrowheads are placed at the ends of dimension lines.

Uses:

- Indicate the limits of a measurement.
- Show the beginning and end of a dimension.

4. Dimension figures

Dimension figures are numerical values showing the actual measurements of an object.

Examples:

- 50 mm.
- 100 mm.
- 250 mm.
- 500 mm.

5. Leader line

A leader line is a thin line used to connect a note or dimension to a particular feature of an object.

It is useful for identifying:

- Holes.
- Curved surfaces.
- Special features.
- Material specifications.

6. Dimension symbols

Standard symbols are used to communicate particular features.

Symbol	Meaning	Example
Ø	Diameter	Ø20 mm
R	Radius	R15 mm
□	Square	□25 mm
°	Degrees	45°
±	Plus or minus tolerance	20 ± 0.2 mm
M	Metric screw thread	M10

7. Units

Units indicate the measurement system used.

Common units include:

- Millimetres (mm).

- Centimetres (cm).
- Metres (m).

Millimetres are commonly used for engineering component drawings.

C. Types of dimensions

1. Linear dimensions

These indicate straight-line distances.

Examples:

- Length.
- Width.
- Height.
- Thickness.
- Depth.

2. Angular dimensions

These indicate the angle between two lines or surfaces.

Examples:

- 30°.
- 45°.
- 60°.
- 90°.

3. Diameter dimensions

These indicate the distance across a circular feature through its centre.

Example: Ø20 mm.

4. Radius dimensions

These indicate the distance from the centre of a circle or arc to its circumference.

Example: R10 mm.

5. Location dimensions

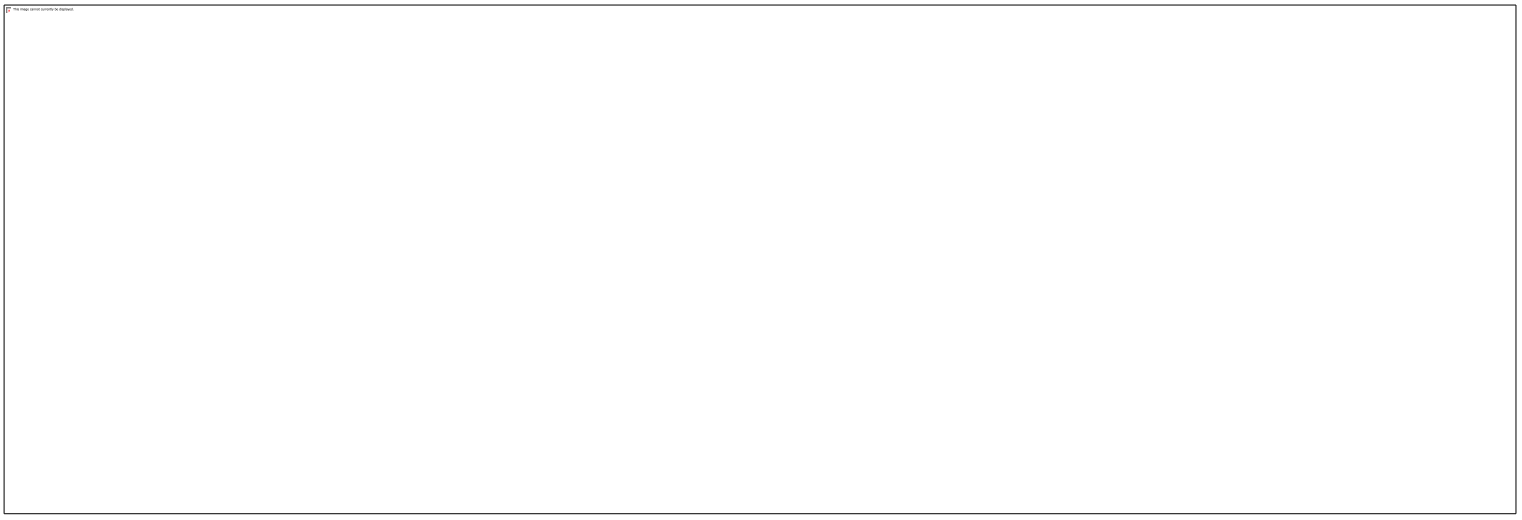
These indicate the position of a particular feature relative to a reference point or surface.

Example: The centre of a mounting hole is located 25 mm from the left edge of an enclosure.

D. Dimensioning techniques

1. Chain dimensioning

Chain dimensioning involves placing a series of dimensions consecutively from one feature to another.



Advantages:

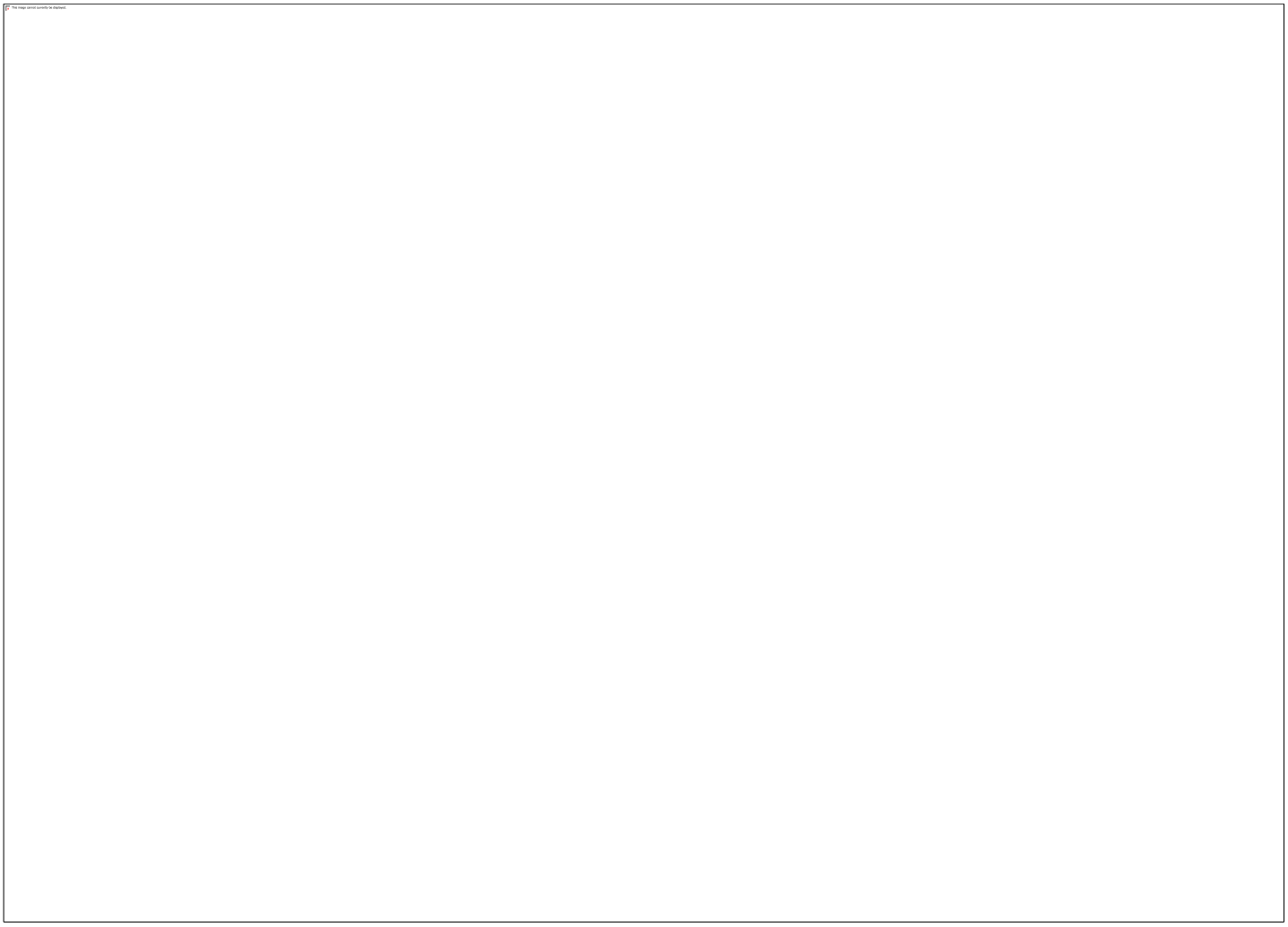
- Simple to apply.
- Suitable for a series of related features.
- Easy to understand.

Disadvantage:

- Small measurement errors may accumulate along the chain.

2. Baseline or datum dimensioning

Baseline dimensioning involves measuring several features from a common reference line or datum.



Advantages:

- Reduces the accumulation of dimensional errors.
- Provides a common reference point.
- Suitable for accurately positioning holes and other features.

3. Parallel dimensioning

Parallel dimensioning involves placing dimensions parallel to one another, usually from a common reference point.

Advantages:

- Provides a clear arrangement of dimensions.
- Reduces overlapping dimension lines.
- Makes drawings easier to read.

4. Combined dimensioning

Combined dimensioning involves using two or more dimensioning methods in the same drawing.

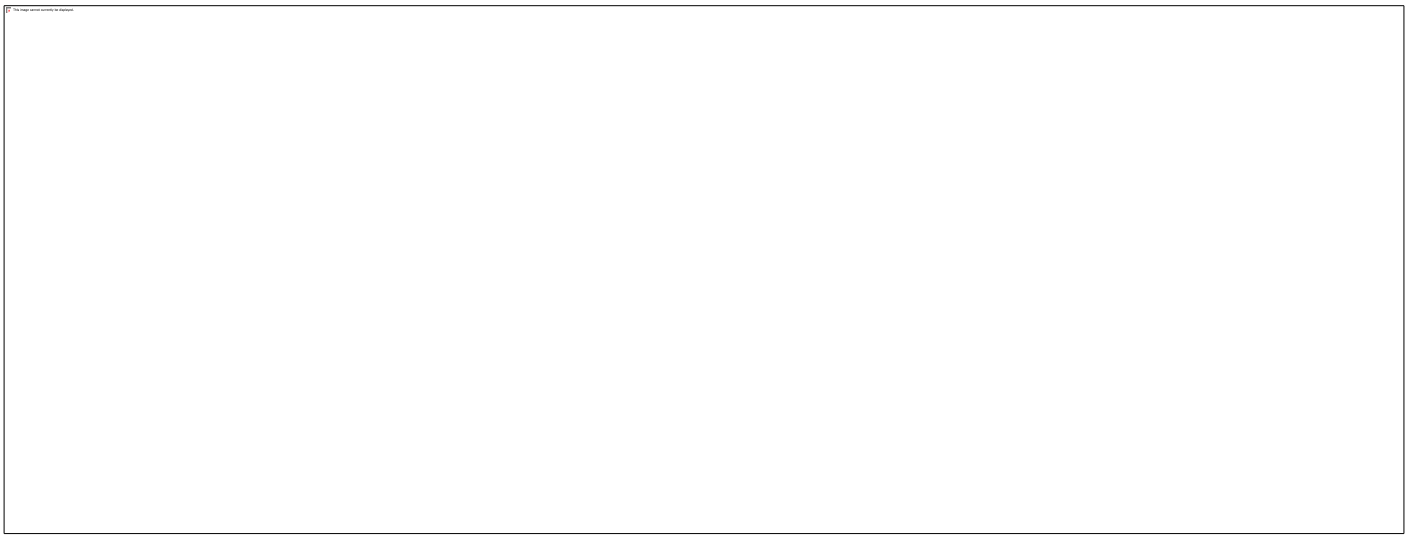
It is suitable for objects with many features and different measurement requirements.

E. Rules for dimensioning orthographic drawings

1. Use standard units consistently.
2. Place dimensions where they are easy to read.
3. Avoid unnecessary repetition of dimensions.
4. Do not use visible outlines as dimension lines.
5. Keep dimension lines outside the object outline where possible.
6. Avoid crossing dimension lines.
7. Use thin continuous lines for dimension and extension lines.
8. Use clear and legible numerical figures.
9. Place arrowheads accurately at the ends of dimension lines.
10. Indicate diameter using Ø.
11. Indicate radius using R.
12. Provide sufficient dimensions to manufacture or install the object.
13. Avoid dimensioning hidden features unless necessary.
14. Maintain consistent spacing between dimension lines.
15. Use an appropriate scale for the drawing.

1.2.17 Line Types Used in Orthographic Projection

Different line types are used to communicate different features of an object.



Line type	Appearance	Application
Continuous thick line	_____	Visible outlines and edges
Continuous thin line	_____	Dimension lines and extension lines
Dashed thin line	- - - - - -	Hidden details
Chain thin line	— · — · —	Centre lines and axes
Cutting plane line	Thick chain line with arrows	Indicates where an object is cut
Freehand thin line	Irregular continuous line	Short breaks and limits of partial sections
Zigzag thin line	/////\	Long breaks in objects

Importance of standard line types

1. They make technical drawings easier to interpret.
2. They distinguish visible and hidden features.
3. They improve communication between engineers and technicians.
4. They promote uniformity.
5. They reduce misunderstanding during manufacturing and installation.

1.2.18 Sectional Orthographic Views

Definition

A sectional view is an orthographic representation obtained by imagining that an object is cut by a plane to reveal its internal construction.

It is used when an ordinary front, plan or end elevation cannot clearly show internal features.

Types of sectional views

1. Full sectional view

The object is imagined to be cut completely through by a cutting plane.

It reveals the internal features of the object.

2. Half-sectional view

Half of the object is represented in section while the other half shows the external appearance.

It is commonly used for symmetrical objects.

3. Offset sectional view

The cutting plane is bent or offset to pass through several important features that do not lie in a straight line.

4. Broken-out sectional view

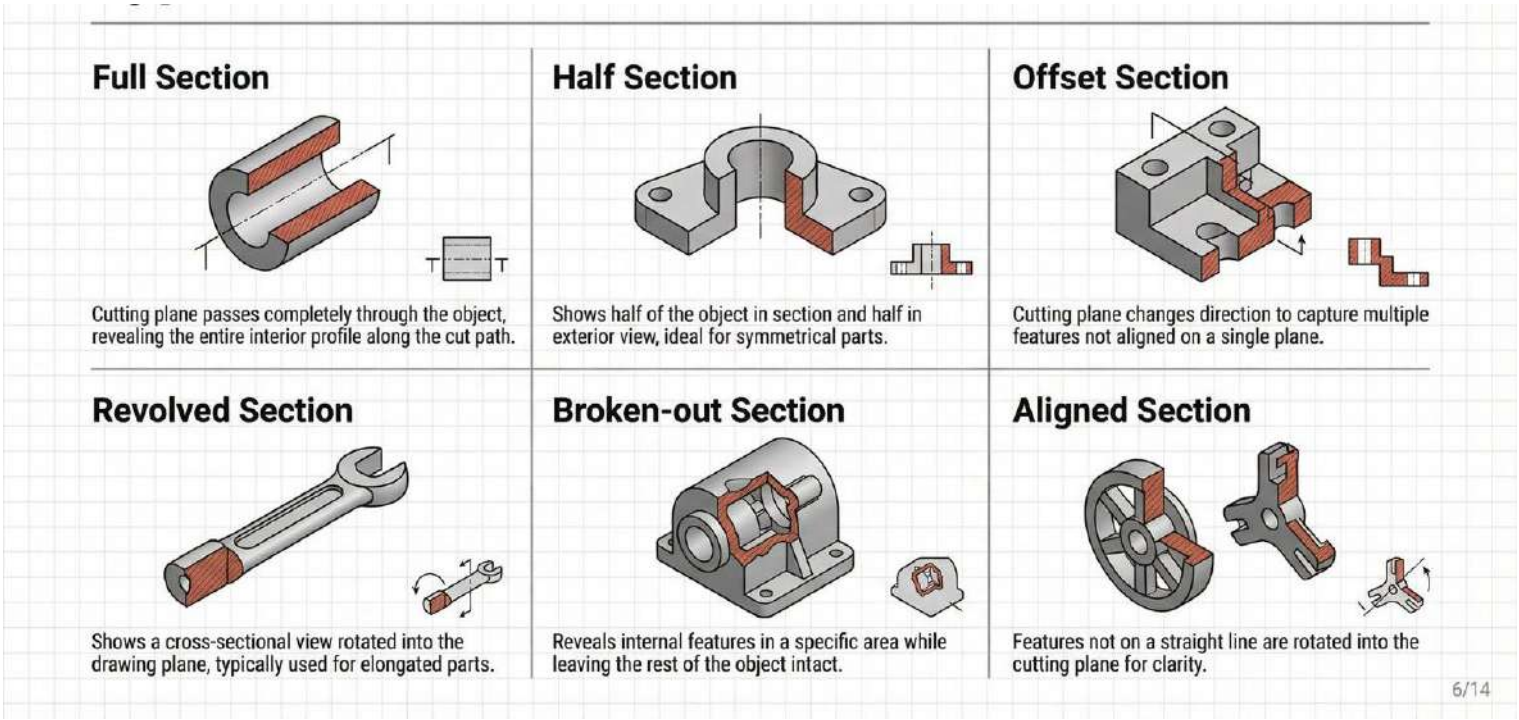
A small portion of the object is imagined to be removed to expose an internal feature.

Hatching in sectional views

Hatching refers to thin, equally spaced parallel lines drawn on surfaces exposed by an imaginary cut.

Rules for hatching:

1. Use thin continuous lines.
2. Maintain uniform spacing.
3. Use a consistent angle, commonly 45°.
4. Avoid overcrowding the sectioned area.
5. Different adjacent components may use different hatch directions or spacing to distinguish them.
6. Do not hatch empty spaces such as holes.



Importance of sectional views in electrical technology

1. They show the internal arrangement of electrical equipment.

2. They help technicians understand the construction of components.
3. They assist in identifying internal defects.
4. They guide manufacturing and assembly.
5. They improve maintenance and repair work.

1.2.19 Scale in Orthographic Projection

Definition

Scale is the ratio between the dimensions of an object as represented on a drawing and its actual dimensions.

It allows objects that are too large or too small to be represented conveniently on drawing paper.

Types of scales

1. Full-size scale (1:1)

The drawing has the same dimensions as the actual object.

Example:

An object measuring 100 mm is drawn as 100 mm.

2. Reducing scale

The drawing is smaller than the actual object.

Examples:

- 1:2.
- 1:5.
- 1:10.
- 1:100.

Example:

A 200 mm electrical enclosure drawn at a scale of 1:2 will measure 100 mm on the drawing.

3. Enlarging scale

The drawing is larger than the actual object.

Examples:

- 2:1.
- 5:1.
- 10:1.

Example:

A 10 mm electrical terminal drawn at a scale of 5:1 will measure 50 mm on the drawing.

Scale calculations

The formula is:

$$Scale = \frac{Drawing\ size}{Actual\ size}$$

Example 1: Reducing scale

An electrical enclosure has an actual width of 400 mm. It is drawn at a scale of 1:4. Calculate the drawing width.

Solution:

Drawing width=400/4

=100 mm

Example 2: Enlarging scale

A small electrical component measures 15 mm. It is drawn at a scale of 4:1. Calculate the drawing size.

Solution:

Drawing size=15×4

=60 mm

Example 3: Determining the scale

A cable connector with an actual length of 80 mm is represented by a drawing measuring 40 mm.

$$\text{Scale} = \frac{\text{Drawing size}}{\text{Actual size}}$$

$$= \frac{40}{80}$$

$$= \frac{1}{2}$$

Therefore, the scale is **1:2**.

Important: Dimensions written on an engineering drawing normally indicate the actual size of the object, not the measured size on the paper.

1.2.20 Practical Application: Orthographic Drawing of an Electrical Enclosure

Learning activity

A learner is provided with an electrical enclosure commonly used in a Kenyan building installation.

The enclosure has the following dimensions:

- Width: 150 mm.
- Height: 200 mm.
- Depth: 80 mm.

The learner is required to prepare its orthographic drawing using first-angle projection.



Materials and equipment

1. Drawing board.
2. Drawing paper.
3. T-square.
4. Set squares.
5. Scale ruler.
6. HB pencil.
7. Eraser.
8. Compass.
9. Drawing clips.

Procedure

1. Collect the required drawing instruments.
2. Study the electrical enclosure and identify its main features.
3. Select the front elevation.
4. Determine the appropriate drawing scale.
5. Draw the front elevation.
6. Project the plan below the front elevation.
7. Project the right-hand end elevation to the left of the front elevation.
8. Add visible outlines.
9. Add hidden details where necessary.
10. Dimension the three views.
11. Insert the first-angle projection symbol.
12. Check the accuracy and neatness of the drawing.

Expected competencies

By completing the activity, the learner should demonstrate the ability to:

- Select and use drawing instruments correctly.
- Interpret the shape of an electrical component.

- Apply first-angle projection.
- Construct aligned orthographic views.
- Apply standard dimensioning techniques.
- Observe workshop safety.

Safety precautions

1. Handle sharp drawing instruments carefully.
2. Avoid leaving compasses and dividers open on the drawing board.
3. Keep the working surface clean.
4. Store drawing instruments safely after use.
5. Avoid damaging drawing paper with sharp instruments.
6. Maintain proper sitting posture when drawing.

1.2.21 Errors Commonly Made When Constructing Orthographic Drawings

Common error	How to correct it
Incorrect arrangement of views	Identify whether first-angle or third-angle projection is required.
Misaligned views	Use projectors to align corresponding features.
Incorrect dimensions	Measure carefully and check all numerical values.
Wrong line types	Apply standard engineering line conventions.
Poor lettering	Use neat, consistent technical lettering.
Missing hidden details	Identify features that are not visible from the viewing direction.
Incorrect scale	Calculate the scale before starting the drawing.
Overlapping dimensions	Arrange dimensions systematically.
Thick construction lines	Use light lines during construction and darken only final outlines.
Missing projection symbol	Insert the appropriate projection symbol.

Revision Questions and Assessment

STRAND 1.0: FUNDAMENTALS OF ELECTRICITY

SUB-STRAND 1.2: ORTHOGRAPHIC PROJECTION

SECTION A: MULTIPLE-CHOICE QUESTIONS (30 MARKS)

Instructions: Answer all questions. Choose the correct answer from the alternatives A, B, C and D. Each question carries 1 mark.

1. What is orthographic projection?

A. A method of representing objects using freehand sketches.

B. A method of representing three-dimensional objects using two-dimensional views.

C. A method of measuring electrical current.

D. A method of representing objects using pictorial drawings only.

2. Which of the following is a principal view in orthographic projection?

A. Isometric view.

B. Perspective view.

C. Front elevation.

D. Oblique view.

3. Which plane receives the front elevation?

A. Horizontal plane.

B. Vertical plane.

C. Profile plane.

D. Auxiliary plane.

4. The plan of an object is obtained by viewing it from:

A. Below.

B. The front.

C. Above.

D. The side.

5. Which of the following instruments is used to draw horizontal lines?

A. Compass.

B. T-square.

C. Protractor.

D. Divider.

6. An object in first-angle projection is positioned in the:

A. First quadrant.

B. Second quadrant.

C. Third quadrant.

D. Fourth quadrant.

7. In first-angle projection, the plan is positioned:

A. Above the front elevation.

B. Below the front elevation.

C. To the left of the front elevation.

D. To the right of the front elevation.

8. In third-angle projection, the right-hand end elevation is positioned:

A. Above the front elevation.

B. Below the front elevation.

C. To the left of the front elevation.

D. To the right of the front elevation.

9. Which projection method places the object in the third quadrant?

A. First-angle projection.

B. Third-angle projection.

C. Isometric projection.

D. Oblique projection.

10. Which of the following lines is used to represent hidden details?

A. Continuous thick line.

B. Continuous thin line.

C. Dashed thin line.

D. Freehand line.

11. The intersection of the vertical plane and horizontal plane is called:

A. AB line.

B. XY line.

C. CD line.

D. MN line.

12. Which instrument is used to draw circles?

A. T-square.

B. Set square.

C. Compass.

D. Scale ruler.

13. The main purpose of dimensioning is to:

A. Decorate technical drawings.

B. Indicate the measurements of an object.

C. Colour the drawing.

D. Show the material used.

14. Which symbol represents the diameter of a circular feature?

A. R.

B. Ø.

C. ±.

D. °.

15. A radius is the distance between:

A. Two opposite points on a circle.

B. The centre and circumference of a circle.

C. Two parallel lines.

D. Two points on a straight line.

16. Which of the following is used to indicate the limits of a dimension?

A. Extension line.

B. Centre line.

C. Hidden line.

D. Cutting plane line.

17. A sectional view is mainly used to show:

A. External colour.

B. Internal features.

C. The weight of an object.

D. The material cost.

18. What is hatching in sectional drawing?

A. Drawing circles on the object.

B. Drawing parallel lines on cut surfaces.

C. Erasing unwanted lines.

D. Drawing dimension figures.

19. Which of the following is a reducing scale?

A. 5:1.

B. 2:1.

C. 1:5.

D. 1:1.

20. A component measuring 200 mm is drawn at a scale of 1:2. What is its drawing length?

A. 50 mm.

B. 100 mm.

C. 200 mm.

D. 400 mm.

21. Which of the following is an example of an electrical component that can be represented using orthographic projection?

A. Electrical distribution board.

B. Rainfall.

C. Soil.

D. Wind direction.

22. The right-hand end elevation in first-angle projection is placed:

A. To the right of the front elevation.

B. Below the front elevation.

C. To the left of the front elevation.

D. Above the front elevation.

23. Which of the following is used to represent the centre of a circular hole?

A. Dashed line.

B. Centre line.

C. Thick continuous line.

D. Freehand line.

24. Which type of dimensioning uses a common reference point?

A. Chain dimensioning.

B. Baseline dimensioning.

C. Angular dimensioning.

D. Diameter dimensioning.

25. Which of the following is a digital drawing software?

A. Microsoft Calculator.

B. AutoCAD.

C. Microsoft Media Player.

D. Notepad.

26. What is the main function of a profile plane?

A. To receive the plan.

B. To receive the front elevation.

C. To receive the end elevation.

D. To indicate dimensions.

27. A small electrical component of 10 mm is drawn at a scale of 5:1. What is its drawing size?

A. 2 mm.

B. 5 mm.

C. 10 mm.

D. 50 mm.

28. Which of the following is a characteristic of orthographic projection?

A. Projectors are perpendicular to the projection plane.

B. Objects are represented using colours only.

C. Measurements are always exaggerated.

D. Only one view is permitted.

29. Why is orthographic projection important when installing electrical equipment?

A. It increases the electrical voltage.

B. It guides accurate positioning and installation.

C. It reduces electrical resistance.

D. It increases current flow.

30. Which of the following should be done before constructing an orthographic drawing?

A. Colour the drawing.

B. Erase all construction lines.

C. Study the object and identify its features.

D. Draw dimensions without examining the object.

SECTION B: STRUCTURED QUESTIONS (50 MARKS)

Instructions: Answer all questions. Show all necessary working where applicable. Use appropriate drawing instruments when required.

1: Fundamentals of Orthographic Projection (8 marks)

a) Define orthographic projection. (2 marks)

b) State three principal views used in orthographic projection. (3 marks)

c) Explain three reasons why orthographic projection is important in electrical technology. (3 marks)

2: The Quadrant Method (8 marks)

a) Define the quadrant method as used in orthographic projection. (2 marks)

b) Name the four quadrants used in orthographic projection. (2 marks)

c) State the position of an object in:

i. First quadrant. (1 mark)

ii. Third quadrant. (1 mark)

d) State two functions of the XY reference line. (2 marks)

3: First-Angle and Third-Angle Projection (8 marks)

a) Define first-angle projection. (2 marks)

b) Define third-angle projection. (2 marks)

c) State four differences between first-angle and third-angle projection. (4 marks)

4: Dimensioning and Line Conventions (8 marks)

a) Define dimensioning in technical drawing. (2 marks)

b) State four elements of dimensioning and explain their functions. (4 marks)

c) Identify the line type used to represent:

i. Visible outlines. (1 mark)

ii. Hidden details. (1 mark)

5: Scales and Orthographic Drawing (9 marks)

a) Define the term scale as used in engineering drawing. (2 marks)

b) An electrical control panel has an actual width of 600 mm. Calculate its drawing width when represented at a scale of 1:5. (2 marks)

c) A small electrical connector has an actual length of 20 mm. Calculate its drawing length when represented at a scale of 3:1. (2 marks)

d) State three advantages of using appropriate scales in orthographic drawings. (3 marks)

6: Practical Application in Electrical Technology (9 marks)

An electrician is required to prepare an orthographic drawing of a rectangular electrical enclosure with the following dimensions:

- Width = 150 mm.
- Height = 100 mm.
- Depth = 60 mm.

a) State the three principal views required to represent the enclosure. (3 marks)

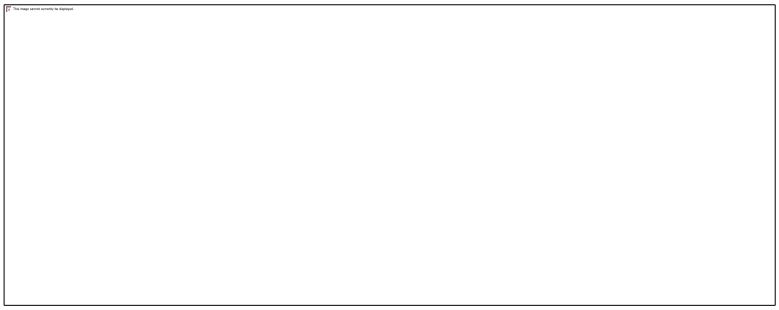
b) Using first-angle projection, describe the correct positions of the three views. (3 marks)

c) State three precautions or procedures that should be observed when preparing the drawing. (3 marks)

1.2.25 Practical Competency-Based Assessment Activity

Individual and group activity

Activity: Preparation of an Orthographic Drawing of an Electrical Junction Box



Scenario:

A local electrical installation contractor in Kenya is planning to install junction boxes in a newly constructed classroom block. The contractor requires accurate technical drawings to guide the fabrication and installation of the boxes.

The learner is required to prepare an orthographic drawing of a junction box using first-angle projection.

Given dimensions:

- Length: 120 mm.

- Width: 80 mm.
- Height: 50 mm.

Tasks:

1. Identify the appropriate drawing instruments.
2. Examine the junction box and identify its main features.
3. Prepare the front elevation.
4. Construct the plan.
5. Construct the end elevation.
6. Apply the correct line conventions.
7. Insert appropriate dimensions.
8. Indicate the projection method.
9. Present the drawing to classmates for evaluation.

Assessment criteria

Assessment area	Expected performance
Selection of instruments	Appropriate instruments selected
Front elevation	Correctly constructed
Plan	Correctly positioned and aligned
End elevation	Correctly constructed
Dimensioning	Accurate and complete
Line conventions	Correctly applied
Neatness	Clear and well presented
Interpretation	Correctly explains the views

Reflection questions

1. Which view was easiest to construct, and why?
2. What challenges did you experience when transferring dimensions?
3. How does orthographic projection help electricians during installation?
4. How can CAD software improve the accuracy of your drawing?

1.2.26 Suggested Answers for Self-Assessment

Section A: Multiple-choice answer key

Question	Answer	Question	Answer	Question	Answer

1	B	11	B	21	A
2	C	12	C	22	C
3	B	13	B	23	B
4	C	14	B	24	B
5	B	15	B	25	B
6	A	16	A	26	C
7	B	17	B	27	D
8	D	18	B	28	A
9	B	19	C	29	B
10	C	20	B	30	C

Section B: Suggested marking guide

Question 1

a) A method of representing three-dimensional objects on two-dimensional planes using perpendicular projectors. (2)

b) Front elevation, plan and end elevation. (3)

c) Any three:

- Accurate representation of components.
- Guides installation.
- Assists manufacturing.
- Improves communication.
- Supports maintenance. (3)

Question 2

a) A method of dividing space into four sections using the vertical and horizontal projection planes. (2)

b) First, second, third and fourth quadrants. (2)

c)

- First quadrant: Above HP and in front of VP. (1)
- Third quadrant: Below HP and behind VP. (1)

d) Any two:

- Separates the vertical and horizontal planes in the reference system.
- Provides a reference for positioning and projecting views. (2)

Question 3

a) Projection method in which the object is in the first quadrant. (2)

b) Projection method in which the object is in the third quadrant. (2)

c) Any four correct differences from the comparison table. (4)

Question 4

a) The process of indicating measurements on a technical drawing. (2)

b) Any four correctly explained:

- Dimension line.

- Extension line.
- Arrowheads.
- Dimension figures.
- Leader line.
- Units. (4)

c)

- Visible outlines: Continuous thick line. (1)
- Hidden details: Dashed thin line. (1)

Question 5

a) Ratio of drawing size to actual size. (2)

b)

Drawing size=6005Drawing size=5600

=120 mm=120 mm

(2)

c)

Drawing size=20×3Drawing size=20×3

=60 mm=60 mm

(2)

d) Any three:

- Enables large objects to fit on paper.
- Enlarges small objects for detailed representation.
- Improves drawing presentation.
- Allows convenient representation of objects. (3)

Question 6

a)

- Front elevation.
- Plan.
- End elevation. (3)

b)

- Front elevation at the centre.
- Plan below the front elevation.
- Right-hand end elevation to the left of the front elevation. (3)

c) Any three:

- Use appropriate drawing instruments.
- Maintain correct alignment.

- Apply correct line conventions.
- Use accurate dimensions.
- Maintain neatness.
- Observe drawing safety. (3)

1.2.27 Teacher's Guidance and Recommended Learning Resources

Recommended teaching and learning resources

1. Electrical junction boxes.
2. Distribution boards.
3. Electrical control panels.
4. Transformer models.
5. Drawing boards.
6. T-squares.
7. Set squares.
8. Drawing papers.
9. Scale rulers.
10. Computers with CAD software.
11. Engineering drawing textbooks.
12. Projector or digital display.

Recommended teaching approaches

- Demonstration.
- Guided discovery.
- Group discussions.
- Practical drawing exercises.
- Project-based learning.
- Peer assessment.
- Individual assignments.
- Digital research and presentations.

Suggested assessment methods

- Oral questioning.
- Written exercises.
- Observation during practical activities.
- Portfolio assessment.
- Practical drawing assessment.
- Peer evaluation.
- End-of-sub-strand assessment.

STRAND 1.0: FUNDAMENTALS OF ELECTRICITY

SUB-STRAND 1.3: ELECTRICAL DIAGRAMS

INTRODUCTION TO THE SUB-STRAND

Electrical diagrams are essential tools used by electricians, electrical engineers, technicians, contractors and other professionals in the electrical industry.

They provide a visual representation of electrical systems, components and connections. Instead of explaining an electrical installation using lengthy written descriptions, standard symbols and lines are used to communicate information clearly.

In Kenya, electrical diagrams are used when designing, installing, testing, maintaining and repairing electrical systems in:

- Residential buildings.
- Commercial buildings.
- Schools and learning institutions.
- Hospitals and health centres.
- Industrial installations.
- Offices and public buildings.
- Agricultural processing facilities.
- Electrical power distribution systems.

For example, when an electrician is installing lighting points and socket outlets in a newly constructed classroom block, an electrical drawing helps identify the location of switches, lamps, sockets, distribution boards and connecting cables.

Electrical drawings also help ensure that electrical installations are properly planned and that work is carried out according to the relevant electrical safety requirements.

1.3.1 MEANING AND CONCEPT OF ELECTRICAL DIAGRAMS

Definition of an electrical diagram

An **electrical diagram** is a graphical representation of an electrical circuit, installation or system using standard symbols, lines, labels and other technical drawing conventions to show electrical components and their interconnections.

Electrical diagrams communicate how electrical equipment is arranged and connected to enable the generation, transmission, distribution and utilisation of electrical energy.

Explanation of electrical diagrams

An electrical diagram may represent:

- The components used in an electrical circuit.
- The connections between electrical components.
- The direction of electrical connections.
- The arrangement of switches and protective devices.
- The position of electrical accessories in a building.
- The relationship between different parts of an electrical system.
- The control and operation of electrical equipment.

For instance, a simple lighting circuit diagram may show a power supply, protective device, switch, lamp and connecting conductors.



Examples of electrical diagrams used in Kenya

1. **Domestic electrical diagrams:** Used when installing lighting points, socket outlets and other accessories in residential buildings.

2. **Commercial electrical diagrams:** Used in offices, shopping centres, hotels and other commercial buildings.

3. **Industrial electrical diagrams:** Used in factories, workshops and processing plants to show motor circuits and control systems.

4. **Power distribution diagrams:** Used to represent the distribution of electrical energy from transformers to consumers.

5. **Control circuit diagrams:** Used to represent circuits controlling motors, pumps, machines and other equipment.

6. **Architectural electrical drawings:** Used to show the location of electrical accessories on building floor plans.

7. **Electronic circuit diagrams:** Used to represent electronic components such as resistors, capacitors, transistors and integrated circuits.

1.3.2 IMPORTANCE OF ELECTRICAL DIAGRAMS IN ELECTRICAL TECHNOLOGY

Electrical diagrams are important because they provide a standard method of communicating technical information.

The following are the major reasons why electrical diagrams are used.

1. Communication

- Electrical diagrams provide a common language among electricians, engineers, technicians and contractors.
- They enable professionals to understand electrical installations without lengthy explanations.
- Standard symbols reduce confusion during electrical work.

2. Planning and designing electrical installations

- Electrical diagrams help technicians plan electrical installations before actual construction begins.
- They show the intended positions of switches, lamps, sockets and distribution boards.

- They help determine the arrangement of electrical equipment.

3. Installation of electrical systems

- They guide electricians when connecting electrical components.
- They show how different electrical accessories should be interconnected.
- They help ensure that the installation follows the intended design.

4. Troubleshooting electrical faults

- Electrical diagrams help technicians trace electrical connections.
- They make it easier to identify faulty components.
- They assist in locating open circuits, short circuits and incorrect connections.

5. Maintenance and repair

- They provide information required when maintaining electrical equipment.
- They help technicians understand the construction and operation of electrical systems.
- They make replacement of components easier.

6. Safety

- They help identify protective devices such as fuses, circuit breakers and residual current devices.
- They assist in planning safe electrical installations.
- They help technicians understand circuit arrangements before carrying out work.

7. Cost estimation

- They assist in determining the quantities of materials required.
- They help estimate the number of cables, switches, lamps and other accessories.
- They minimise unnecessary expenditure.

8. Documentation

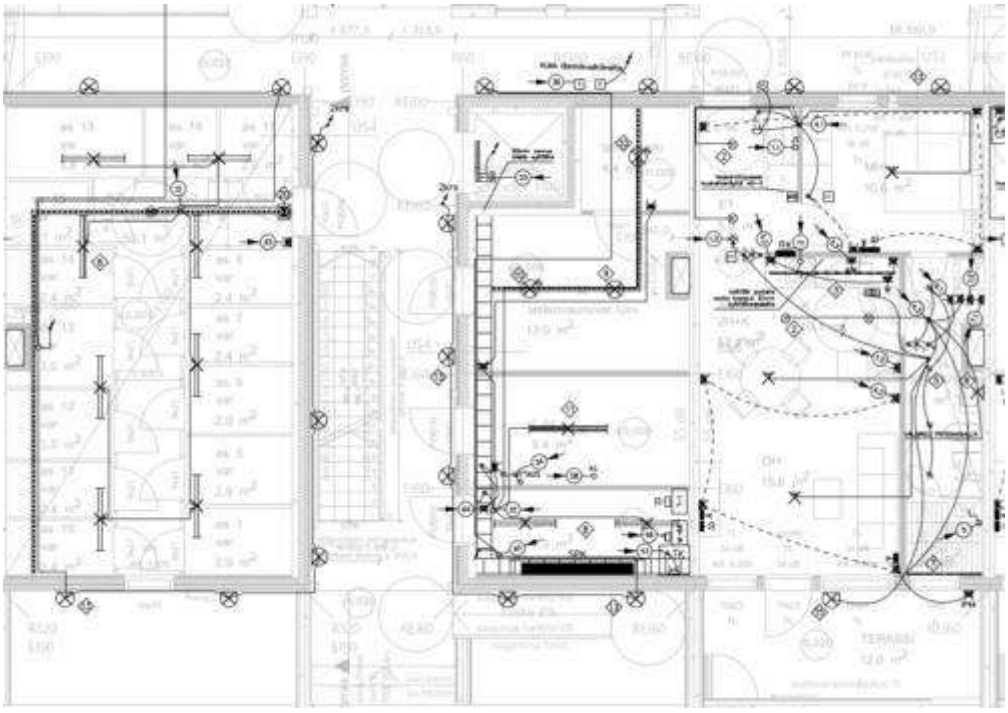
- Electrical diagrams provide permanent records of installations.
- They are useful when future alterations are required.
- They assist in maintaining building electrical records.

9. Training and education

- They help learners understand electrical principles.
- They provide a visual way of learning how circuits operate.
- They support practical training in electrical workshops.

10. Standardisation

- They promote uniformity in the representation of electrical components.
- They enable drawings to be interpreted by different professionals.
- They encourage the use of recognised electrical symbols and conventions.



1.3.3 ELECTRICAL SYMBOLS

Definition of electrical symbols

Electrical symbols are standard graphical signs used to represent electrical and electronic components in circuit diagrams, wiring diagrams and other electrical drawings.

They replace lengthy descriptions and make electrical drawings simple, clear and easy to interpret.

Importance of electrical symbols

1. They simplify electrical drawings.
2. They save drawing time and space.
3. They promote standardisation.
4. They improve communication among electrical professionals.
5. They reduce errors when interpreting circuits.
6. They help identify electrical components.
7. They assist in circuit construction and troubleshooting.
8. They make electrical drawings easier to reproduce.
9. They enable learners to understand electrical circuits.
10. They support the design and maintenance of electrical systems.

Characteristics of standard electrical symbols

- They should be clear and easy to recognise.
- They should be drawn according to recognised conventions.
- They should be consistent throughout a drawing.
- They should represent specific components or functions.
- They should be appropriately labelled where necessary.
- They should be connected using suitable lines to show electrical relationships.

1.3.4 COMMON ELECTRICAL SYMBOLS AND THEIR FUNCTIONS

Electrical components are represented using different symbols depending on their functions.

The symbols below are schematic representations for learning purposes. Actual symbol details may vary according to the applicable IEC or other recognised drawing standard.

A. Conductors and connection symbols



Component	Symbol description	Function
Connecting wire	Straight line	Provides a path for electric current.
Connected wires	Intersecting lines with a junction dot	Shows conductors electrically joined.
Crossing wires	Crossing lines without a junction	Shows wires crossing without electrical connection, where the drawing convention indicates this.
Earth connection	Earth symbol	Provides a connection to earth for safety or reference.
Protective earth	Protective earth symbol	Connects exposed conductive parts to the protective earthing system.
Terminal	Small terminal mark	Indicates a connection point.

Explanation of conductors

A conductor is a material that allows electric current to flow through it easily.

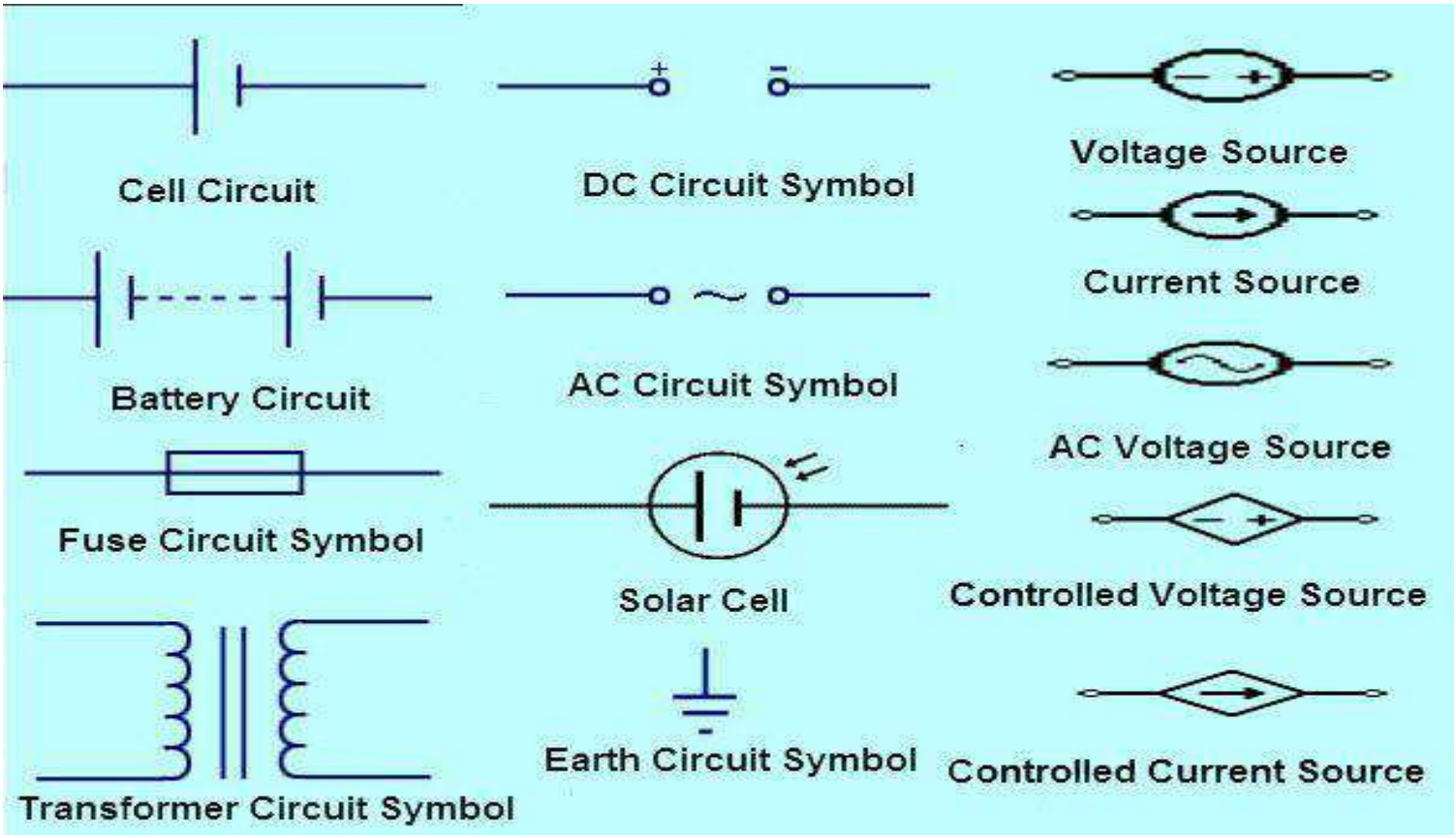
Examples:

- Copper wire.
- Aluminium conductor.

- Copper cables.

In electrical drawings, straight lines are commonly used to represent conductors connecting components.

B. Sources of electrical energy



Component	Symbol description	Function
Single cell	Two parallel unequal lines	Supplies direct current electrical energy.
Battery	Several pairs of parallel unequal lines	Supplies electrical energy through multiple cells.
DC voltage source	Circle with polarity markings or standard DC source marking	Supplies direct voltage.
AC voltage source	Circle with sine-wave marking	Supplies alternating voltage.
Generator	Generator symbol	Converts mechanical energy into electrical energy.
Solar cell	Solar cell symbol with incoming arrows	Converts solar energy into electrical energy.

Explanation

1. **Cell:** A device that converts chemical energy into electrical energy.

2. **Battery:** A combination of one or more electrochemical cells used to provide electrical energy.

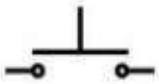
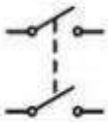
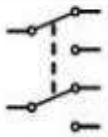
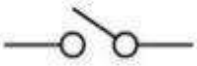
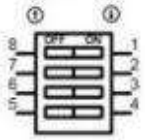
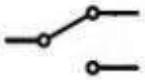
3. **AC source:** Provides alternating current, in which the direction of current changes periodically.

4. **DC source:** Provides direct current, which flows in one direction.

5. **Generator:** Converts mechanical energy into electrical energy through electromagnetic induction.

6. **Solar cell:** Converts sunlight directly into electrical energy.

C. Switching and control devices

Push Button (Normally Open)		DPST Switch	
Push Button (Normally Closed)		DPDT Switch	
SPST Switch		DIP Switch	
SPDT Switch		Solder Bridge	
Jumper			

Component	Symbol description	Function
Single-pole single-throw switch (SPST)	One movable contact and one fixed contact	Opens or closes a circuit.
Single-pole double-throw switch (SPDT)	One common terminal and two alternative contacts	Directs current along one of two paths.
Double-pole single-throw switch (DPST)	Two mechanically linked switching contacts	Controls two conductors simultaneously.
Double-pole double-throw switch (DPDT)	Two linked changeover contacts	Changes two circuit connections simultaneously.
Normally open push button (NO)	Push-button contact normally open	Closes a circuit when pressed.
Normally closed push button (NC)	Push-button contact normally closed	Opens a circuit when pressed.

Changeover switch	Common terminal with two alternative contacts	Changes the electrical connection from one path to another.
Two-way lighting switch	Changeover switching arrangement	Controls one lighting point from two locations.

1. Single-pole single-throw switch (SPST)

- Controls one electrical circuit.
- Has one pole and one switching position.
- It can open or close a circuit.
- It is commonly used in simple lighting circuits.

Example: A single lighting switch used to control a lamp in a classroom.

2. Single-pole double-throw switch (SPDT)

- Has one common terminal.
- Has two alternative output terminals.
- It directs current to either of two paths.
- It is used in changeover and two-way switching applications.

3. Double-pole single-throw switch (DPST)

- Controls two separate conductors simultaneously.
- Both contacts operate together.
- It is useful where two conductors must be switched at the same time.

4. Push-button switch

- Operates when pressure is applied.
- May be normally open or normally closed.
- Commonly used in industrial control panels.

Example: A green start push button used to initiate the operation of a motor control circuit.

5. Two-way switch

- Allows a lighting point to be controlled from two different locations.
- Commonly used in staircases, corridors and large rooms.
- It uses two changeover switches connected through traveller conductors.

D. Protection devices

Component	Symbol description	Function
Fuse	Small rectangular or standard fuse element symbol	Protects circuits against excessive current by melting.
Circuit breaker	Standard breaker contact symbol	Automatically interrupts a circuit under specified fault conditions.
Thermal overload relay	Overload relay symbol	Protects motors against sustained overload current.
Earth leakage protection device	Standard residual-current protective device symbol	Detects residual current and disconnects the circuit when appropriate.
Surge protective device (SPD)	Standard surge protection symbol	Limits transient overvoltages.

1. Fuse

A fuse is a protective device containing a metal element that melts when current exceeds its specified rating for sufficient time.

Functions:

- Protects electrical equipment.
- Interrupts excessive current.
- Helps prevent damage caused by overcurrent.
- Reduces the risk of fire arising from electrical faults.

2. Circuit breaker

A circuit breaker is an automatically operated switching device designed to protect electrical circuits against specified fault currents.

Functions:

- Interrupts fault current.
- Protects cables and electrical equipment.
- Can be reset after a fault has been identified and corrected.
- Provides switching and isolation functions depending on its design and rating.

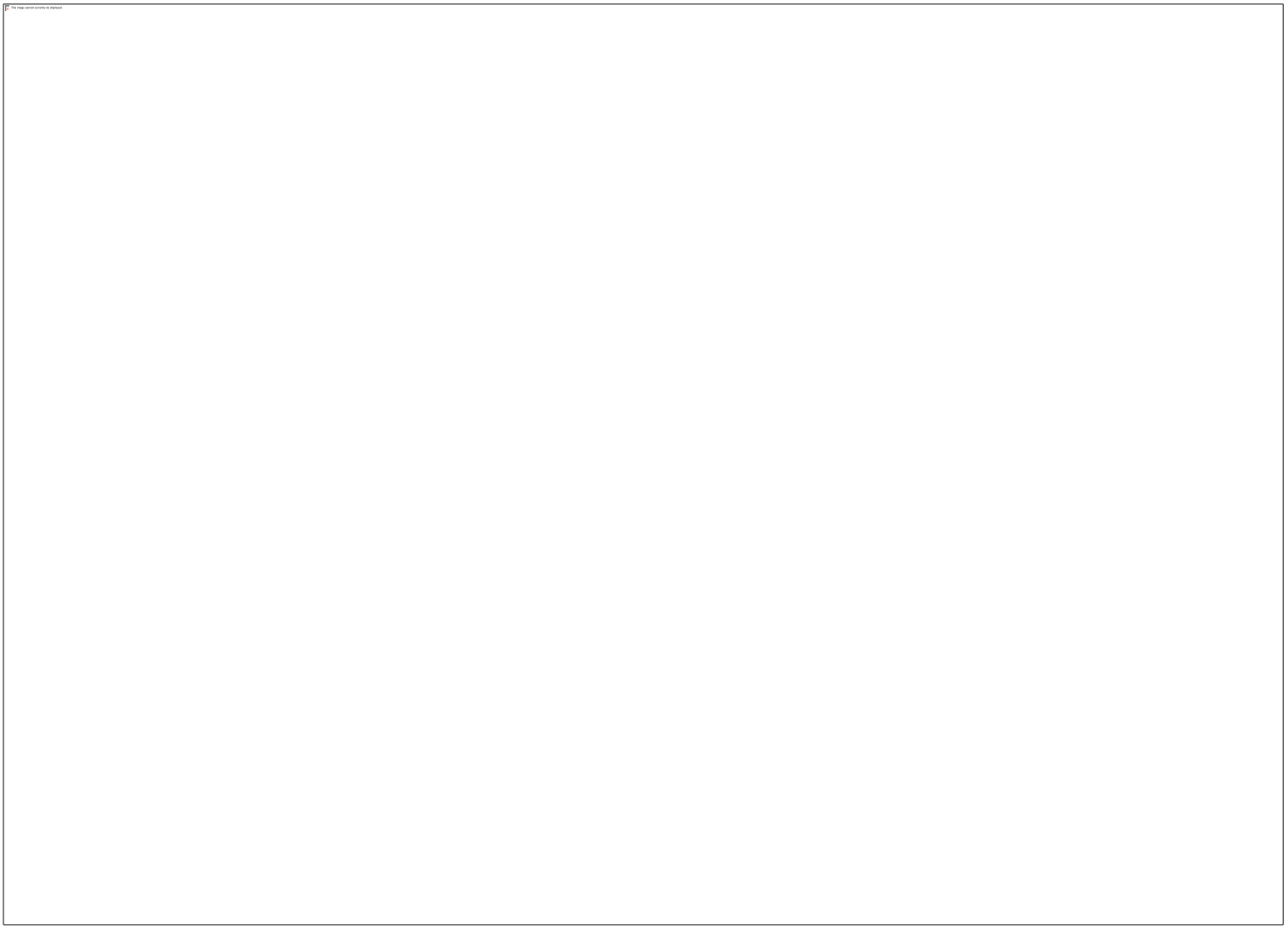
3. Thermal overload relay

- Protects electric motors against sustained overload conditions.
- Detects excessive motor current.
- Causes the control circuit to disconnect the motor.
- Is commonly used in motor control installations.

4. Residual current device (RCD)

- Detects an imbalance between currents in the conductors being monitored.
- Disconnects the circuit when residual current reaches its operating threshold.
- Provides additional protection against electric shock and certain electrical fire risks.
- Does not replace overcurrent protection unless it is a combined device such as an RCBO.

E. Load symbols



Component	Symbol description	Function
Lamp	Circle with a cross	Converts electrical energy into light.
Resistor	IEC rectangular resistor symbol	Limits current or produces a voltage drop.
Variable resistor	Resistor with diagonal arrow	Provides adjustable resistance.
Heater	Heating element symbol	Converts electrical energy into heat.
Electric motor	Circle marked M	Converts electrical energy into mechanical energy.
Bell	Bell symbol	Produces an audible ringing sound.
Buzzer	Buzzer symbol	Produces an audible warning signal.
Speaker	Speaker symbol	Converts electrical signals into sound.

Detailed explanations

1. Lamp

A lamp is an electrical device that converts electrical energy into light energy.

Applications:

- Domestic lighting.
- Classroom lighting.
- Street lighting.
- Security lighting.

2. Resistor

A resistor is a passive electrical component that opposes the flow of electric current.

Functions:

- Limits current.
- Produces a voltage drop.
- Protects sensitive electronic components.
- Controls electrical signals.

3. Variable resistor

A variable resistor is a resistor whose resistance can be adjusted.

Applications:

- Controlling current.
- Adjusting signal levels.
- Controlling brightness in suitable electronic circuits.

4. Electric motor

An electric motor converts electrical energy into mechanical energy.

Applications in Kenya:

- Water pumping.
- Workshop machinery.
- Industrial processing.
- Fans and ventilation systems.
- Agricultural equipment.

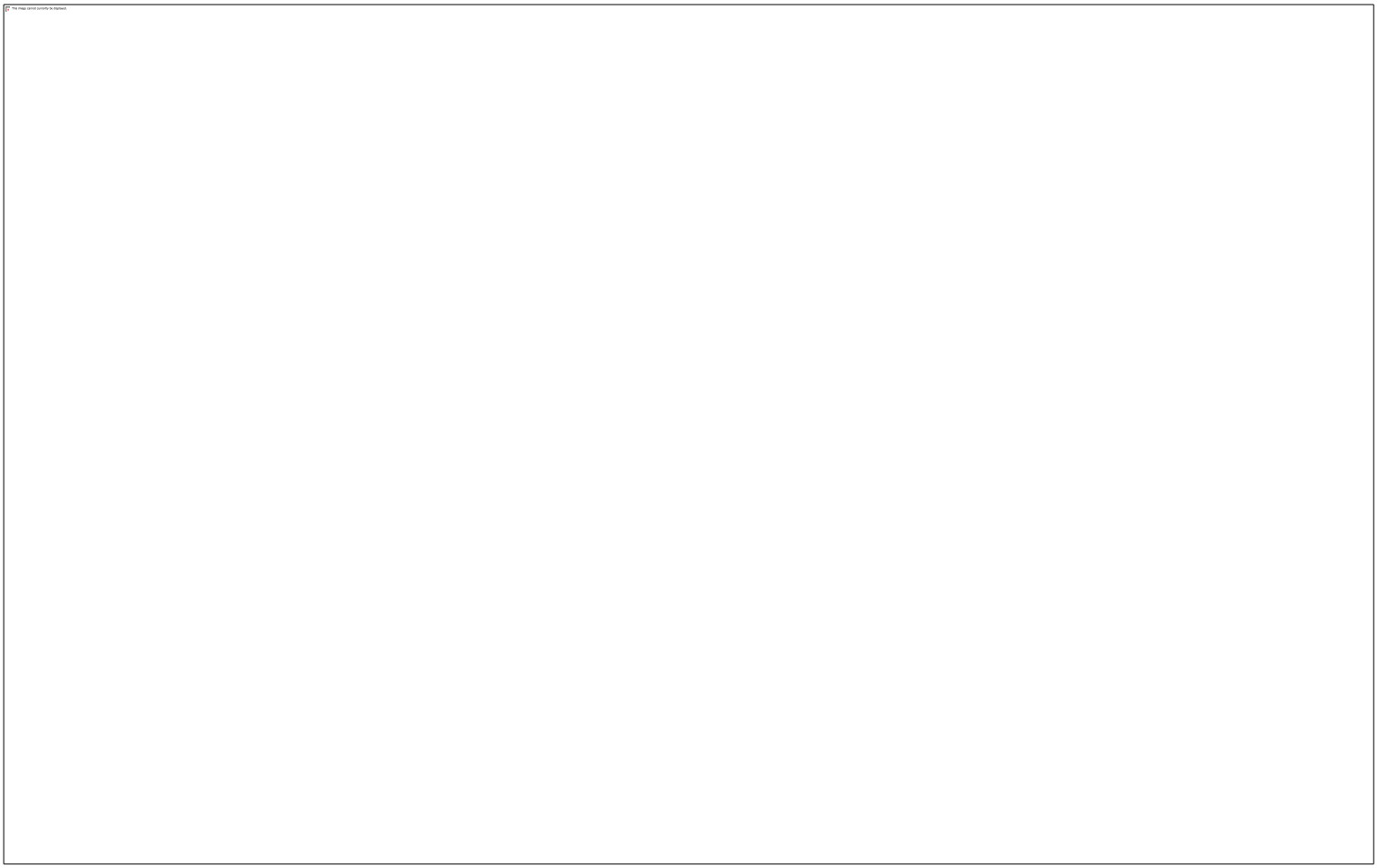
5. Bell and buzzer

These are electrical signalling devices used to produce sound.

Applications:

- School bells.
- Doorbells.
- Alarm systems.
- Industrial warning systems.

F. Measuring instruments



Instrument	Symbol description	Function
Ammeter	Circle marked A	Measures electric current.
Voltmeter	Circle marked V	Measures potential difference.
Ohmmeter	Circle marked Ω	Measures electrical resistance.
Wattmeter	Circle marked W	Measures electrical power.
Energy meter	Energy meter symbol	Measures electrical energy consumed.
Frequency meter	Circle marked Hz	Measures frequency.
Multimeter	Meter symbol with multiple measurement functions	Measures different electrical quantities.

1. Ammeter: Measures current in amperes (A). It is connected in series when measuring current in a conventional circuit.

2. Voltmeter: Measures voltage in volts (V). It is connected in parallel across the component whose voltage is being measured.

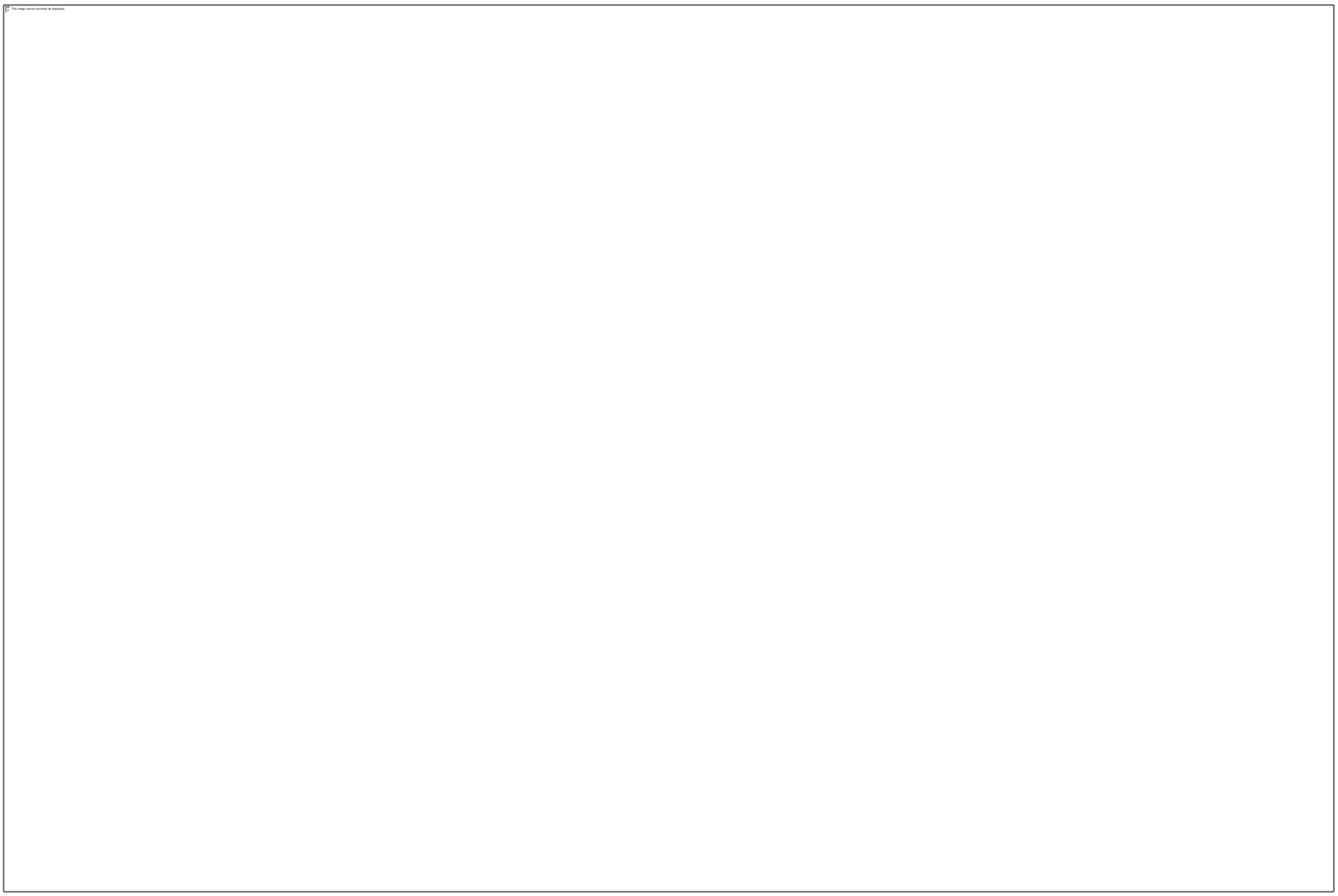
3. Ohmmeter: Measures resistance in ohms (Ω). Resistance should normally be measured with the circuit isolated and de-energised.

4. Wattmeter: Measures electrical power in watts (W).

5. Energy meter: Measures electrical energy consumption, commonly in kilowatt-hours (kWh).

6. Frequency meter: Measures the number of cycles of an alternating waveform per second, expressed in hertz (Hz).

G. Electronic component symbols



Component	Symbol description	Function
Resistor	Rectangular symbol	Opposes current flow.
Capacitor	Two parallel plates	Stores electrical energy in an electric field.
Polarised capacitor	Capacitor with polarity marking	Stores electrical energy and must be connected with correct polarity.
Inductor	Coil symbol	Stores energy in a magnetic field.
Diode	Diode symbol	Allows current to flow mainly in one direction.
Light-emitting diode (LED)	Diode with outward arrows	Emits light when forward biased.

Transistor	Three-terminal transistor symbol	Amplifies or switches electrical signals.
Integrated circuit (IC)	Rectangular block with terminals	Performs electronic functions in a circuit.

Detailed explanations

1. Capacitor

A capacitor is an electronic component that stores electrical energy in an electric field.

Uses:

- Filtering in power supplies.
- Timing circuits.
- Signal coupling.
- Motor starting and running in suitable AC motor designs.

2. Inductor

An inductor is a passive electrical component consisting of a coil of wire that stores energy in a magnetic field when current flows through it.

Uses:

- Filtering.
- Transformers and power electronics.
- Signal processing.
- Energy storage in switching circuits.

3. Diode

A diode is a semiconductor component that allows current to flow mainly in one direction.

Uses:

- Rectification.
- Reverse-polarity protection.
- Signal detection.
- Voltage regulation when designed as a Zener diode.

4. LED

A light-emitting diode is a semiconductor device that emits light when appropriately forward biased.

Uses:

- Indicator lamps.
- Display systems.
- Energy-efficient lighting.
- Electronic signalling.

5. Transistor

A transistor is a semiconductor device used for switching and amplification.

Uses:

- Electronic control circuits.
- Amplifiers.
- Switching power supplies.
- Digital electronic systems.

6. Integrated circuit

An integrated circuit is a miniature electronic circuit containing several interconnected electronic components fabricated on a semiconductor chip.

Uses:

- Computers.
- Communication equipment.
- Electronic control systems.
- Digital devices.

1.3.5 TYPES OF ELECTRICAL DRAWINGS

Electrical drawings are classified according to the type of information they communicate and the purpose for which they are prepared.

The main types include:

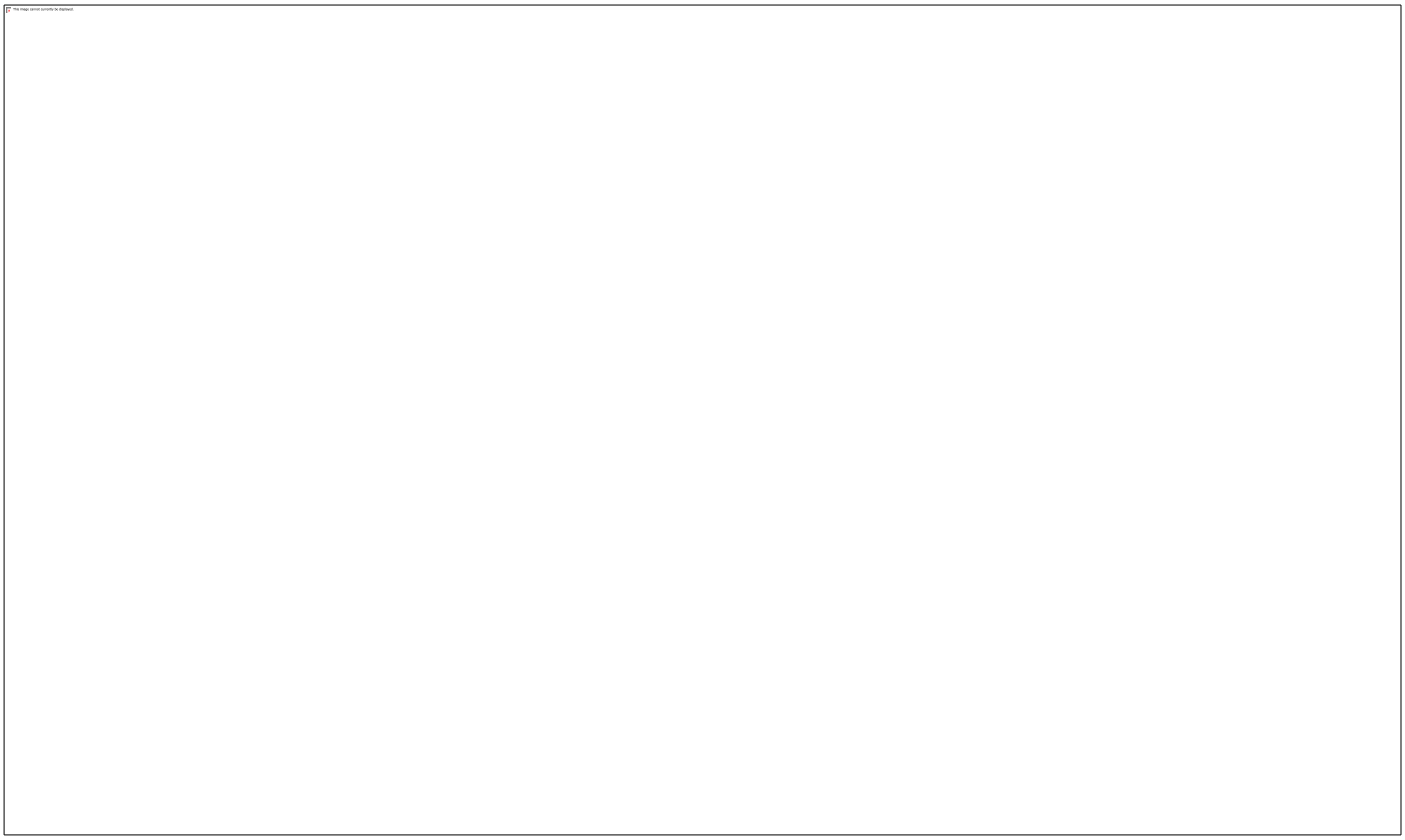
1. Schematic diagrams.
2. Wiring diagrams.
3. Line diagrams.
4. Single-line diagrams.
5. Block diagrams.
6. Ladder diagrams.
7. Architectural electrical drawings.
8. Installation layout drawings.
9. Pictorial diagrams.

A. Schematic diagrams

Definition

A schematic diagram is a simplified graphical representation of an electrical or electronic circuit using standard symbols to show the electrical relationships and functional connections between components.

It focuses on how a circuit operates rather than the actual physical positions of the components.



Characteristics of schematic diagrams

1. They use standard electrical symbols.
2. They show electrical connections between components.
3. They do not necessarily represent the actual physical arrangement of components.
4. They show the functional relationship between circuit components.
5. They are usually simple and easy to interpret.
6. They can be used to analyse circuit operation.
7. They are useful in troubleshooting and repairing electrical equipment.

Applications of schematic diagrams

- Designing electronic circuits.
- Representing domestic lighting circuits.
- Designing motor control circuits.
- Showing battery charging circuits.
- Representing power supply circuits.
- Explaining the operation of electrical equipment.

Advantages

1. Easy to understand.
2. Reduces unnecessary drawing details.
3. Makes troubleshooting easier.
4. Saves drawing space.

5. Shows the functional relationship between components.

Limitations

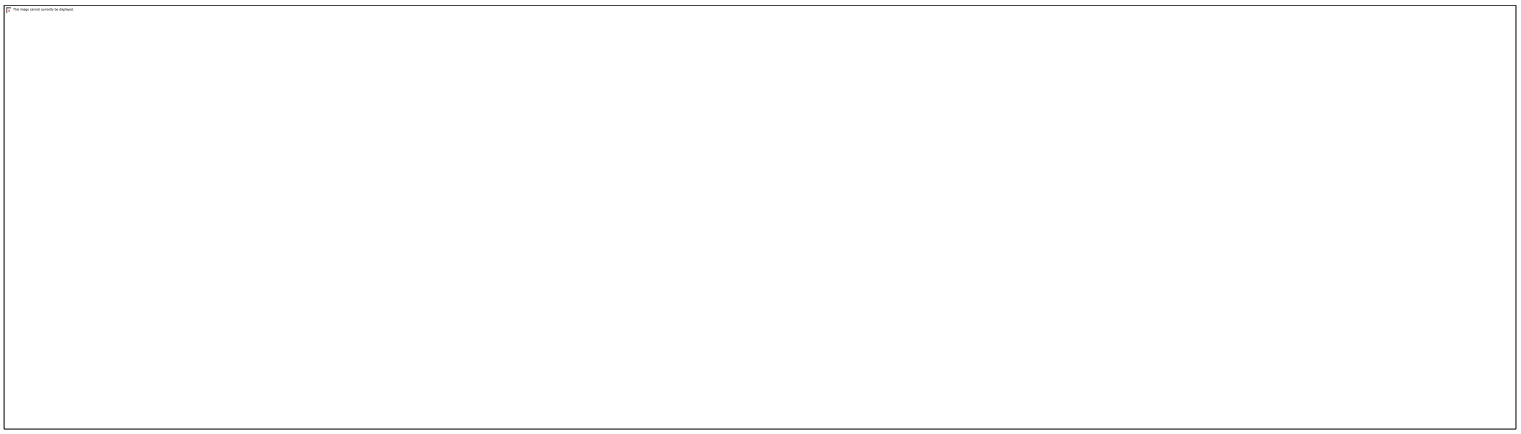
1. Does not necessarily show the actual position of components.
2. May not show the physical cable routing.
3. Requires knowledge of electrical symbols.
4. May not provide sufficient information for physical installation on its own.

B. Wiring diagrams

Definition

A wiring diagram is a technical drawing that shows the actual electrical connections between components, including terminals, conductors and connection points.

Unlike schematic diagrams, wiring diagrams provide more information about how components are physically connected.



Characteristics of wiring diagrams

1. Show the actual connections between electrical components.
2. Identify terminals and connection points.
3. May indicate conductor colours.
4. May show cable sizes and conductor identification.
5. Help technicians connect components correctly.
6. May show the physical arrangement of wiring.
7. Provide useful information during installation and maintenance.

Applications

- Domestic electrical installations.
- Electrical control panels.
- Motor connections.
- Distribution board wiring.
- Lighting and socket circuits.
- Industrial equipment installations.

Advantages

1. Guide electricians when connecting electrical accessories.
2. Reduce wiring mistakes.
3. Assist in identifying terminals.
4. Support fault diagnosis.
5. Provide detailed connection information.

Limitations

1. Can become complicated where many components are involved.
2. May occupy more drawing space.
3. Require careful interpretation of terminal markings.
4. May need to be supplemented with installation layout drawings.

C. Line diagrams

Definition

A line diagram is a simplified electrical drawing that uses lines and standard symbols to represent the arrangement and interconnection of electrical components or circuits.

It is commonly used to communicate the general arrangement of an electrical installation.

Characteristics

- Uses lines to represent electrical connections.
- Uses standard symbols for components.
- Provides a simplified view of an electrical system.
- Helps explain the arrangement of circuits.
- Can represent the main connections in an installation.

Applications

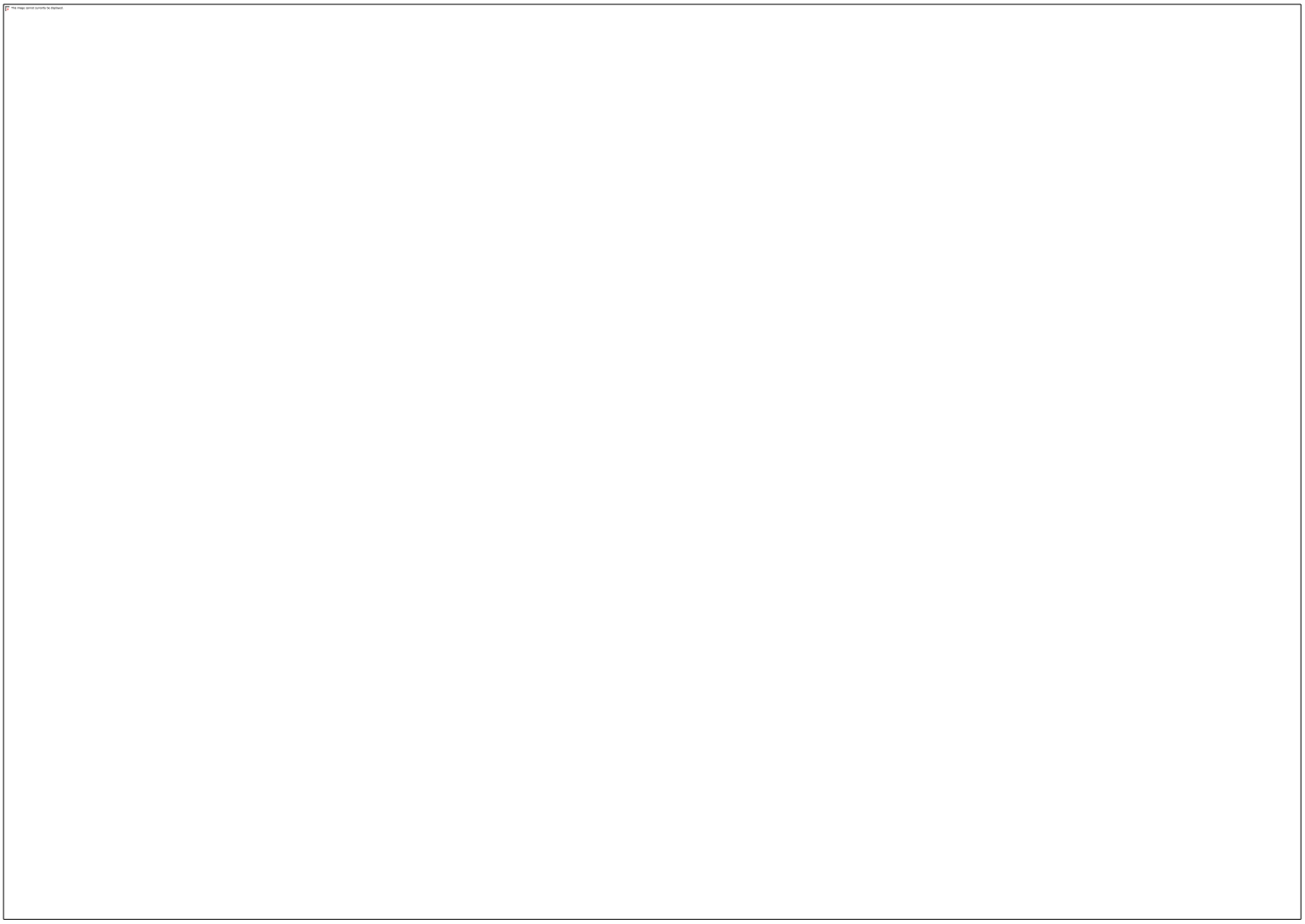
- Domestic installations.
- Lighting circuits.
- Power distribution.
- Electrical installation planning.
- Control systems.

D. Single-line diagrams

Definition

A single-line diagram is a simplified electrical drawing in which one line represents a circuit or a group of conductors, depending on the drawing convention.

It is commonly used in power distribution systems to represent the major components and their electrical connections.



Components represented in a single-line diagram

1. Generators.
2. Transformers.
3. Busbars.
4. Circuit breakers.
5. Isolators.
6. Protective devices.
7. Distribution feeders.
8. Electrical loads.

Applications in Kenya

- Kenya Power distribution networks.
- Industrial power distribution systems.
- Commercial building electrical installations.
- School and hospital distribution systems.
- Solar photovoltaic installations.
- Generator and transformer installations.

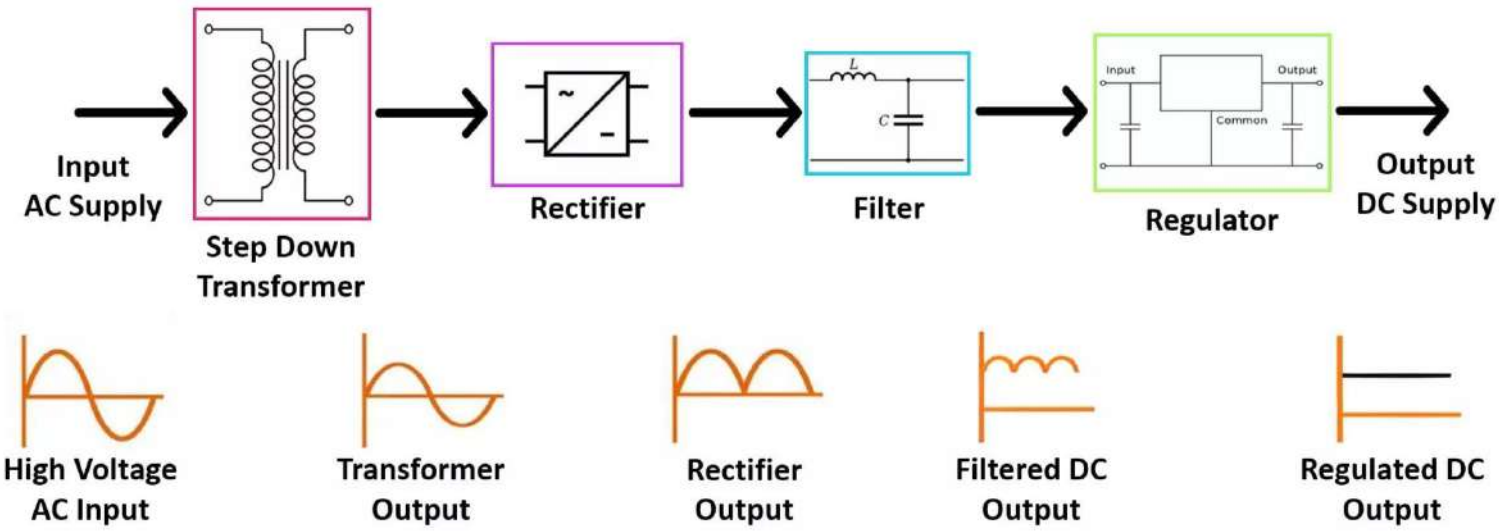
Importance

1. Simplifies complex power systems.
2. Shows the major electrical connections.
3. Assists in system planning.
4. Helps identify protective devices.
5. Supports electrical fault analysis.
6. Provides a useful overview of power distribution.

E. Block diagrams

Definition

A block diagram is a simplified graphical representation of a system in which rectangular blocks represent major functional units and connecting lines or arrows show the flow of signals, energy or information.



Example: DC power supply block diagram

The main stages of a simple DC power supply are:

AC supply

Transformer

Rectifier

Filter

Voltage regulator

DC load

Explanation of the stages

1. **AC supply:** Provides alternating electrical energy.
2. **Transformer:** Changes the AC voltage to the required level.
3. **Rectifier:** Converts AC into pulsating DC.

4. **Filter:** Reduces unwanted fluctuations in the rectified output.
5. **Voltage regulator:** Maintains a more stable DC output voltage.
6. **Load:** Uses the electrical energy supplied by the circuit.

Applications of block diagrams

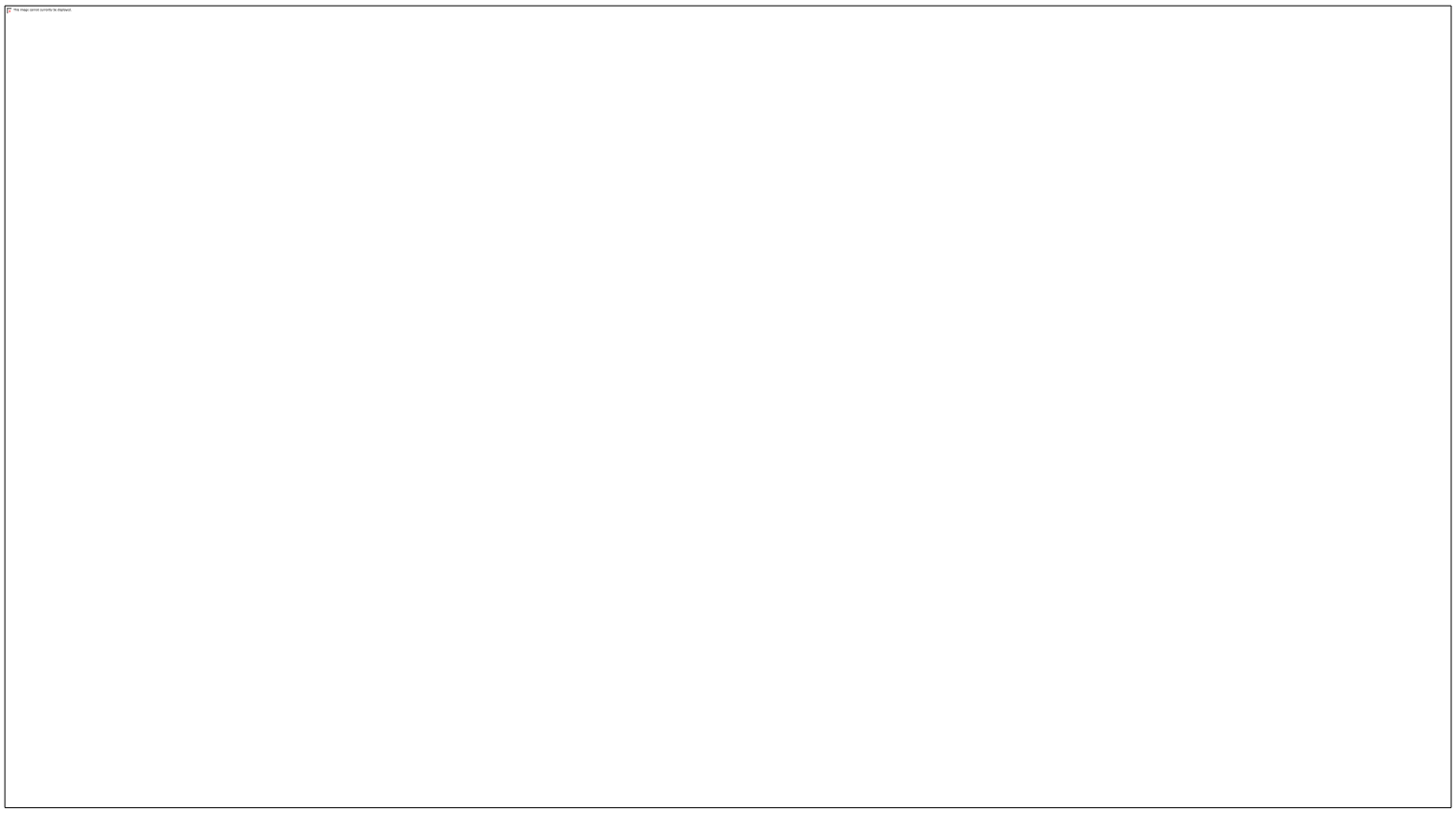
- Power supply systems.
- Solar energy systems.
- Communication systems.
- Electronic control systems.
- Automatic control installations.
- Industrial production systems.

F. Ladder diagrams

Definition

A ladder diagram is a graphical representation of an electrical control circuit using two vertical power rails connected by horizontal lines called rungs.

It is commonly used in industrial control systems and programmable logic controller (PLC) programming.



Main features

1. Two vertical power rails.
2. Horizontal rungs.
3. Input contacts.
4. Output coils.
5. Control devices.

6. Protective contacts.
7. Logic connections.

Applications

- Motor starting circuits.
- Industrial automation.
- Pump control.
- Conveyor systems.
- Machine control panels.
- PLC control systems.

Advantages

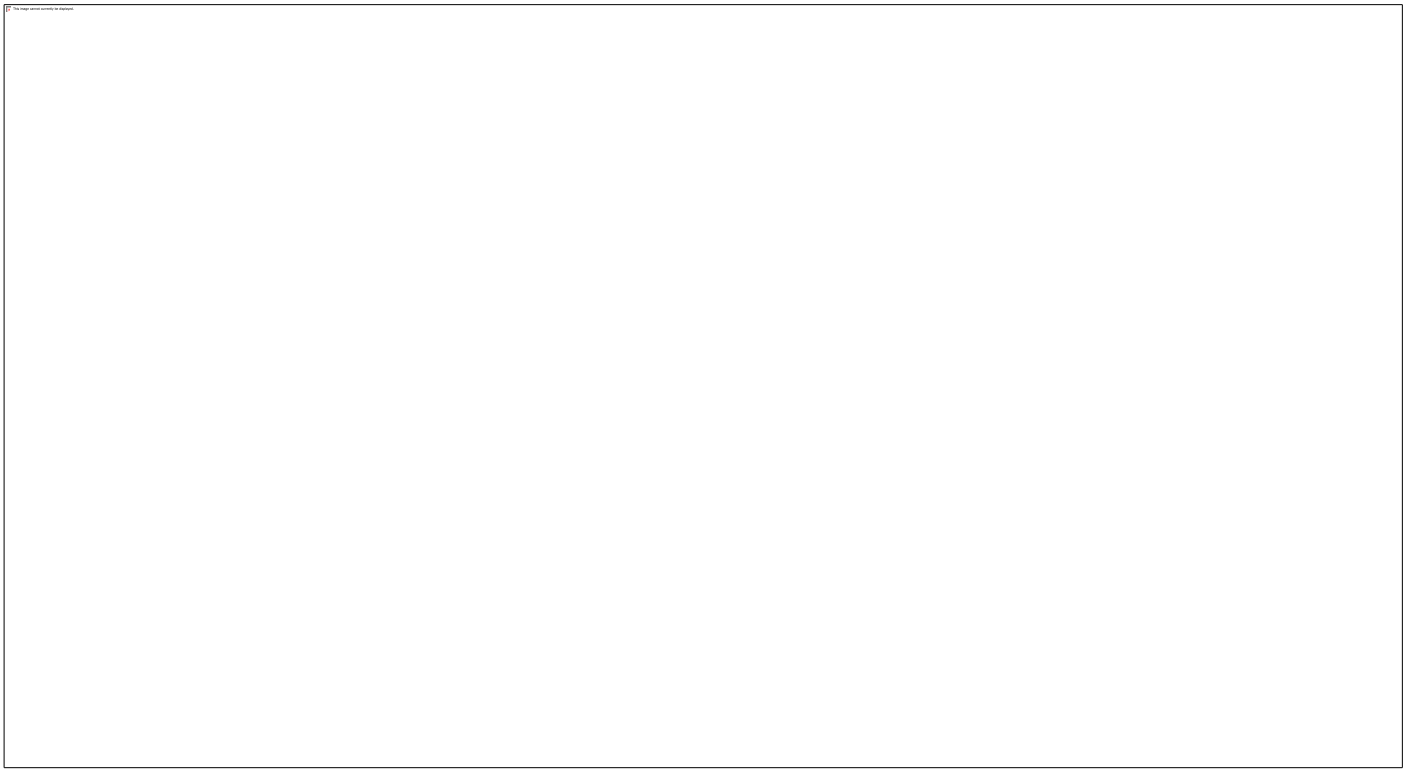
- Easy to understand control logic.
- Supports systematic fault tracing.
- Simplifies industrial control design.
- Can be used for PLC programming.
- Clearly represents the logical operation of a control system.

G. Architectural electrical drawings

Definition

An architectural electrical drawing is a technical drawing prepared on or in relation to a building plan to show the location, type and arrangement of electrical installations and accessories within a building.

These drawings are commonly prepared as part of the electrical services drawings for building construction.



Information shown on architectural electrical drawings

1. Lighting points.
2. Switch positions.
3. Socket outlets.
4. Distribution boards.
5. Ceiling fans.
6. Air-conditioning outlets.
7. Data and communication outlets.
8. Smoke detectors and alarm devices.
9. Emergency lighting.
10. Cable routes and circuit identification.
11. Earthing and bonding arrangements where required.
12. Equipment locations.

Importance in building construction

- Guides the installation of electrical accessories.
- Helps coordinate electrical services with architectural and structural work.
- Helps identify the number and position of electrical points.
- Assists in estimating materials.
- Helps avoid clashes with plumbing and other building services.
- Supports inspection and future maintenance.

H. Pictorial diagrams

Definition

A pictorial diagram is an electrical drawing that represents components in a form resembling their actual physical appearance.

It is useful for learners who are beginning to study electrical connections.



Characteristics

1. Components are drawn to resemble their actual appearance.
2. It shows the general physical arrangement of components.
3. It is often easier for beginners to recognise components.
4. It may show how wires connect to actual terminals.
5. It is useful for demonstrations and training.

Limitations

- Can be difficult to use for complex circuits.
- May occupy considerable drawing space.
- May not show the electrical relationship as clearly as a schematic diagram.
- Components may not be drawn to scale.

1.3.6 COMPARISON OF TYPES OF ELECTRICAL DRAWINGS

Type	Main purpose	Important feature
Schematic diagram	Shows circuit operation	Uses standard symbols
Wiring diagram	Shows actual connections	Shows terminals and conductors
Line diagram	Shows simplified electrical arrangement	Uses lines and symbols
Single-line diagram	Shows power system arrangement	Simplifies conductors into single lines
Block diagram	Shows functional stages	Uses blocks and connecting arrows
Ladder diagram	Shows control logic	Uses rails and rungs
Architectural drawing	Shows installation positions in buildings	Uses building floor plans
Pictorial diagram	Shows physical appearance	Resembles actual components

Important distinction

A schematic diagram explains how a circuit functions, while a wiring diagram explains how the electrical components are physically connected.

An architectural electrical drawing shows where electrical accessories are positioned in a building.

These drawings can be used together during electrical installation work.

1.3.7 STANDARD CONVENTIONS USED IN ELECTRICAL DRAWINGS

Electrical drawings use standard conventions to ensure that information is presented clearly and consistently.

A. Electrical connecting lines

Lines are used to represent conductors and connections between electrical components.

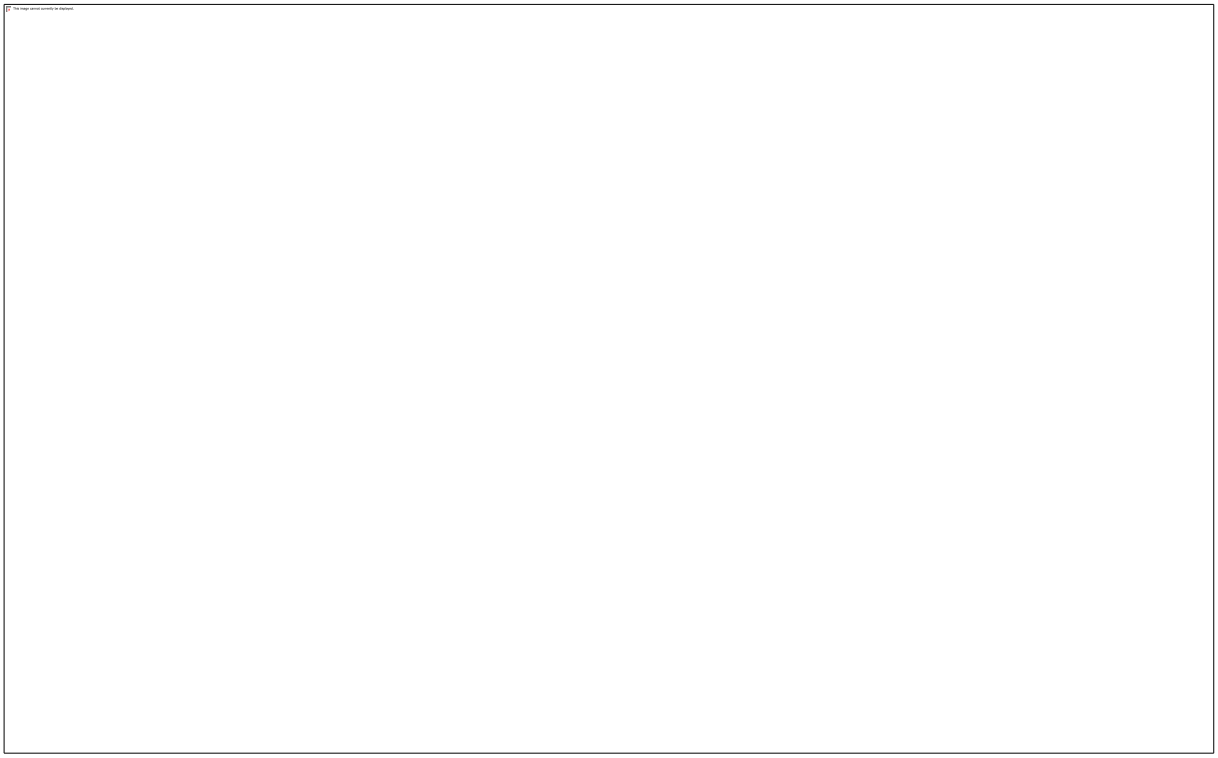
Types include:

1. Solid connecting lines.
2. Junction lines.
3. Crossing lines.
4. Control connection lines.
5. Protective conductor lines.

B. Junctions and crossings

A junction is a point at which two or more conductors are electrically connected.

A crossing represents conductors that pass across one another without necessarily being connected.



Important:

- A junction dot normally indicates an electrical connection.
- Crossing wires without a junction dot are commonly used to indicate no electrical connection where the applicable drawing convention permits.
- Always interpret the drawing according to its stated symbol and line conventions.

C. Conductor identification

Conductors may be identified using letters, numbers or colour references.

Common identification in modern Kenyan electrical installations follows recognised IEC-based practices.

Conductor	Common identification	Function

Line/live (single-phase)	Brown	Carries supply voltage to the load
Neutral	Blue	Provides the neutral return path
Protective earth	Green/yellow	Provides a protective fault-current path

For three-phase installations, common IEC conductor colours are:

Conductor	**Colour**
L1	Brown
L2	Black
L3	Grey
Neutral	Blue
Protective earth	Green/yellow

Note: Conductor identification must follow the applicable installation standard and project specifications. Colour alone must never be relied upon to establish that a conductor is safe.

D. Letter and number identification

Electrical components may be labelled using letters or reference designations.

Examples include:

Designation	**Common meaning**
M	Motor
K	Relay or contactor
F	Protective device, depending on the convention
S	Switch
Q	Switching or circuit protection device, depending on the standard
X	Terminal or connector
H	Signalling device or indicator
T	Transformer

Reference designations depend on the applicable drawing standard and project legend.

E. Drawing scales

Electrical drawings may use different scales depending on their purpose.

Examples:

- 1:1 – Full-size representation.
- 1:2 – Half-size representation.
- 1:50 – Building floor plans.
- 1:100 – Large building layouts.
- 1:200 – Large site plans.

A scale must be indicated where it is relevant to interpreting the drawing.

1.3.8 ELECTRICAL DRAWING SHEETS AND THEIR CONTENTS

A properly prepared electrical drawing should contain sufficient information to enable the user to understand its purpose.

Main parts of an electrical drawing sheet

1. Drawing title

Indicates the subject of the drawing.

Example: Electrical Lighting and Socket Layout – Classroom Block.

2. Drawing number

A unique reference number used to identify the drawing.

3. Scale

Shows the relationship between the drawing size and actual dimensions where applicable.

4. Legend

A list explaining the symbols used in the drawing.

5. Revision details

Shows changes made to the drawing.

6. Date

Indicates when the drawing was prepared or revised.

7. Drawn by

Identifies the person who prepared the drawing.

8. Checked and approved by

Identifies the responsible reviewers or approvers where required.

9. Project information

Includes the project name, location and relevant client information.

10. Notes

Provide additional technical information necessary for interpreting the drawing.

1.3.9 DRAWING SIMPLE ELECTRICAL CIRCUIT DIAGRAMS

Meaning of an electrical circuit diagram

An electrical circuit diagram is a drawing that uses standard symbols and connecting lines to represent the components and electrical connections in a circuit.

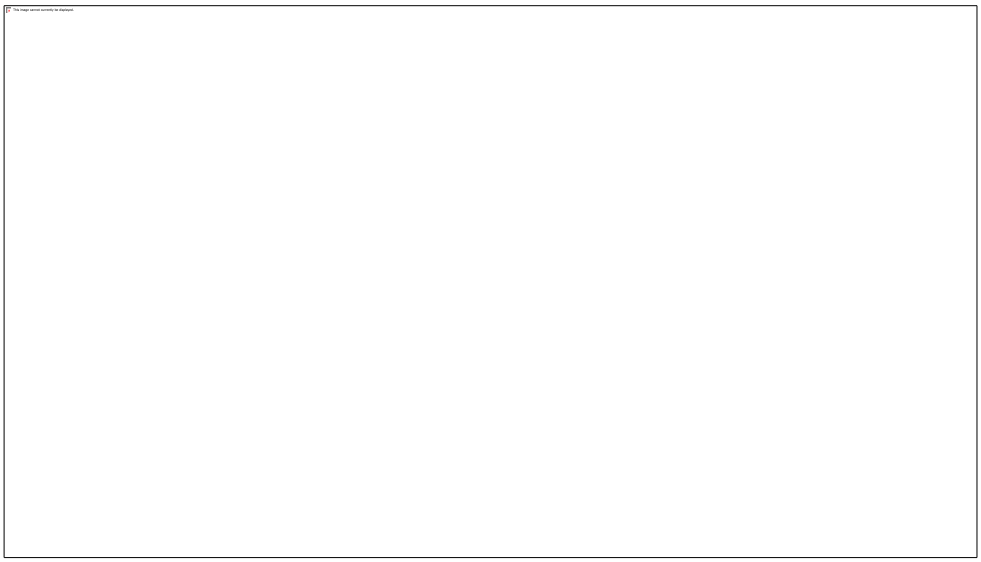
It helps learners understand how electric current flows and how different components work together.

A. Simple lighting circuit

A simple lighting circuit consists of:

- A source of electrical energy.
- A protective device.
- A switch.

- A lamp.
- Connecting conductors.



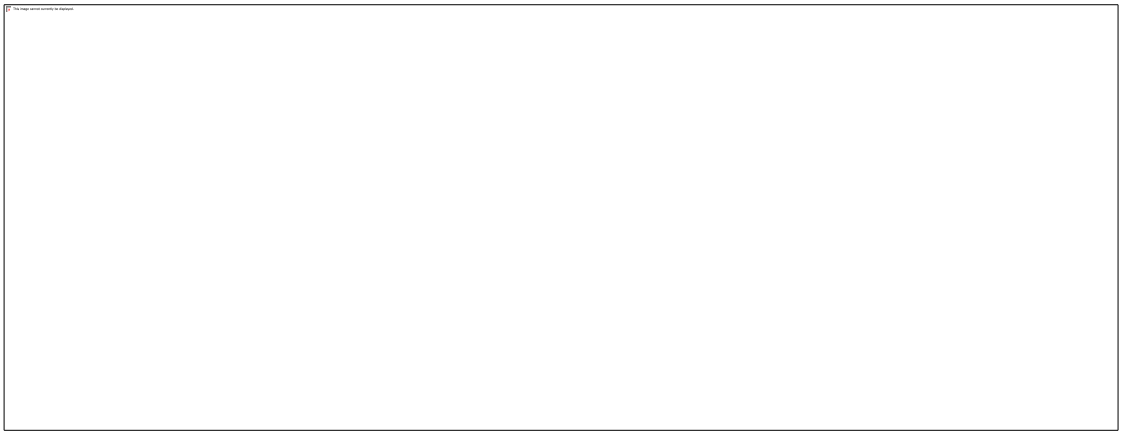
Explanation of the circuit

1. The electrical supply provides energy to the circuit.
2. The protective device protects the circuit against specified overcurrent conditions.
3. The switch controls the operation of the lamp.
4. When the switch is closed, the circuit is completed.
5. Current flows through the lamp and it illuminates.
6. When the switch is opened, the circuit is interrupted and the lamp goes off.

Important installation principle: In a conventional single-phase lighting circuit, the switch is connected in the line conductor so that the lamp holder or lighting point is not left connected to the line when switched off. The circuit must be properly protected and earthed as required.

B. Circuit containing two lamps in parallel

In a parallel circuit, components are connected across the same two supply points.



Characteristics of a parallel lighting circuit

1. Each lamp receives the same supply voltage.
2. Each lamp has its own current path.
3. If one lamp fails open-circuit, the other can continue operating.

4. The total current is the sum of the currents in the branches.
5. It is commonly used in domestic lighting installations.

C. Series circuit

In a series circuit, components are connected one after another to form a single current path.



Characteristics of a series circuit

1. The same current flows through all components.
2. The supply voltage is shared between the components.
3. If one component opens the circuit, current stops flowing throughout the circuit.
4. The total resistance is the sum of the individual resistances.
5. It has only one main path for current.

D. Comparison between series and parallel circuits

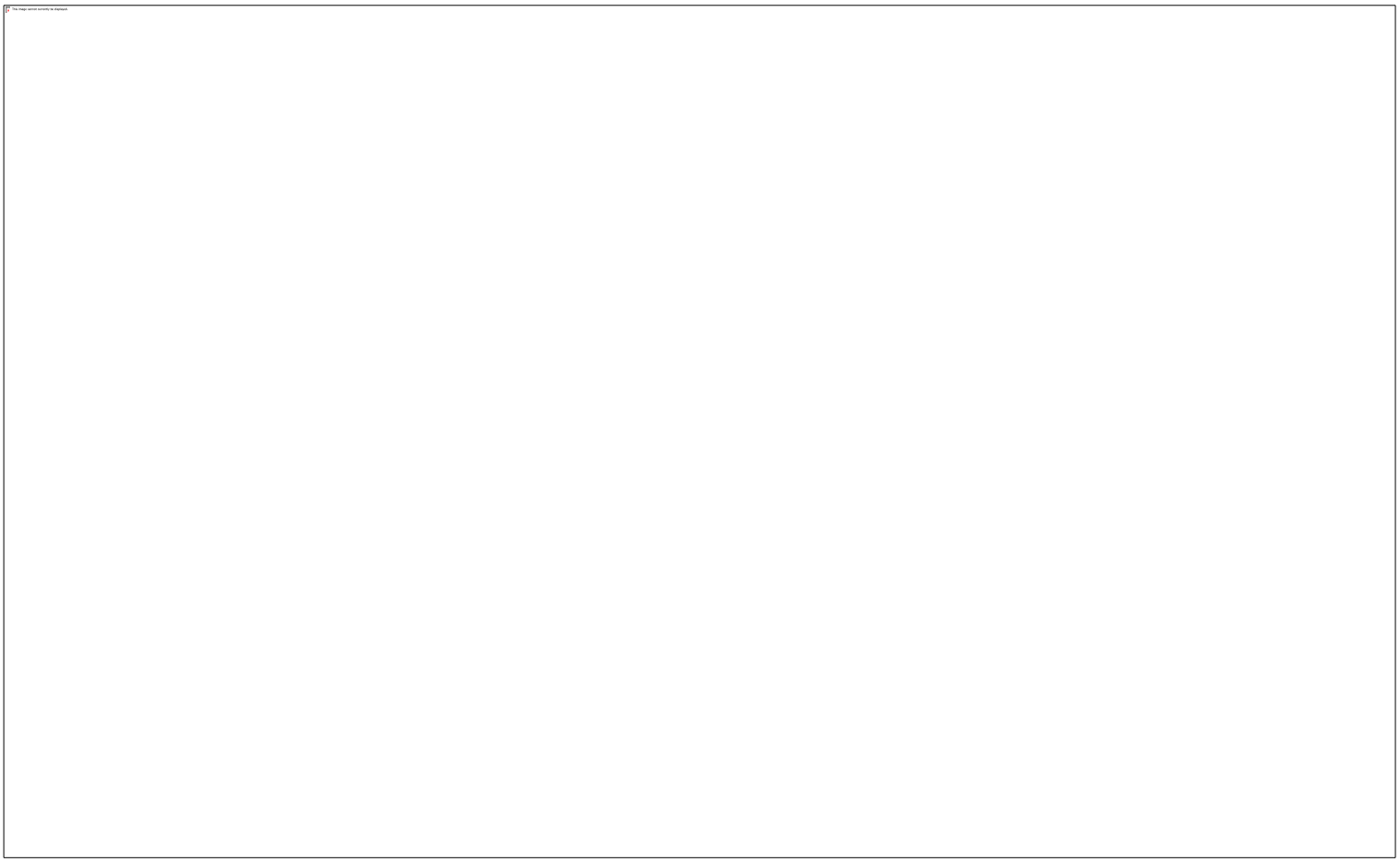
Feature	Series circuit	Parallel circuit
Current path	One	Multiple branches
Current	Same through components	Divided between branches
Voltage	Shared	Same across branches
Failure of one load	May interrupt the whole circuit	Other branches can continue operating
Total resistance	Sum of resistances	Less than the smallest branch resistance for ordinary positive resistors
Domestic lighting	Not the normal arrangement for independent lamps	Common arrangement

E. Simple bell circuit

Operation:

1. The transformer provides the required low voltage.
2. The push button controls the circuit.
3. When the push button is pressed, the circuit is completed.
4. Current flows through the bell.
5. The bell produces sound.
6. When the push button is released, the circuit opens and the bell stops.

F. Simple motor control circuit



Main components:

1. Power supply.
2. Circuit protection.
3. Stop push button.
4. Start push button.
5. Contactor.
6. Overload relay.
7. Electric motor.

Explanation of operation:

- The stop push button is normally closed.
- The start push button is normally open.
- Pressing the start button energises the contactor coil when the control circuit is healthy.

- The contactor closes its main power contacts and supplies the motor.
- An auxiliary contact may provide a holding or sealing circuit.
- Pressing the stop button interrupts the coil circuit.
- An overload relay can interrupt the control circuit when the motor experiences a sustained overload.

1.3.10 PROCEDURE FOR DRAWING ELECTRICAL DIAGRAMS

Electrical diagrams should be drawn systematically to ensure clarity, correctness and standardisation.

Materials and equipment required

1. Drawing board.
2. Drawing paper.
3. HB pencil.
4. Ruler.
5. T-square.
6. Set squares.
7. Eraser.
8. Compass.
9. Drawing templates.
10. Computer with circuit drawing software where available.

General procedure

Step 1: Identify the purpose of the drawing

Determine whether the drawing is a schematic, wiring, line, ladder or architectural electrical drawing.

Step 2: Identify the components

List all the electrical components required.

Step 3: Select appropriate symbols

Use standard symbols to represent the components.

Step 4: Determine the circuit arrangement

Establish how the components are electrically connected.

Step 5: Select the drawing sheet

Choose suitable paper size and orientation.

Step 6: Draw the main supply connections

Represent the supply and main conductors using the correct conventions.

Step 7: Insert the component symbols

Position symbols in a logical arrangement.

Step 8: Connect the symbols

Use straight and clear lines to show electrical connections.

Step 9: Label the components

Identify components using suitable letters, numbers and descriptions.

Step 10: Add the drawing legend

Provide explanations of symbols that may not be familiar to the reader.

Step 11: Add title block information

Include the drawing title, date, drawing number and other required information.

Step 12: Inspect the drawing

Check:

- Accuracy of symbols.
- Correctness of connections.
- Neatness.
- Completeness.
- Correct labels.
- Consistency of drawing conventions.

Step 13: Present the drawing

Submit the drawing for assessment, review or approval.

1.3.11 INTERPRETATION OF ELECTRICAL CIRCUIT DIAGRAMS

Definition

Interpretation of an electrical circuit diagram is the process of examining electrical symbols, lines, labels and connections to understand the components, their functions and how the circuit operates.

A technician must be able to interpret a drawing before installing, testing or repairing an electrical circuit.

Steps in interpreting an electrical diagram

1. Read the drawing title.
2. Identify the type of drawing.
3. Examine the symbol legend.
4. Identify the power supply.
5. Identify the protective devices.
6. Identify the control devices.
7. Identify the electrical loads.
8. Trace the connecting conductors.
9. Identify the terminals and component labels.
10. Determine the sequence of circuit operation.
11. Identify the earthing and protective arrangements.
12. Compare the drawing with the actual installation.

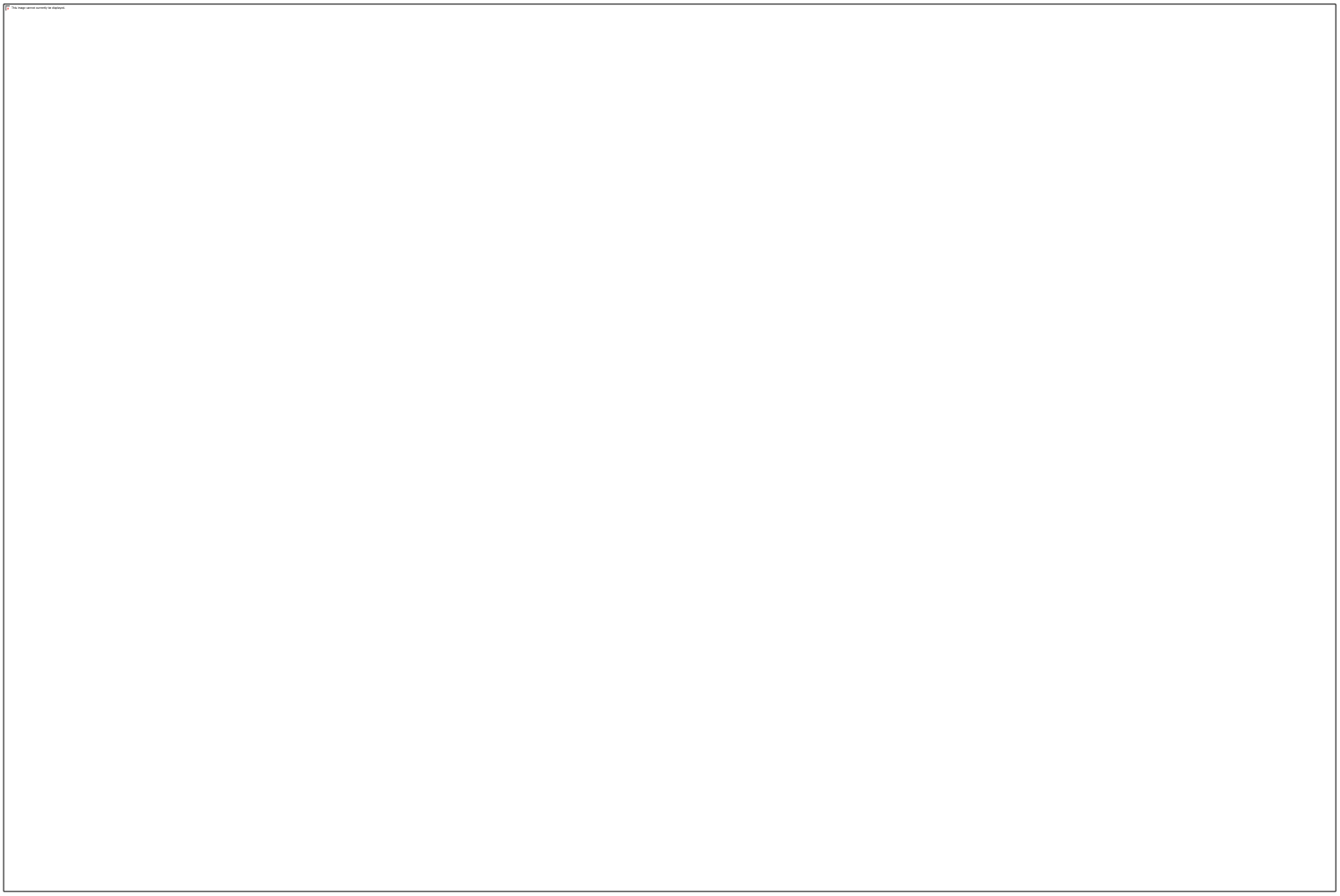
A learner examining this drawing should identify:

Component	Actual electrical component	Function
Supply	Electrical source	Provides electrical energy
Protective device	Fuse or circuit breaker	Provides overcurrent protection
Switch	One-way wall switch	Controls the lamp
Lamp	Lighting fitting	Produces light
Conductor	Insulated cable	Carries electrical current
Protective earth	Earthing conductor	Provides a fault-current path

Relationship between symbols and actual components

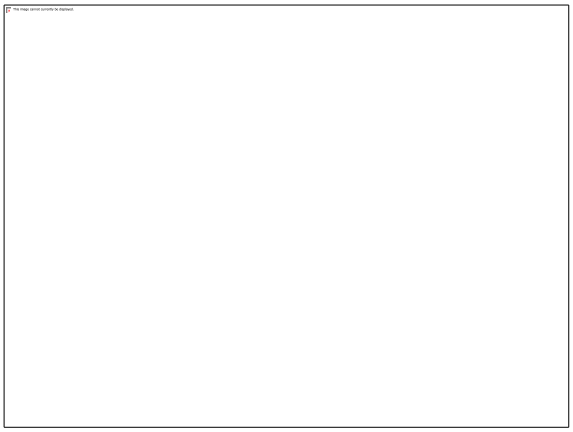
Electrical symbols are simplified representations of actual physical components.

For example:



Electrical symbol

Resistor symbol



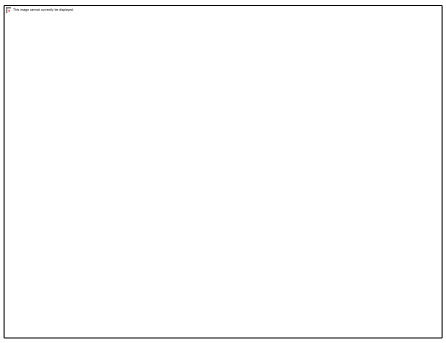
Actual component

Physical resistor



Electrical symbol

Switch symbol



Actual component

Physical switch

Why learners should understand actual electrical components

1. To identify components during practical work.
2. To connect the correct terminals.
3. To select appropriate equipment.
4. To understand the relationship between drawings and installations.
5. To diagnose faults.
6. To improve safety during electrical work.

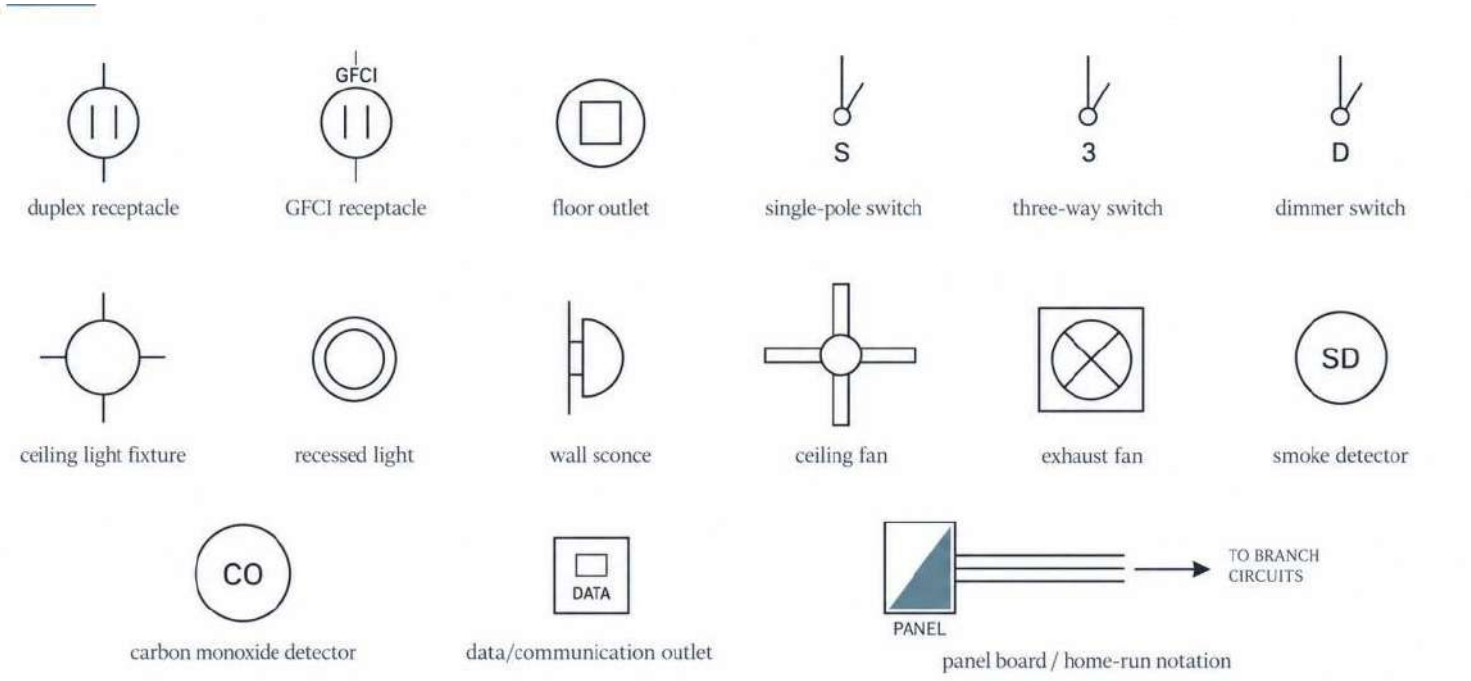
1.3.12 ELECTRICAL SYMBOLS ON ARCHITECTURAL DRAWINGS

Meaning of architectural drawings

An architectural drawing is a technical representation of a proposed or existing building showing its design, dimensions, spaces, openings and construction features.

Electrical installation information may be added to architectural drawings to show the intended location of electrical accessories and services.

Common electrical symbols used on building plans



The following table gives examples of common plan abbreviations and notations. Exact graphic symbols and abbreviations should always be confirmed using the drawing legend and applicable standard.

Symbol/abbreviation	Common meaning	Application
L or LP	Lighting point	Position of a light fitting
S or S1	One-way switch	Controls a lighting circuit
S2	Two-way switching notation in some drawings	Controls lighting from two locations
SO	Socket outlet	General-purpose power connection
DB	Distribution board	Houses circuit protective and switching devices
EF	Extractor fan	Provides mechanical ventilation
CF	Ceiling fan	Provides air circulation
SM	Smoke detector	Detects smoke
EM	Emergency light	Provides lighting during power failure

JB	Junction box	Houses conductor connections
TV	Television outlet	Provides television signal connection
DATA	Data outlet	Provides network connection

Detailed explanation of symbols on architectural plans

1. Lighting point

- Indicates the position of a lighting fitting.
- May represent a ceiling-mounted or wall-mounted light.
- Used to plan illumination in rooms, corridors and other spaces.

2. One-way switch

- Indicates a switch controlling a lighting point from one location.
- Commonly used in classrooms, bedrooms and offices.

3. Two-way switch

- Used to control one lighting point from two different locations.
- Suitable for staircases and long corridors.

4. Socket outlet

- Indicates a point where portable electrical equipment can be connected.
- Used in classrooms, offices, kitchens and residential rooms.

5. Distribution board

- Indicates the position of the electrical distribution board.
- It distributes electrical power to final circuits through protective devices.

6. Ceiling fan

- Indicates the position of a fan.
- Used for air circulation in classrooms and other occupied spaces.

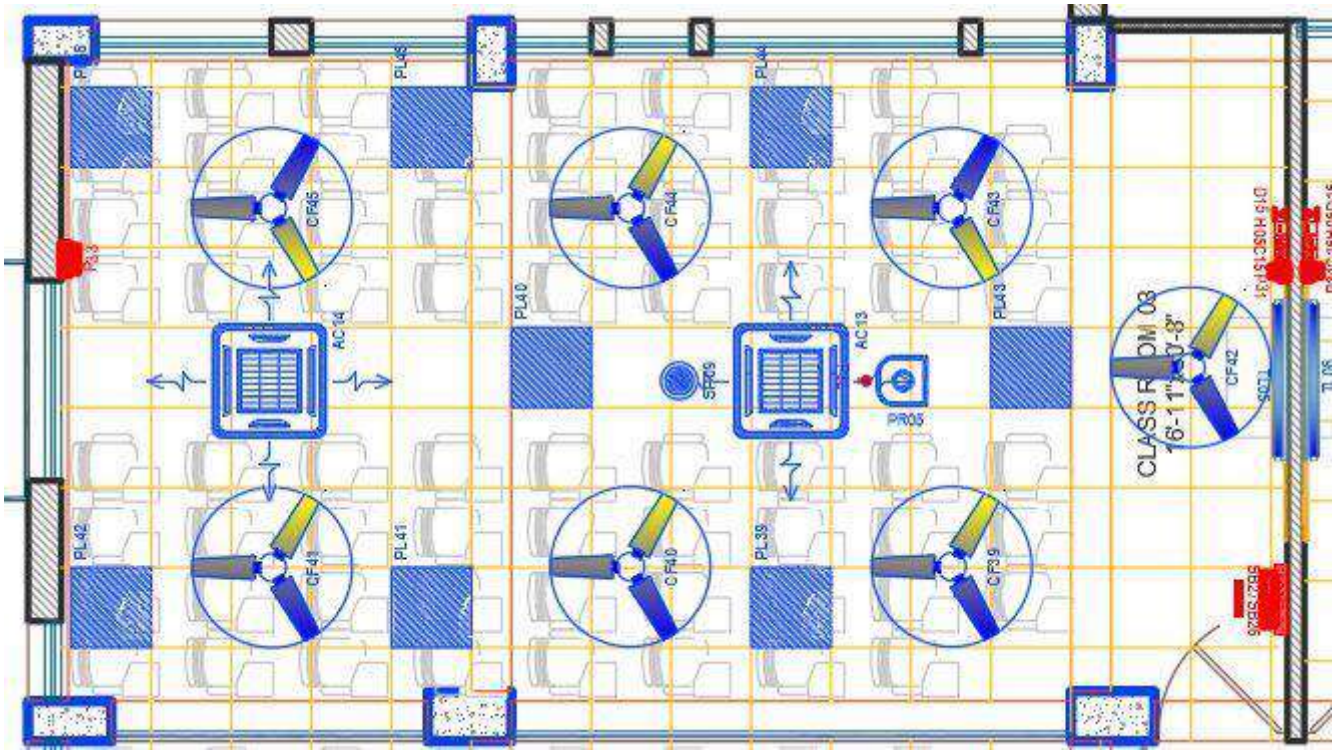
7. Emergency lighting

- Indicates the position of emergency lighting fittings.
- Provides illumination when the normal lighting supply fails.

8. Smoke detector

- Indicates the position of a smoke detection device.
- Forms part of a fire detection and alarm system.

Example: Electrical layout of a Kenyan classroom



An electrical plan for a classroom may indicate:

1. Ceiling lighting points.
2. Wall switches near the entrance.
3. Socket outlets at designated positions.
4. Ceiling fans where required.
5. Emergency lighting.
6. A distribution board serving the classroom block.
7. Data and communication outlets.
8. Cable routes where specified.

Interpretation of a classroom electrical plan

When examining the plan, the learner should:

- Identify the room boundaries.
- Locate all lighting points.
- Identify switch positions.
- Locate socket outlets.
- Identify the distribution board.
- Trace the indicated circuit connections.
- Read the drawing legend.
- Compare the drawing with the actual classroom layout.

Importance of electrical drawings in building construction in Kenya

1. They assist contractors in planning electrical installations.
2. They coordinate electrical work with building construction.

3. They assist in locating electrical accessories.
4. They help estimate installation materials.
5. They support inspection and testing.
6. They provide reference documents for maintenance.
7. They help reduce unnecessary alterations during construction.

1.3.13 DOMESTIC ELECTRICAL INSTALLATION DRAWINGS

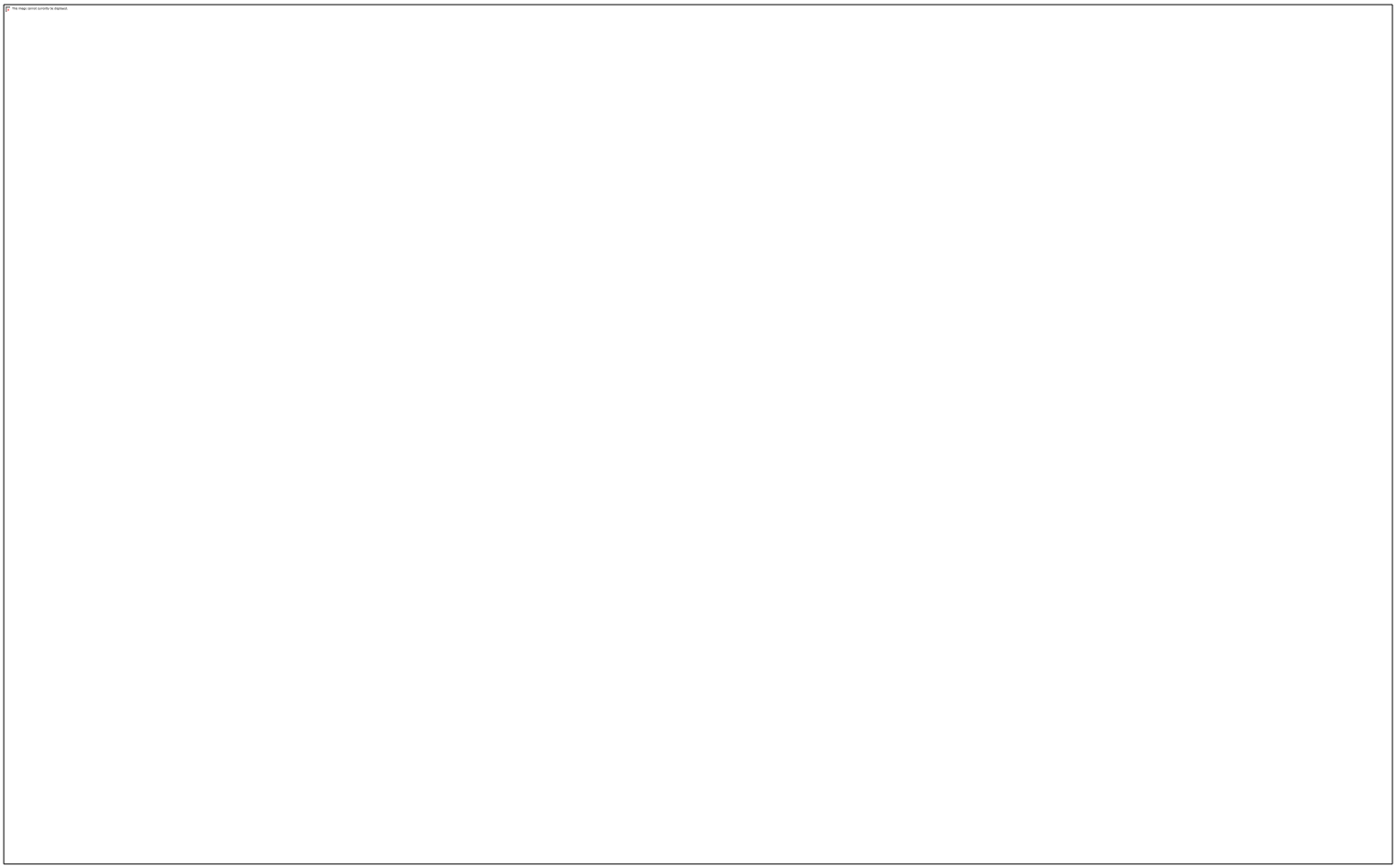
Definition

A domestic electrical installation drawing is a technical drawing showing the arrangement, location and connections of electrical equipment and accessories in a residential building.

It is used when planning and installing electrical systems in houses, apartments and other residential premises.

Main components shown in domestic electrical drawings

1. Lighting points.
2. One-way switches.
3. Two-way switches.
4. Socket outlets.
5. Distribution boards.
6. Circuit breakers.
7. Residual current protection devices.
8. Earthing arrangements.
9. Water heaters.
10. Cooker outlets.
11. Extractor fans.
12. Cable routes.



Common domestic electrical circuits

1. Lighting circuit

- Supplies electrical energy to lighting points.
- Includes switches, lamps and appropriate protective devices.
- Usually uses a parallel arrangement so that lighting points operate independently.

2. Socket outlet circuit

- Supplies electrical energy to socket outlets.
- Allows appliances to be connected.
- Requires suitable cable sizes and overcurrent and residual-current protection as specified by the installation design.

3. Cooker circuit

- Supplies electrical energy to an electric cooker.
- Requires an appropriately rated circuit and protective device.
- The cable and accessories must be selected according to the load and installation conditions.

4. Water heater circuit

- Supplies electrical energy to a water heating appliance.
- Requires suitable circuit protection and isolation.
- Appropriate earthing and additional shock protection must be provided.

5. Outdoor lighting circuit

- Supplies electricity to external lighting fittings.
- Used in compounds, security lighting and pathways.
- Requires equipment suitable for the environmental conditions.

Example: Electrical installation in a Kenyan residential house

Consider a three-bedroom house with:

- Sitting room.
- Kitchen.
- Three bedrooms.
- Bathroom.
- Corridor.
- External compound.

The electrical drawing may show:

Area	Electrical accessories
Sitting room	Lighting points, switches, socket outlets and television outlet
Kitchen	Lighting, socket outlets and cooker connection
Bedroom 1	Lighting and socket outlets
Bedroom 2	Lighting and socket outlets
Bedroom 3	Lighting and socket outlets
Bathroom	Suitable lighting and water-heater connection where applicable
Corridor	Lighting and two-way switching where required
Compound	External lighting and suitable outdoor accessories

Practical consideration: Electrical accessories in bathrooms and other locations exposed to moisture must be selected and installed according to the appropriate protection zones and applicable electrical installation requirements.

1.3.14 INDUSTRIAL ELECTRICAL DRAWINGS

Definition

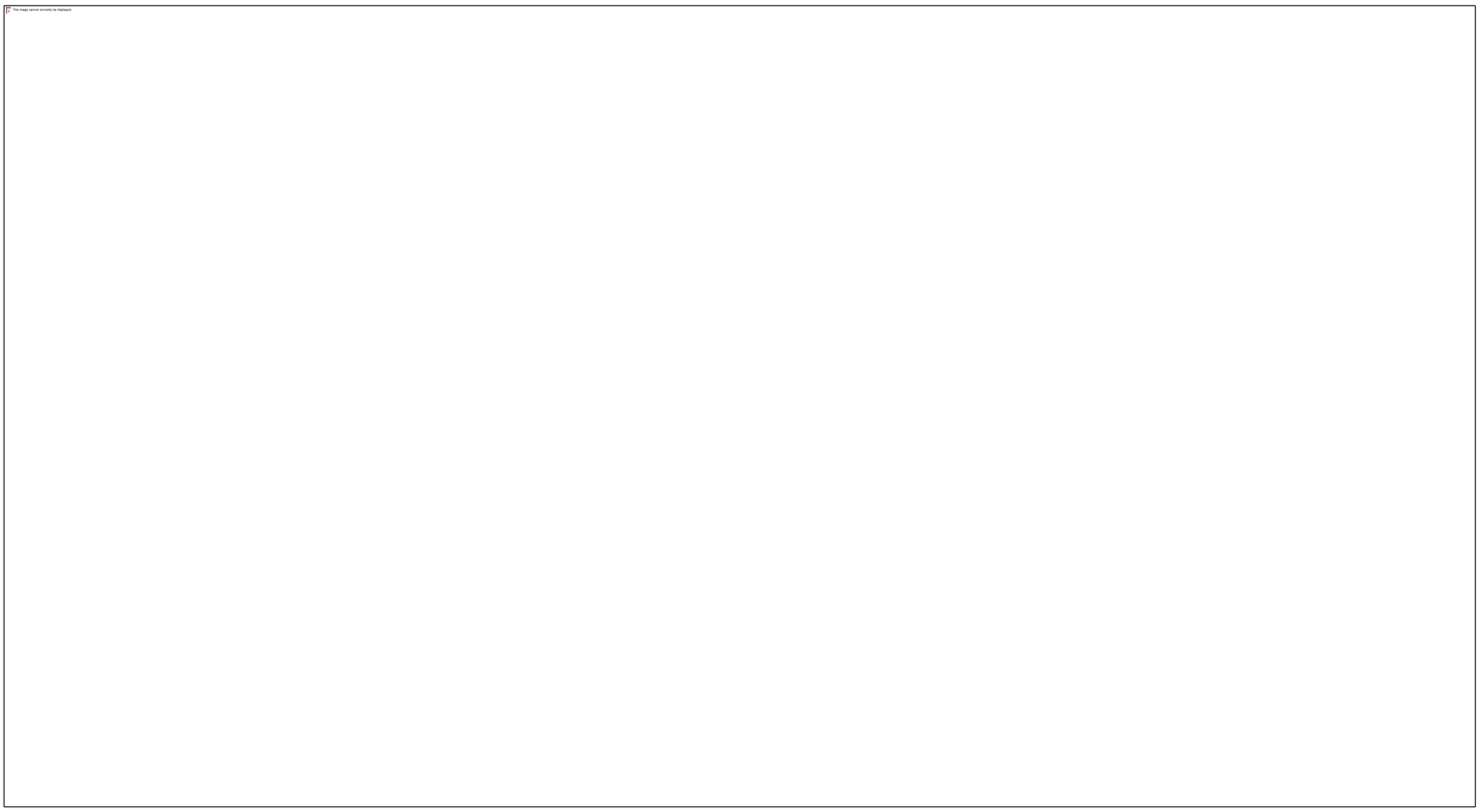
An industrial electrical drawing is a technical representation of electrical systems used in factories, workshops, processing plants and other industrial facilities.

These drawings are used to plan, install, operate and maintain industrial electrical equipment.

Common industrial electrical drawings

1. Motor control diagrams.

2. Power circuit diagrams.
3. Control circuit diagrams.
4. Wiring diagrams.
5. Ladder diagrams.
6. Single-line diagrams.
7. Instrumentation diagrams.
8. Panel layout drawings.



Main electrical components represented

Component	Function
Electric motor	Converts electrical energy into mechanical energy
Contactor	Electrically operates power contacts
Overload relay	Protects motors against sustained overload
Circuit breaker	Provides circuit protection
Push button	Provides manual control
Indicator lamp	Indicates an operating condition
Timer relay	Provides time-dependent switching

Limit switch	Detects the position or movement of a machine part
Transformer	Changes AC voltage level
PLC	Controls industrial processes through programmed logic

Applications in Kenyan industries

Industrial electrical drawings are useful in:

- Tea processing factories.
- Dairy processing plants.
- Grain milling facilities.
- Cement manufacturing plants.
- Textile factories.
- Water pumping stations.
- Food processing industries.
- Welding and fabrication workshops.
- Agricultural processing facilities.

Importance of industrial electrical drawings

1. They guide installation of industrial machinery.
2. They help technicians understand control circuits.
3. They assist in fault diagnosis.
4. They improve equipment maintenance.
5. They support automation.
6. They help identify protective devices.
7. They improve coordination between electrical and mechanical systems.

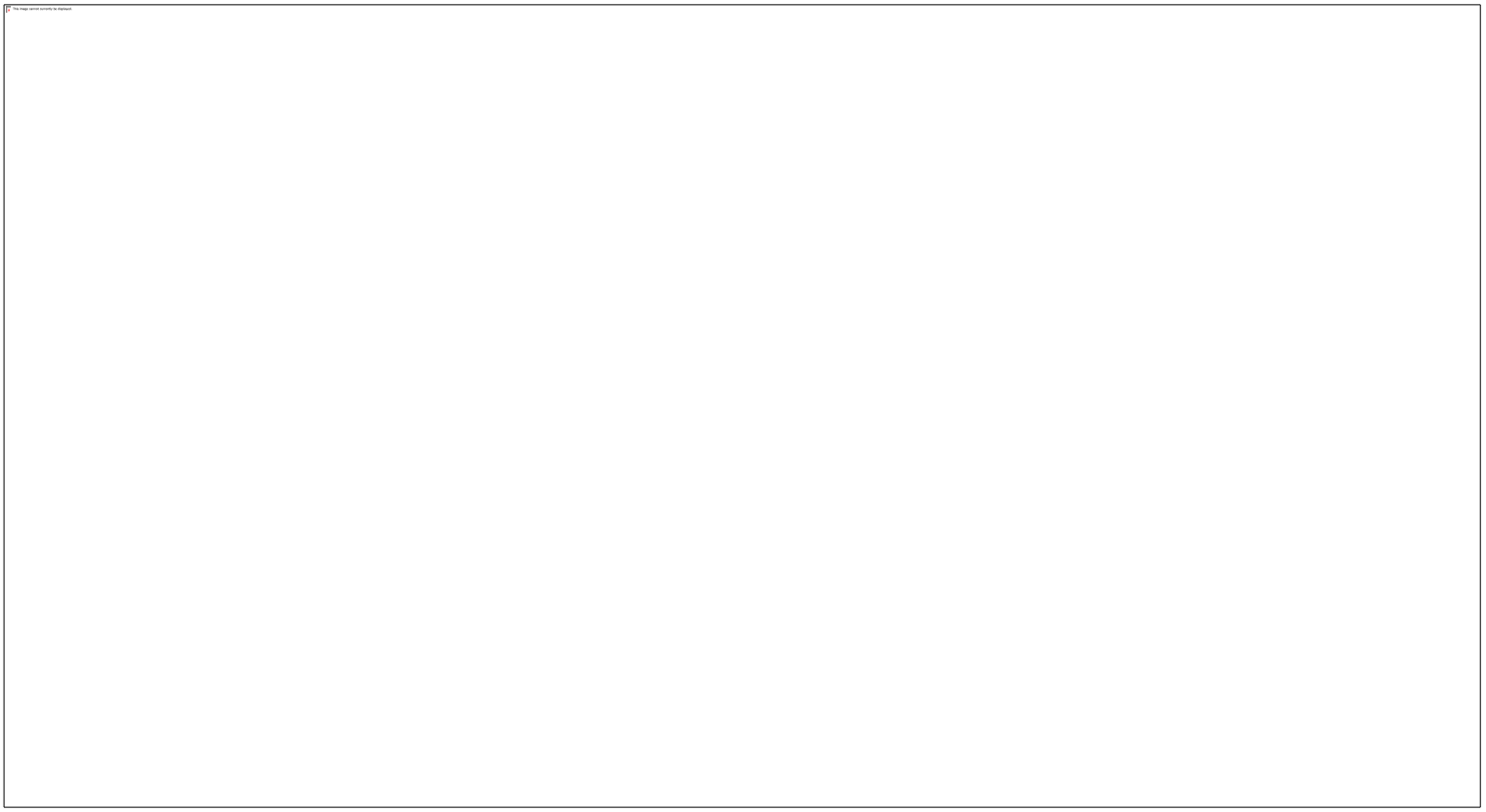
1.3.15 COMPUTER-AIDED ELECTRICAL DRAWING

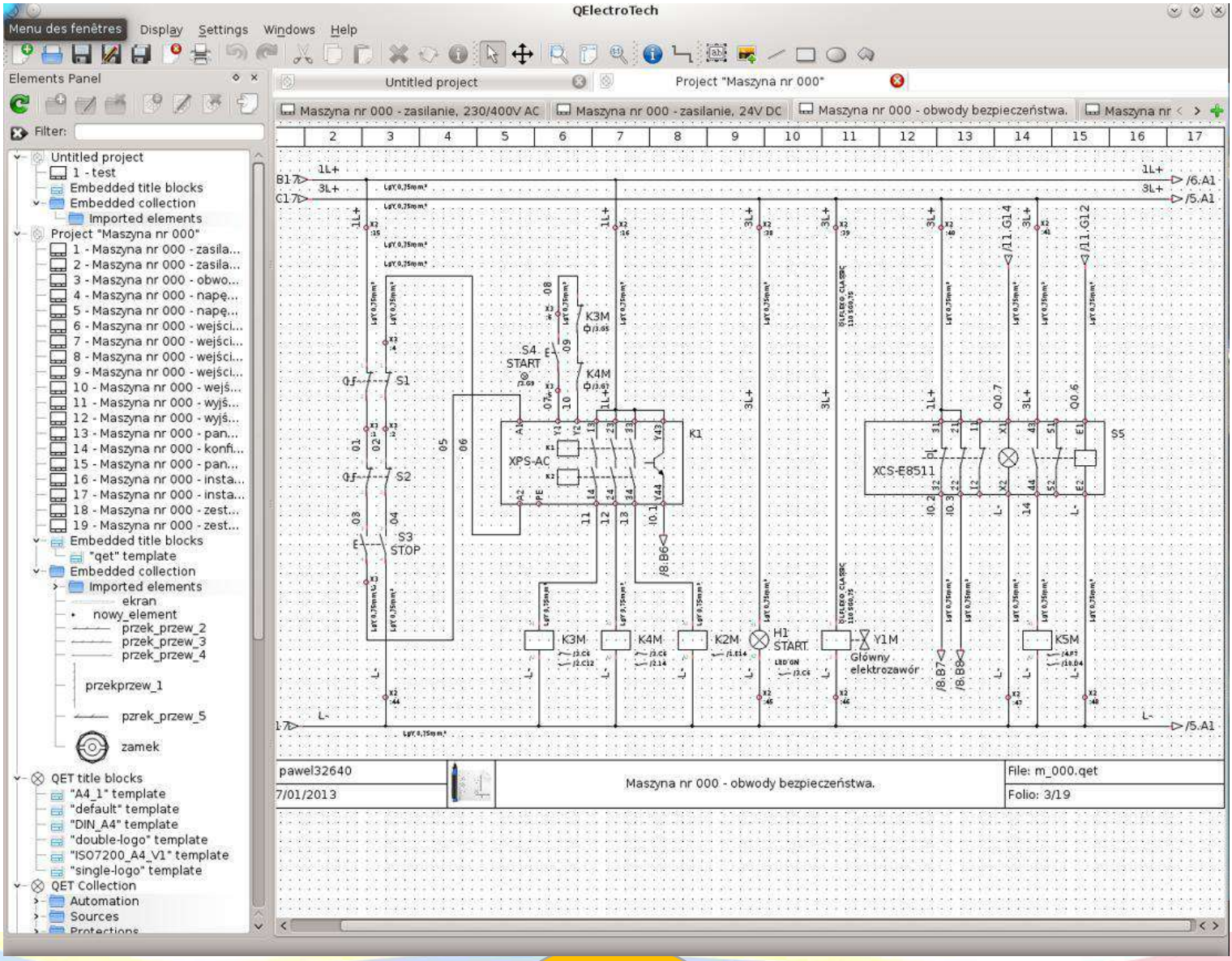
Definition

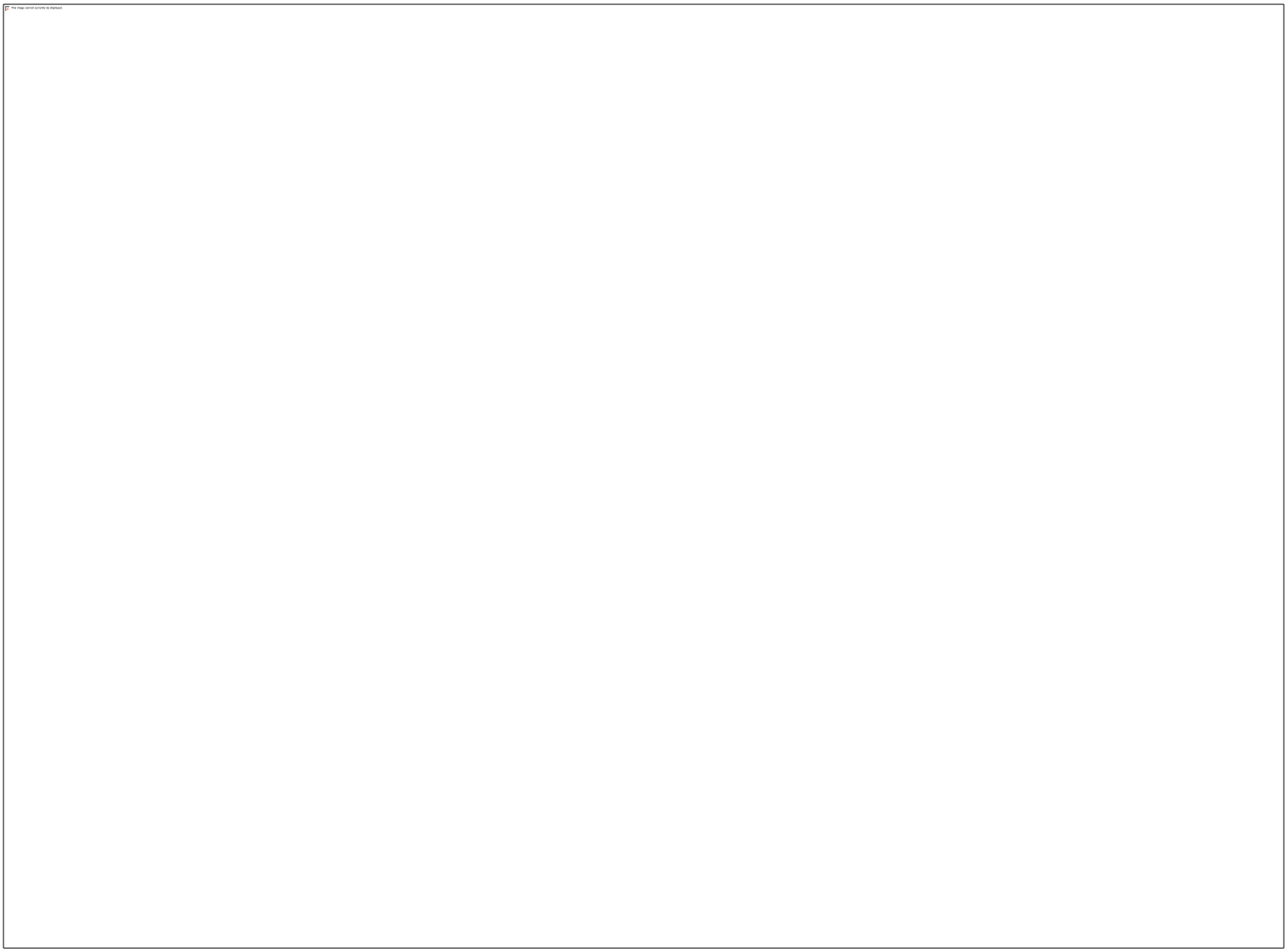
Computer-aided electrical drawing is the use of computer software to prepare, modify, store and reproduce electrical diagrams and installation drawings.

Digital drawing tools enable electrical technicians and engineers to prepare accurate diagrams more efficiently than manual drawing alone.

Examples of software used







1. AutoCAD

- Used for preparing technical and electrical installation drawings.
- Helps create building electrical layouts.
- Supports accurate dimensions and annotations.

2. AutoCAD Electrical

- Specialised electrical design software.
- Provides electrical symbol libraries.
- Helps prepare wiring diagrams and control circuit drawings.
- Supports component identification and documentation.

3. QElectroTech

- Used to prepare electrical schematic diagrams.
- Provides electrical symbol libraries.
- Useful for educational and technical drawing activities.

4. KiCad

- Used for electronic circuit schematic design.
- Supports electronic component symbols.

- Can be used to design printed circuit boards.

5. FreeCAD

- Used for technical drawing and three-dimensional modelling.
- Can support engineering design and documentation.

Advantages of computer-aided electrical drawing

1. High drawing accuracy.
2. Faster preparation of drawings.
3. Easy editing and correction.
4. Easy storage of electronic files.
5. Simple sharing of drawings.
6. Availability of standard symbol libraries.
7. Easy duplication of similar drawings.
8. Improved presentation.
9. Better management of revisions.
10. Ability to print drawings at different scales.

Disadvantages

1. Requires computers and electricity.
2. Some software packages require paid licences.
3. Requires training and digital skills.
4. Software or hardware failures can interrupt work.
5. Incorrect information entered into software can produce inaccurate drawings.
6. Files may be lost without proper backup.

Practical learning activity: Drawing a simple circuit using software

Task: Use available circuit drawing software to prepare a diagram containing a power source, switch, resistor and lamp.

Procedure:

1. Open the electrical drawing software.
2. Select a new schematic drawing.
3. Identify the symbol library.
4. Select the required electrical symbols.
5. Place the symbols on the drawing sheet.
6. Connect the symbols using conductor lines.
7. Label the components.
8. Check the circuit connections.
9. Save the drawing.

10. Present the completed drawing to classmates.

1.3.16 DIFFERENCE BETWEEN ELECTRICAL DRAWINGS AND ELECTRICAL SYMBOLS

These two terms are related but do not mean the same thing.

Electrical symbols	Electrical drawings
Graphical representations of individual components or functions.	Complete representations of electrical circuits or installations.
Represent specific devices.	Show the arrangement and connections of devices.
Examples include lamp, switch and resistor symbols.	Examples include wiring diagrams and schematic diagrams.
Form building blocks of electrical drawings.	Combine symbols, lines, labels and other information.

Example: A lamp symbol represents one lighting device, while a lighting circuit drawing shows the lamp, switch, supply and connecting conductors.

1.3.17 FAULT FINDING USING ELECTRICAL DIAGRAMS

Definition

Fault finding is the systematic process of identifying, locating and determining the cause of a problem in an electrical circuit or installation.

Electrical diagrams provide essential information during fault-finding activities.

Common electrical faults

1. Open-circuit fault

An open circuit occurs when the conducting path is broken, preventing current from flowing.

Possible causes:

- Broken conductor.
- Loose terminal.
- Burnt fuse.
- Damaged switch.
- Disconnected wire.

2. Short-circuit fault

A short circuit occurs when conductors at different potentials become connected through an unintended low-impedance path.

Possible causes:

- Damaged insulation.
- Incorrect wiring.
- Loose wire strands.

- Conductors touching each other.

3. Earth fault

An earth fault occurs when an unintended connection develops between a live conductor and earth or an earthed conductive part.

Possible causes:

- Damaged cable insulation.
- Moisture entering electrical equipment.
- Faulty electrical appliances.
- Damaged electrical accessories.

4. Overload fault

An overload occurs when a circuit carries current exceeding its intended current-carrying capacity for a sufficient period.

Possible causes:

- Connecting too many loads.
- Operating equipment beyond its rated capacity.
- Mechanical overloading of a motor.

How electrical diagrams assist in fault finding

1. They help identify the affected circuit.
2. They show the location of protective devices.
3. They help trace conductors.
4. They indicate the connection points.
5. They help identify the components that may be faulty.
6. They provide a reference for testing.
7. They assist in restoring the circuit correctly after repairs.

Safe fault-finding procedure

1. Identify the reported problem.
2. Obtain and study the correct electrical diagram.
3. Isolate the affected circuit using an appropriate safe isolation procedure.
4. Verify that the circuit is de-energised using a suitable approved voltage tester.
5. Identify the likely fault location.
6. Carry out appropriate tests using suitable instruments.
7. Repair or replace defective components.
8. Inspect the completed work.
9. Carry out the required tests before re-energising.
10. Restore the supply only after confirming that the installation is safe.

SAFETY REMINDER

Learners should not experiment with live mains electrical circuits. Practical activities involving mains installations must be supervised by a competent instructor and carried out using appropriate isolation, protective equipment and safe working procedures. Low-voltage training kits should be used for basic circuit-building exercises.

1.3.18 ELECTRICAL DRAWINGS AND OCCUPATIONAL SAFETY

Electrical drawings contribute to safe working practices in electrical technology.

Safety benefits

1. They help identify electrical supply sources.
2. They show protective devices.
3. They indicate earthing arrangements.
4. They assist in identifying isolation points.
5. They help prevent incorrect connections.
6. They support proper equipment selection.
7. They provide information for inspection and testing.
8. They help technicians understand the arrangement of installations before working on them.

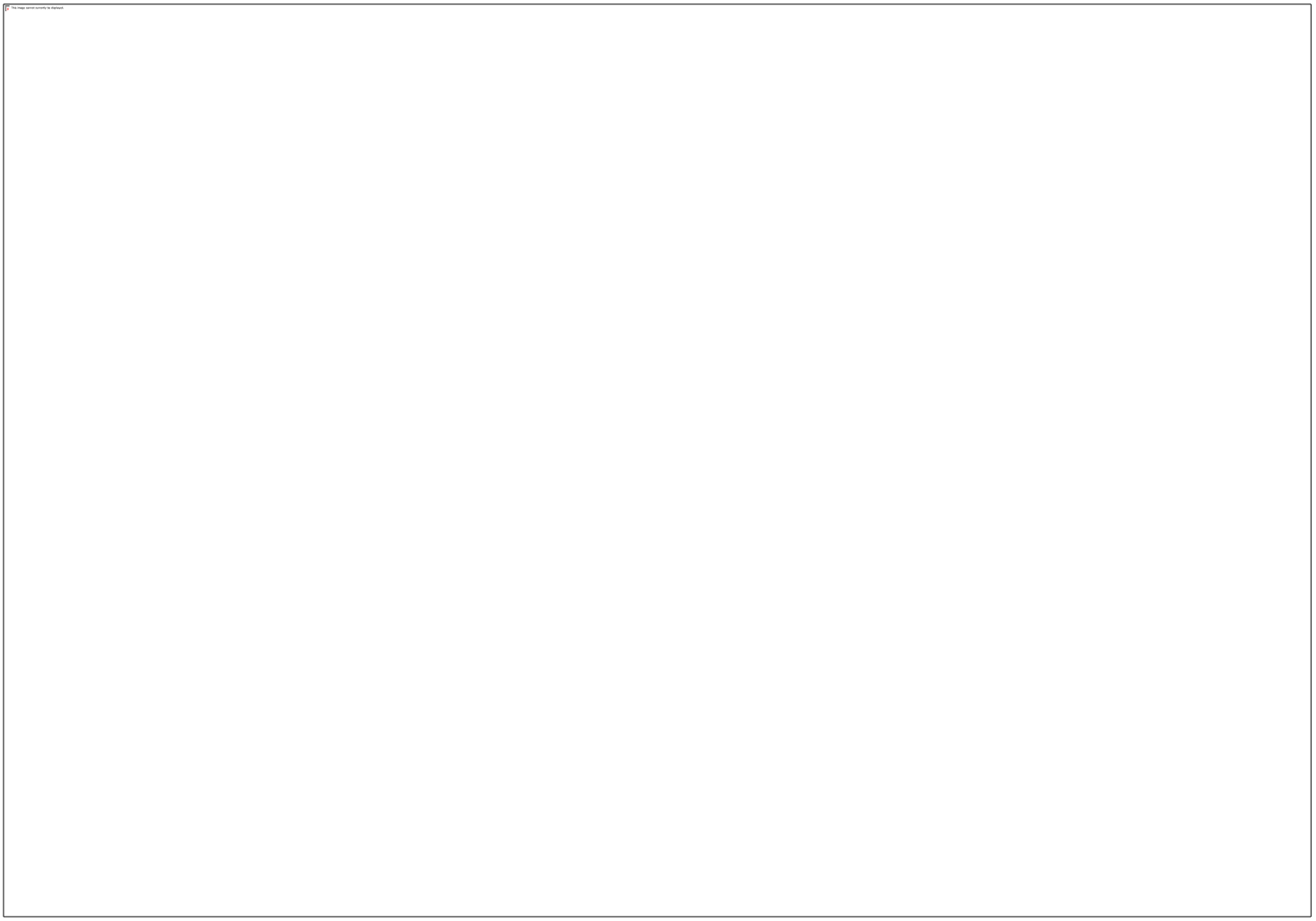
Safety precautions when preparing electrical drawings

1. Keep drawing instruments in good condition.
2. Avoid sharp objects being left carelessly on drawing tables.
3. Maintain good lighting and ventilation.
4. Keep computers and electrical equipment in safe working condition.
5. Do not connect actual electrical components to mains supplies during drawing exercises.
6. Use approved low-voltage training kits for practical demonstrations.
7. Keep the workshop clean.
8. Follow the instructor's safety instructions.

1.3.19 COMPETENCY-BASED PRACTICAL LEARNING ACTIVITIES

The following activities help learners acquire practical skills in electrical drawing and interpretation.

Activity 1: Developing an electrical symbol chart



Instructions:

Working in groups, prepare a chart showing at least 20 electrical and electronic symbols.

Include:

- Symbol.
- Name of component.
- Function.
- Application in electrical technology.

Expected learning outcomes:

The learner should be able to:

- Identify common electrical symbols.
- Explain their functions.
- Relate symbols to actual components.
- Communicate technical information through drawings.

Activity 2: Drawing a simple lighting circuit

Materials:

- Low-voltage training power supply.

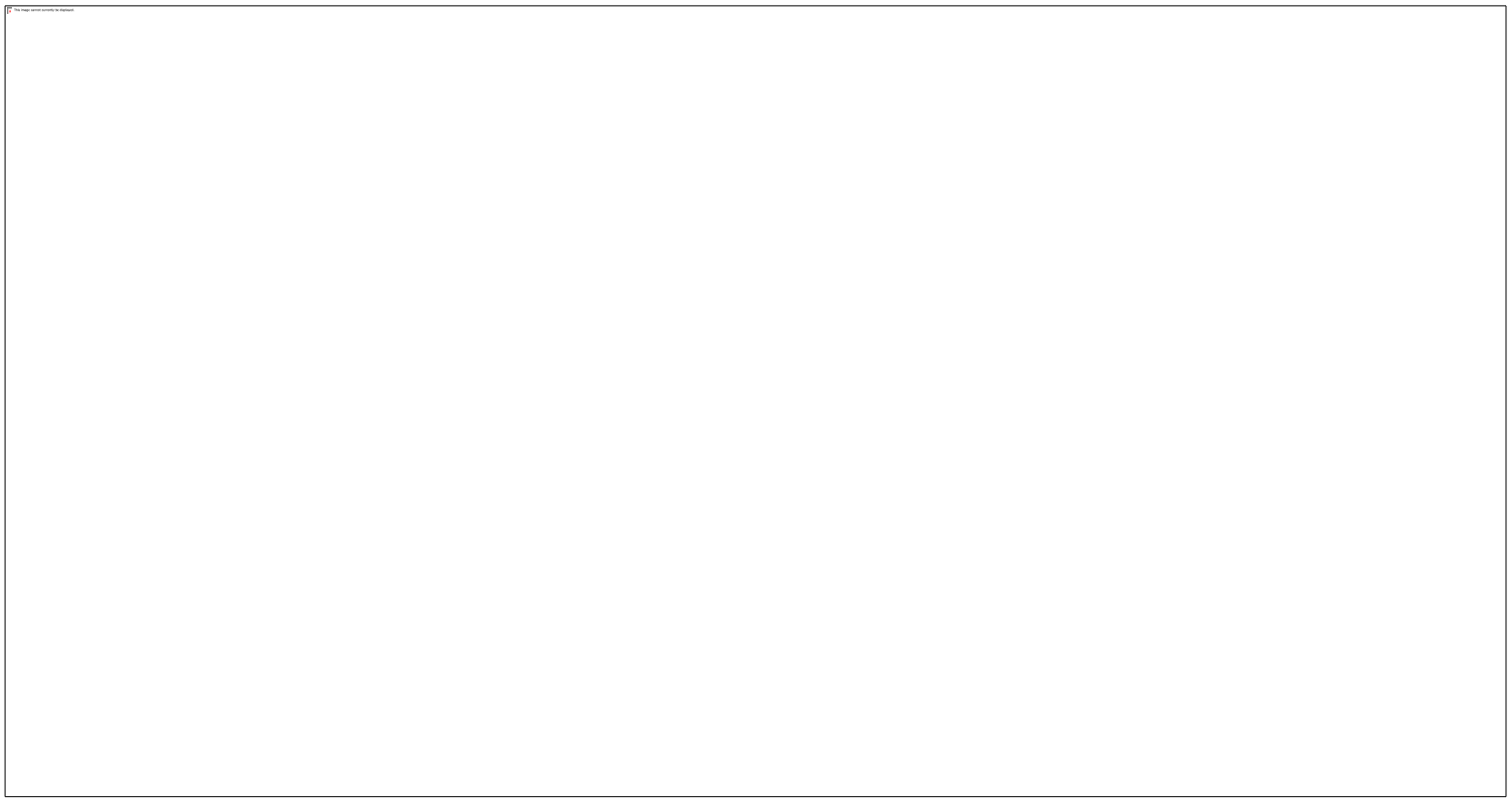
- Switch.
- Lamp.
- Connecting wires.
- Protective device suitable for the training circuit.
- Drawing instruments.

Procedure:

1. Identify all the components.
2. Draw the schematic diagram.
3. Represent each component using the appropriate symbol.
4. Connect the symbols using straight lines.
5. Label the components.
6. Explain the operation of the circuit.
7. Compare the drawing with the actual low-voltage training circuit.

Expected outcome: The learner should demonstrate the ability to prepare and interpret a simple lighting circuit diagram.

Activity 3: Interpreting an architectural electrical drawing



Scenario:

A contractor is planning electrical installations in a new classroom block in a Kenyan school.

Tasks:

1. Study the supplied building plan.

2. Identify the lighting points.
3. Identify switch positions.
4. Locate socket outlets.
5. Identify the distribution board.
6. Explain the functions of the electrical symbols.
7. Prepare a simple electrical layout.
8. Present the drawing to the class.

Activity 4: Using digital tools to prepare an electrical schematic

Tasks:

1. Open an available electrical drawing application.
2. Select suitable electrical symbols.
3. Draw a simple circuit.
4. Connect all components.
5. Label the components.
6. Save the drawing.
7. Present the drawing for peer assessment.

REVISION EXERCISES AND ASSESSMENT

STRAND 1.0: FUNDAMENTALS OF ELECTRICITY

SUB-STRAND 1.3: ELECTRICAL DIAGRAMS

SECTION A: MULTIPLE-CHOICE QUESTIONS (30 MARKS)

Instructions: Answer all questions. Choose the correct answer from the alternatives A, B, C and D. Each question carries 1 mark.

1. What is an electrical diagram?

A. A drawing showing the physical appearance of a building only.

B. A graphical representation of an electrical circuit or installation.

C. A drawing showing the dimensions of furniture.

D. A picture showing electrical tools.

2. Which of the following is the main purpose of electrical symbols?

A. To decorate electrical drawings.

B. To represent electrical components graphically.

C. To increase the electrical voltage.

D. To reduce electrical resistance.

3. Which electrical drawing uses standard symbols to show the functional connections of a circuit?

A. Pictorial diagram.

B. Architectural drawing.

C. Schematic diagram.

D. Building elevation.

4. Which type of electrical drawing shows the actual connections between components and their terminals?

A. Wiring diagram.

B. Block diagram.

C. Pictorial drawing.

D. Site plan.

5. Which of the following is used to represent a power distribution system in a simplified form?

A. Pictorial diagram.

B. Single-line diagram.

C. Freehand drawing.

D. Perspective drawing.

6. Which electrical drawing uses rectangular blocks to represent functional units?

A. Wiring diagram.

B. Ladder diagram.

C. Block diagram.

D. Architectural drawing.

7. Which of the following is commonly represented by a circle marked A?

A. Voltmeter.

B. Ammeter.

C. Wattmeter.

D. Ohmmeter.

8. Which instrument is used to measure potential difference?

A. Ammeter.

B. Ohmmeter.

C. Voltmeter.

D. Wattmeter.

9. Which of the following components is represented by a resistor symbol?

A. A device that opposes current flow.

B. A device that produces light.

C. A device that stores mechanical energy.

D. A device that generates sound.

10. Which component is used to store electrical energy in an electric field?

A. Resistor.

B. Capacitor.

C. Switch.

D. Fuse.

11. What is the main function of a diode?

A. To amplify sound.

B. To allow current to flow mainly in one direction.

C. To measure voltage.

D. To store electrical energy in a magnetic field.

12. Which electronic component is commonly used for switching and amplification?

A. Resistor.

B. Fuse.

C. Transistor.

D. Lamp.

13. Which electrical device converts electrical energy into mechanical energy?

A. Transformer.

B. Electric motor.

C. Fuse.

D. Capacitor.

14. Which device protects an electrical circuit by melting when excessive current flows through it?

A. Switch.

B. Fuse.

C. Voltmeter.

D. Resistor.

15. Which device automatically interrupts a circuit under specified fault conditions?

A. Circuit breaker.

B. Lamp.

C. Capacitor.

D. Ammeter.

16. Which device is used to control a lighting point from two different locations?

A. One-way switch.

B. Two-way switching arrangement.

C. Fuse.

D. Resistor.

17. What does a junction dot in an electrical diagram normally indicate?

A. An open circuit.

B. An electrical connection.

C. A broken conductor.

D. An electrical load.

18. Which conductor is identified by the green/yellow colour combination in IEC-based wiring practices?

A. Line conductor.

B. Neutral conductor.

C. Protective earth conductor.

D. Switched line conductor.

19. What is the common IEC colour identification for a single-phase line conductor?

A. Blue.

B. Green/yellow.

C. Brown.

D. White.

20. Which electrical drawing is commonly used to represent the control logic of industrial equipment?

A. Ladder diagram.

B. Pictorial diagram.

C. Architectural elevation.

D. Site plan.

21. Which software is commonly used for electrical and technical drawing?

A. AutoCAD.

B. Microsoft Media Player.

C. Calculator.

D. Paint only.

22. Which component is commonly represented by the letter M in an electrical drawing?

A. Meter.

B. Motor.

C. Main switch.

D. Microphone.

23. What is the function of a distribution board?

A. To generate electrical energy.

B. To distribute electrical energy to different final circuits.

C. To measure temperature.

D. To store electrical energy.

24. Which type of drawing shows the location of switches, lamps and socket outlets on a building floor plan?

A. Block diagram.

B. Architectural electrical drawing.

C. Pictorial circuit diagram.

D. Ladder diagram.

25. What is the main purpose of a legend in an electrical drawing?

A. To indicate the cost of equipment.

B. To explain the symbols used in the drawing.

C. To show the weight of electrical components.

D. To show the colour of the building.

26. Which component is used to protect an electric motor against sustained overload?

A. Thermal overload relay.

B. Lamp.

C. Voltmeter.

D. Capacitor.

27. In a simple lighting circuit, what happens when the switch is opened?

A. The lamp becomes brighter.

B. The circuit is interrupted.

C. The current increases.

D. The supply voltage doubles.

28. Which of the following is an advantage of computer-aided electrical drawing?

A. It prevents all electrical faults.

B. It allows easy editing and storage of drawings.

C. It eliminates the need for technical knowledge.

D. It automatically makes every electrical installation safe.

29. Which fault occurs when the conducting path is broken?

A. Short circuit.

B. Overload.

C. Open circuit.

D. Earth fault.

30. Why should electrical diagrams be studied before installation work begins?

A. To increase the cost of the project.

B. To understand the arrangement and connections of components.

C. To avoid using electrical symbols.

D. To eliminate the need for protective devices.

SECTION B: STRUCTURED QUESTIONS (50 MARKS)

Instructions: Answer all questions. Show relevant examples and use appropriate electrical symbols where necessary.

QUESTION 1: Fundamentals of Electrical Diagrams (8 marks)

a) Define an electrical diagram. (2 marks)

b) State three reasons why electrical diagrams are important in electrical technology. (3 marks)

c) Identify three categories of professionals who use electrical drawings in their work. (3 marks)

QUESTION 2: Electrical Symbols (8 marks)

a) Define an electrical symbol. (2 marks)

b) State four electrical components commonly represented using standard electrical symbols. (2 marks)

c) Explain the functions of the following electrical components:

i. Fuse. (1 mark)

ii. Circuit breaker. (1 mark)

iii. Resistor. (1 mark)

iv. Capacitor. (1 mark)

QUESTION 3: Types of Electrical Drawings (8 marks)

a) Define a schematic diagram. (2 marks)

b) State three differences between a schematic diagram and a wiring diagram. (3 marks)

c) Explain three applications of single-line diagrams in electrical technology. (3 marks)

QUESTION 4: Electrical Circuit Diagrams (8 marks)

a) State four components required when constructing a simple lighting circuit. (4 marks)

b) Explain the operation of a simple lighting circuit controlled by a one-way switch. (2 marks)

c) State two reasons why standard electrical symbols should be used when drawing electrical circuits. (2 marks)

QUESTION 5: Architectural Electrical Drawings (9 marks)

a) Define an architectural electrical drawing. (2 marks)

b) Identify four electrical accessories that may be represented on an architectural electrical floor plan. (4 marks)

c) Explain three reasons why electrical drawings are important during the construction of a classroom block in a Kenyan school. (3 marks)

QUESTION 6: Interpretation and Application of Electrical Drawings (9 marks)

A technician is required to install electrical equipment in a small food-processing workshop in Kenya.

The workshop contains lighting points, socket outlets, a distribution board, an electric motor and a control panel.

a) Identify three types of electrical drawings that may be required for the installation. (3 marks)

b) Explain the purpose of each of the following drawings:

i. Wiring diagram. (1 mark)

ii. Single-line diagram. (1 mark)

iii. Ladder diagram. (1 mark)

c) State three safety precautions that should be observed when using electrical drawings during installation work. (3 marks)

1.3.23 SUGGESTED ANSWERS AND MARKING GUIDE

SECTION A: MULTIPLE-CHOICE ANSWERS

Question	Answer	Question	Answer	Question	Answer
1	B	11	B	21	A
2	B	12	C	22	B
3	C	13	B	23	B
4	A	14	B	24	B
5	B	15	A	25	B
6	C	16	B	26	A
7	B	17	B	27	B
8	C	18	C	28	B
9	A	19	C	29	C
10	B	20	A	30	B

SECTION B: SUGGESTED MARKING SCHEME

QUESTION 1 (8 marks)

a) An electrical diagram is a graphical representation of an electrical circuit or installation using standard symbols, lines and labels. (2)

b) Any three:

- Facilitates communication.
- Guides electrical installation.
- Assists fault finding.
- Supports maintenance.
- Helps estimate materials.
- Promotes safety. (3)

c) Any three:

- Electrical engineers.
- Electricians.
- Electrical technicians.
- Electrical contractors.
- Electrical inspectors.
- Electrical designers. (3)

QUESTION 2 (8 marks)

a) An electrical symbol is a standard graphical sign representing an electrical or electronic component in a technical drawing. (2)

b) Any four:

- Switch.
- Lamp.
- Fuse.
- Resistor.
- Capacitor.
- Motor.
- Ammeter.
- Voltmeter. (2)

c)

i. Fuse: Protects a circuit against excessive current by melting its element. (1)

ii. Circuit breaker: Automatically interrupts a circuit under specified fault conditions. (1)

iii. Resistor: Opposes or limits the flow of electric current. (1)

iv. Capacitor: Stores electrical energy in an electric field. (1)

QUESTION 3 (8 marks)

a) A schematic diagram is a graphical representation of an electrical circuit using standard symbols to show the functional connections between components. (2)

b) Any three differences:

Schematic diagram	**Wiring diagram**

Shows functional relationships.	Shows actual electrical connections.
Uses simplified symbols.	Shows terminals and conductors.
Does not necessarily show physical arrangement.	Provides physical connection information.

(3)

c) Any three:

- Represents electrical power distribution systems.
- Shows connections between transformers and circuit breakers.
- Assists in planning industrial electrical installations.
- Helps analyse power distribution systems.
- Assists in identifying protective devices. (3)

QUESTION 4 (8 marks)

a) Any four:

- Power source.
- Protective device.
- One-way switch.
- Lamp.
- Connecting conductors. (4)

b)

- When the switch is closed, the circuit is completed and current flows through the lamp, causing it to illuminate.
- When the switch is opened, the circuit is interrupted and the lamp goes off. (2)

c) Any two:

- Promote standardisation.
- Improve communication.
- Reduce errors.
- Make drawings easier to interpret.
- Simplify circuit representation. (2)

QUESTION 5 (9 marks)

a) An architectural electrical drawing is a technical drawing showing the position and arrangement of electrical accessories and installations on a building plan. (2)

b) Any four:

- Lighting points.
- Switches.
- Socket outlets.

- Distribution boards.
- Ceiling fans.
- Smoke detectors.
- Emergency lights.
- Data outlets. (4)

c) Any three:

- Guides the installation of electrical accessories.
- Helps determine the position of electrical equipment.
- Assists in estimating materials.
- Helps coordinate electrical work with construction activities.
- Supports inspection and maintenance.
- Minimises installation errors. (3)

QUESTION 6 (9 marks)

a) Any three:

- Wiring diagram.
- Single-line diagram.
- Schematic diagram.
- Ladder diagram.
- Architectural electrical layout. (3)

b)

i. Wiring diagram: Shows actual electrical connections between components and their terminals. (1)

ii. Single-line diagram: Represents the main components and connections of a power distribution system in simplified form. (1)

iii. Ladder diagram: Represents the control logic of an electrical system using rails and rungs. (1)

c) Any three:

- Isolate the electrical supply before working on the installation.
- Verify that the circuit is de-energised using an appropriate tester.
- Use appropriate personal protective equipment.
- Follow the correct electrical drawing.
- Use suitable protective devices.
- Ensure proper earthing and bonding.
- Work under competent supervision.
- Test the installation before energising. (3)

1.3.24 TEACHER'S GUIDANCE AND RECOMMENDED LEARNING RESOURCES

Recommended teaching and learning resources

1. Electrical symbol charts.
2. Domestic electrical installation diagrams.
3. Industrial wiring diagrams.
4. Electrical circuit components.
5. Distribution boards.
6. Switches and socket outlets.
7. Fuses and circuit breakers.
8. Electrical measuring instruments.
9. Drawing boards and drawing instruments.
10. Computers and CAD software.
11. Projectors and digital displays.
12. Low-voltage electrical training kits.

Recommended teaching approaches

- Demonstration.
- Guided discovery.
- Group discussions.
- Practical drawing exercises.
- Project-based learning.
- Peer assessment.
- Digital research.
- Site visits to electrical installation projects.

STRAND 2.0: ELECTRICAL MACHINES

SUB-STRAND 2.1: MEASURING INSTRUMENTS

INTRODUCTION TO THE SUB-STRAND

Electrical measuring instruments are essential tools used in electrical technology to determine the values of different electrical quantities such as current, voltage, resistance, power and energy.

An electrical technician must understand how to select, connect, operate, read and maintain measuring instruments when carrying out electrical installation, testing, troubleshooting and maintenance activities.

In Kenya, electrical measuring instruments are commonly used by:

- Electrical installation technicians.
- Electrical engineers.
- Electrical contractors.
- Power distribution technicians.
- Electrical maintenance personnel.
- Electronics technicians.

- Solar photovoltaic technicians.
- Electrical workshop instructors and learners.

For example, an electrician installing a solar photovoltaic system in a school may use a digital multimeter to measure the DC voltage of a solar panel, check battery voltage and test the continuity of electrical conductors.

Similarly, technicians working on electrical distribution systems use instruments to measure voltage, current, resistance and other electrical quantities to establish whether equipment is operating correctly.

This sub-strand introduces learners to coil-based measuring instruments, their operating principles, range extension, calibration, error correction and the use of analogue and digital measuring instruments.

2.1.1 MEANING AND CONCEPT OF ELECTRICAL MEASURING INSTRUMENTS

Definition of an electrical measuring instrument

An **electrical measuring instrument** is a device used to determine the magnitude or value of an electrical quantity such as voltage, current, resistance, power, frequency or electrical energy.

The instrument provides a reading that enables an electrical technician to assess the performance and condition of an electrical circuit or equipment.

Explanation

Electrical measuring instruments operate using different physical and electrical principles to detect and indicate measured quantities.

Some instruments use the movement of a coil in a magnetic field to produce pointer movement, while others use electronic circuits to process and display measurements digitally.

Measurements may be displayed through:

- A moving pointer on a graduated scale.
- A digital numerical display.
- A graphical representation.
- A recording system.

Examples of electrical measuring instruments

1. **Ammeter:** Measures electric current in amperes (A).
2. **Voltmeter:** Measures potential difference in volts (V).
3. **Ohmmeter:** Measures electrical resistance in ohms (Ω).
4. **Wattmeter:** Measures electrical power in watts (W).
5. **Energy meter:** Measures electrical energy consumed, commonly in kilowatt-hours (kWh).
6. **Frequency meter:** Measures the frequency of an alternating electrical supply in hertz (Hz).
7. **Multimeter:** Measures several electrical quantities, depending on its design.
8. **Clamp meter:** Measures current by sensing the magnetic field around a conductor without requiring the conductor to be disconnected.

9. **Insulation resistance tester:** Measures the resistance of electrical insulation using a specified test voltage.

10. **Power factor meter:** Measures the power factor of an AC electrical circuit.

2.1.2 IMPORTANCE OF ELECTRICAL MEASURING INSTRUMENTS

Electrical measuring instruments are important in electrical technology because they provide information about the condition and performance of electrical systems.

1. Testing electrical circuits
   - They help determine whether electrical circuits are operating correctly.
   - They are used to measure voltage, current and resistance.
   - They assist in checking electrical connections.

2. Fault diagnosis
   - They help identify open circuits.
   - They assist in detecting short circuits.
   - They help locate faulty electrical components.
   - They support troubleshooting of electrical installations.

3. Electrical installation
   - They help verify the supply voltage.
   - They assist in testing electrical connections.
   - They help establish whether an installation meets specified requirements.
   - They support testing before an installation is put into service.

4. Equipment maintenance
   - They help monitor the performance of electrical machines.
   - They identify abnormal operating conditions.
   - They assist in determining when equipment requires repair or replacement.
   - They help prevent equipment damage.

5. Electrical safety
   - They help identify dangerous voltages.
   - They assist in checking the continuity of protective conductors.
   - They help test insulation resistance.
   - They support verification of electrical installations.

6. Energy management
   - They help determine the amount of electrical energy consumed.
   - They assist in identifying energy wastage.
   - They help monitor electrical power usage.
   - They support energy conservation programmes.

7. Research and experimentation
   - They help learners investigate electrical principles.
   - They provide data for scientific experiments.
   - They assist in verifying theoretical calculations.
   - They help compare different electrical components.

8. Quality control
   - They help verify equipment specifications.

- They assist in checking manufacturing standards.
- They help ensure electrical products operate within their specified limits.

9. Calibration and accuracy

- They help verify the accuracy of other measuring devices.
- They are used in calibration laboratories.
- They assist in maintaining reliable measurement standards.

10. Renewable energy installations

In Kenya, electrical measuring instruments are important when installing and maintaining:

- Solar photovoltaic systems.
- Battery storage systems.
- Solar water pumping systems.
- Wind energy systems.
- Mini-grid installations.

2.1.3 CLASSIFICATION OF ELECTRICAL MEASURING INSTRUMENTS

Electrical measuring instruments can be classified according to their operating principle, display method, function and measurement method.

A. Classification according to operating principle

1. Moving coil instruments

These instruments operate through the interaction between a current-carrying coil and a magnetic field.

Examples:

- Permanent Magnet Moving Coil (PMMC) instruments.
- Galvanometers.
- Moving coil ammeters.
- Moving coil voltmeters.

2. Moving iron instruments

These instruments operate through the movement of a soft iron element in a magnetic field produced by an electrical current.

Examples:

- Moving iron ammeters.
- Moving iron voltmeters.

3. Electrodynamometer instruments

These instruments operate through the interaction of magnetic fields produced by fixed and moving coils.

Examples:

- Electrodynamometer ammeters.
- Electrodynamometer voltmeters.
- Dynamometer-type wattmeters.

4. Induction-type instruments

These instruments operate through electromagnetic induction.

Examples:

- Induction energy meters.
- Induction-type measuring instruments.

5. Electrostatic instruments

These instruments operate through the force of attraction or repulsion between electrically charged plates.

They are particularly useful for measuring high voltages.

6. Digital electronic instruments

These instruments use electronic circuits to process measured electrical quantities and display the results numerically.

Examples:

- Digital multimeters.
- Digital voltmeters.
- Digital ammeters.
- Digital clamp meters.

B. Classification according to display method

1. Analogue measuring instruments

These instruments display measurements using a pointer that moves over a graduated scale.

Example: An analogue moving coil ammeter.

2. Digital measuring instruments

These instruments display measurements as numerical values on a digital screen.

Example: A digital multimeter.

C. Classification according to measurement method

1. Direct measuring instruments

These instruments provide a reading of the measured quantity directly from their scale or display.

Examples:

- Ammeter.
- Voltmeter.
- Ohmmeter.
- Digital multimeter.

2. Indirect measuring instruments

These instruments determine an electrical quantity through measurements of other related quantities and mathematical calculations.

Example:

Electrical power in a DC circuit can be calculated using:

$$P = VI$$

Where:

- P = electrical power in watts.
- V = voltage in volts.
- I = current in amperes.

If a circuit has a voltage of 12 V and current of 2 A:

$$P = 12 \times 2 = 24W$$

Therefore, the electrical power is 24 W.

2.1.4 COIL-BASED MEASURING INSTRUMENTS

Definition

A coil-based measuring instrument is an electrical measuring device that uses the interaction between a current-carrying coil and a magnetic field to produce a mechanical movement that indicates the measured electrical quantity.

The movement may be displayed by a pointer moving over a graduated scale.

Principle of operation

Many coil-based instruments operate on the principle of electromagnetic effects.

When electric current flows through a coil placed in a magnetic field, a force acts on the coil conductors.

This force produces a turning effect known as torque.

The torque causes the coil to rotate, resulting in the movement of a pointer over a calibrated scale.

The amount of pointer movement depends on the magnitude of the current flowing through the coil and the design of the instrument.

Main types of coil-based measuring instruments

11. Permanent Magnet Moving Coil (PMMC) instruments.
12. Moving iron instruments.
13. Electrodynamometer instruments.

The PMMC instrument is particularly important when studying the conversion of galvanometers into ammeters and voltmeters.

2.1.5 PERMANENT MAGNET MOVING COIL (PMMC) INSTRUMENT

Definition

A Permanent Magnet Moving Coil (PMMC) instrument is an electrical measuring instrument in which a light rectangular coil rotates within the magnetic field of a permanent magnet when electric current passes through it.

The movement of the coil is transmitted to a pointer, which indicates the measured value on a graduated scale.

PMMC instruments are commonly used for measuring direct current (DC) and direct voltage (DC voltage).

Principle of operation of a PMMC instrument

The PMMC instrument works on the principle that a current-carrying conductor placed in a magnetic field experiences a mechanical force.

When current flows through the moving coil:

14. The coil produces its own magnetic field.
15. The permanent magnet provides an external magnetic field.
16. The two magnetic fields interact.
17. Forces act on the opposite sides of the coil.
18. These forces produce a turning effect or deflecting torque.
19. The coil rotates against the controlling force provided by the springs.
20. The pointer attached to the moving system moves across the graduated scale.
21. The pointer stops when the deflecting torque balances the controlling torque.

The final pointer position indicates the measured current or voltage.

Main parts of a PMMC instrument

Part	Description and function
Permanent magnet	Produces the magnetic field required for operation.
Pole pieces	Shape and concentrate the magnetic field.
Soft iron core	Produces a strong radial magnetic field and improves sensitivity.
Moving coil	Carries the current being measured and experiences a turning force.
Aluminium former	Supports the coil and contributes to eddy-current damping.
Control springs	Provide controlling torque and conduct current to and from the coil.
Spindle	Supports the moving system and allows rotation.
Pointer	Indicates the measured value on the scale.
Graduated scale	Provides the numerical measurement markings.
Bearings or pivots	Support the moving system and allow smooth movement.
Counterweights	Help balance the moving system where provided.
Damping arrangement	Reduces oscillation and enables the pointer to settle quickly.

Detailed explanation of the components

1. Permanent magnet

- Produces a strong magnetic field.
- Provides the magnetic flux required for the operation of the instrument.
- Is usually made from a suitable permanent magnetic material.
- Ensures that the moving coil experiences a magnetic force.

2. Pole pieces

- Are shaped magnetic components attached to the permanent magnet.
- Direct the magnetic flux through the moving coil.
- Help produce a radial magnetic field.
- Improve the performance and sensitivity of the instrument.

3. Soft iron core

- Is positioned inside the moving coil.
- Concentrates magnetic flux.
- Helps produce a uniform radial magnetic field.
- Improves the linearity of the instrument scale.

4. Moving coil

- Consists of fine insulated copper wire wound into a rectangular shape.
- Is mounted on a light supporting former.
- Carries the current being measured.
- Rotates due to the interaction between its magnetic field and that of the permanent magnet.

5. Control springs

- Are usually made from a suitable conductive spring material.
- Provide the controlling torque.
- Help return the pointer to zero when the measured current is removed.
- Also provide electrical connections to the moving coil.

6. Pointer

- Is attached to the moving system.
- Moves over the graduated scale.
- Indicates the magnitude of the measured quantity.

7. Damping arrangement

- Reduces unwanted oscillations of the pointer.
- Enables the pointer to settle quickly.
- Improves the readability of measurements.

Torque equation of a PMMC instrument

The deflecting torque produced in a PMMC instrument is given by:

$$T_d = NBAI$$

Where:

- T_d = deflecting torque (Nm).
- N = number of turns of the coil.
- B = magnetic flux density (T).
- A = area of the coil (m^2).
- I = current through the coil (A).

The controlling torque produced by the springs is:

$$T_c = k\theta$$

Where:

- T_c = controlling torque.
- k = spring constant.
- θ = angle of deflection in radians.

At equilibrium:

$$T_d = T_c$$

Therefore:

$$NBAI = k\theta$$

Rearranging:

$$\theta = \frac{NBA}{k} I$$

This shows that the angle of deflection is directly proportional to the current flowing through the coil.

$$\boxed{\theta \propto I}$$

Important conclusion: A PMMC instrument has a uniform or linear scale because equal increases in current produce equal increases in pointer deflection, under normal operating conditions.

Working operation of a PMMC instrument

The operation takes place as follows:

22. The instrument is connected to the electrical circuit.
23. Current flows through the moving coil.
24. The coil experiences forces due to the magnetic field.
25. The forces create a deflecting torque.
26. The coil rotates together with the pointer.
27. The control springs resist the rotation.
28. The pointer moves until the deflecting and controlling torques are equal.
29. The reading is taken from the graduated scale.

Advantages of PMMC instruments

30. High accuracy.
31. High sensitivity.
32. Uniform and linear scale.
33. Low power consumption.
34. Good damping characteristics.
35. High torque-to-weight ratio.
36. Easy reading of measurements.
37. Suitable for measuring small DC currents.
38. Good repeatability when properly maintained.
39. Can be converted into ammeters and voltmeters using suitable shunts and multipliers.

Disadvantages of PMMC instruments

40. Generally suitable for DC measurements only.
41. Relatively expensive compared with some simple instruments.
42. Can be affected by temperature changes.
43. Permanent magnets may lose strength with ageing or unsuitable conditions.
44. Delicate moving parts may be damaged by mechanical shock.
45. Overloading may damage the moving coil.

46. Requires correct polarity when connected to DC circuits.

Applications of PMMC instruments

- DC ammeters.
- DC voltmeters.
- Galvanometers.
- Laboratory measuring instruments.
- Battery testing equipment.
- Electronic testing equipment.
- Educational electrical training kits.

2.1.6 GALVANOMETER

Definition

A galvanometer is a sensitive electrical measuring instrument used to detect and measure small electric currents.

A moving coil galvanometer is based on the PMMC operating principle.

It detects the presence, direction and small magnitude of direct current.

Main characteristics of a galvanometer

47. Has a sensitive moving coil.
48. Detects small currents.
49. Has a pointer or another indicating arrangement.
50. Usually has a centre-zero scale in sensitive laboratory designs.
51. Has a relatively high internal resistance compared with a shunt-connected ammeter.
52. Can be converted into an ammeter or voltmeter using suitable external resistors.

Functions of a galvanometer

- Detects small electric currents.
- Indicates the direction of current.
- Measures small DC currents within its rated range.
- Detects current in bridge circuits.
- Assists in electrical experiments.
- Forms the basic movement of some analogue measuring instruments.

Important terms used in galvanometers

1. Full-scale deflection current (Ig)

This is the current required to move the pointer to the maximum marking on the galvanometer scale.

2. Galvanometer resistance (Rg)

This is the internal resistance of the galvanometer coil.

3. Sensitivity

Sensitivity refers to the ability of an instrument to respond to small changes in the measured quantity.

4. Figure of merit

The figure of merit of a galvanometer is the current required to produce one division of pointer deflection.

$$K = \frac{I_g}{n}$$

Where:

- K = figure of merit in A/division.
- I_g = current producing full-scale deflection.
- n = number of scale divisions.

Example

A galvanometer requires 0.002 A to produce 100 divisions of deflection. Determine its figure of merit.

Solution:

$$K = \frac{0.002}{100}$$

Therefore, the figure of merit is:

2.1.7 MOVING IRON (MI) INSTRUMENTS

Definition

A moving iron instrument is an electrical measuring instrument that operates through the attraction or repulsion of a soft iron element in the magnetic field produced by current flowing through a fixed coil.

It is commonly used to measure both alternating current (AC) and direct current (DC).

Principle of operation

A current flowing through a fixed coil produces a magnetic field.

The magnetic field magnetises a soft iron element placed inside or near the coil.

The iron element experiences a force that causes the moving system and pointer to deflect.

The magnitude of the deflection depends on the strength of the magnetic field and therefore on the current flowing through the coil.

For a simple moving iron instrument, the deflecting torque is approximately proportional to the square of current:

$$T_d \propto I^2$$

This explains why a moving iron instrument can measure both AC and DC.

For AC, the average torque depends on the mean square of the current over a cycle.

Types of moving iron instruments

1. Attraction-type moving iron instrument

In this instrument:

- A soft iron piece is positioned near or inside a fixed coil.
- Current flows through the coil.

- The magnetic field magnetises the iron piece.
- The iron is attracted towards the region of stronger magnetic field.
- The pointer moves along the scale.

2. Repulsion-type moving iron instrument

In this instrument:

- Two soft iron vanes are positioned inside a fixed coil.
- One vane is fixed while the other is movable.
- Current flowing through the coil magnetises both vanes.
- Both vanes acquire similar magnetic polarity.
- The vanes repel each other.
- The movable vane causes the pointer to deflect.

Main parts of a moving iron instrument

1. Fixed coil.
2. Soft iron vane.
3. Moving spindle.
4. Pointer.
5. Graduated scale.
6. Control spring.
7. Air-friction damping system.
8. Bearings or pivots.
9. Adjusting mechanism.

Advantages of moving iron instruments

1. Can measure both AC and DC.
2. Have a relatively simple construction.
3. Are generally robust.
4. Can withstand certain temporary overloads better than delicate PMMC movements, depending on design.
5. Are suitable for industrial applications.
6. Are relatively economical.
7. Can be used as ammeters and voltmeters.

Disadvantages

8. Have a non-uniform scale.
9. Generally have lower accuracy than good PMMC instruments on DC.
10. May be affected by stray magnetic fields.
11. Consume more power than many PMMC instruments.
12. May be affected by frequency changes when measuring AC.
13. May have hysteresis errors due to the iron parts.
14. Have lower sensitivity than many PMMC instruments.

Applications

- AC ammeters.
- AC voltmeters.
- DC ammeters.
- DC voltmeters.

- Industrial electrical panels.
- Electrical distribution boards.
- Laboratory measuring equipment.

2.1.8 ELECTRODYNAMOMETER INSTRUMENTS

Definition

An electrodynamometer instrument is an electrical measuring instrument that operates through the interaction of magnetic fields produced by fixed coils and a moving coil.

It can be used to measure AC and DC electrical quantities.

Principle of operation

1. Current flows through the fixed coil.
2. The fixed coil produces a magnetic field.
3. Current also flows through the moving coil.
4. The moving coil produces another magnetic field.
5. The interaction of the two magnetic fields produces a turning torque.
6. The moving coil rotates.
7. The pointer indicates the measured value.
8. The movement stops when the deflecting torque balances the controlling torque.

Main components

- Fixed coils.
- Moving coil.
- Control springs.
- Spindle.
- Pointer.
- Graduated scale.
- Damping system.
- Bearings.

Applications

- AC and DC ammeters.
- AC and DC voltmeters.
- Wattmeters.
- Laboratory electrical measurements.
- Power measurement in electrical installations.

Advantages

1. Can measure AC and DC.
2. Can provide accurate power measurements.
3. Does not depend on a permanent magnet.
4. Suitable for precision laboratory measurements.

Disadvantages

1. Relatively expensive.
2. More sensitive to external magnetic fields.
3. Has a relatively low operating torque.
4. May consume more power than some other instrument types.

5. Requires careful handling and calibration.

2.1.9 COMPARISON OF PMMC, MOVING IRON AND ELECTRODYNAMOMETER INSTRUMENTS

Feature	PMMC	Moving iron	Electrodynamometer
Operating principle	Moving coil in permanent magnetic field	Magnetised iron movement	Interaction of fixed and moving coil fields
Supply measured	DC	AC and DC	AC and DC
Scale	Uniform	Non-uniform	Depends on application
Accuracy	Generally high	Moderate	Can be high
Power consumption	Low	Relatively high	Relatively high
Damping	Usually eddy-current	Usually air friction	Commonly air friction
Main applications	DC ammeters and voltmeters	AC/DC ammeters and voltmeters	Wattmeters and precision meters
External magnetic field effects	Can be shielded	May be significant	May be significant

Important: PMMC instruments should not be connected directly to an AC supply for ordinary measurement because the alternating torque reverses direction and its average value is approximately zero. A suitable rectifier arrangement can be used to measure AC with a PMMC movement.

2.1.10 ANALOGUE MEASURING INSTRUMENTS

Definition

An analogue measuring instrument is a device that displays the measured electrical quantity through continuous movement of a pointer over a graduated scale.

Main features

1. Graduated scale.
2. Moving pointer.
3. Measuring mechanism.
4. Zero adjustment.
5. Range selector where applicable.
6. Input terminals.
7. Protective casing.

Advantages of analogue instruments

- They show continuous changes in measured values.
- They can make trends and fluctuations easy to observe.
- They do not normally require a battery for the indicating movement of a basic passive PMMC voltmeter or ammeter.
- They are useful for understanding the movement of electrical quantities.
- They are useful in electrical training laboratories.

Disadvantages

- Readings may be affected by parallax error.
- They may be less convenient to read than digital instruments.

- Mechanical movement can be damaged by shock.
- They may have limited measurement ranges.
- They require careful zero adjustment.

Reading an analogue scale

To read an analogue instrument correctly:

1. Identify the selected measurement range.
2. Identify the scale corresponding to that range.
3. Check the zero position.
4. Observe the pointer directly from the front.
5. Read the division indicated by the pointer.
6. Apply the correct scale factor where necessary.
7. Record the value together with its unit.

Example

An analogue ammeter has a 0–5 A scale with 50 equal divisions. The pointer is at division 30.

Determine the current.

Solution:

Value per division:

$$\frac{5}{50} = 0.1A$$

Current:

$$I = 30 \times 0.1$$

$$\boxed{I = 3A}$$

2.1.11 DIGITAL MEASURING INSTRUMENTS

Definition

A digital measuring instrument is an electronic instrument that measures an electrical quantity, processes the measured signal and displays the result numerically on a digital screen.

Principle of operation

Digital measuring instruments use electronic circuits to convert measured electrical signals into numerical values.

The general process is:

1. The electrical quantity is applied to the instrument input.
2. An appropriate internal circuit conditions the signal.
3. The signal is processed by an electronic measuring circuit.
4. An analogue-to-digital converter (ADC) converts an analogue signal into digital form.
5. The digital processing circuit determines the measurement value.
6. The result is displayed on the screen.

Main parts of a digital multimeter

Part	Function
LCD display	Displays the measurement reading.
Rotary selector	Selects the measurement function and range.
COM terminal	Common connection for the black test lead.
Voltage/resistance terminal	Used for voltage, resistance and certain other measurements.
Current terminal	Used for current measurements within its specified rating.
Red test lead	Connects the meter to the test point.
Black test lead	Provides the common reference connection.
Internal battery	Supplies power to the meter's electronic circuits.
Internal fuse	Protects designated current measurement circuits.
Electronic measuring circuit	Processes the measured electrical signal.

Functions of a digital multimeter

A digital multimeter can be used to measure:

1. AC voltage.
2. DC voltage.
3. AC current, depending on the model.
4. DC current.
5. Electrical resistance.
6. Continuity.
7. Diode forward voltage.
8. Capacitance, where provided.
9. Frequency, where provided.
10. Temperature, where provided.

Advantages of digital measuring instruments

1. Provide clear numerical readings.
2. Reduce parallax errors.
3. Often provide high accuracy.
4. Are easy to operate after proper training.
5. Can have automatic range selection.
6. Are compact and portable.
7. May include additional measurement functions.
8. Some models provide data storage.
9. May provide automatic polarity indication.
10. Can include overload indication.

Disadvantages

1. Require a power source for their electronic circuits.
2. Can be affected by electrical interference.
3. May display unstable readings when signals fluctuate.
4. Some models are expensive.
5. Electronic components may be damaged by incorrect connections.
6. Batteries require periodic replacement.

7. A digital reading may conceal rapid changes that an analogue pointer can reveal more intuitively.

2.1.12 COMPARISON BETWEEN ANALOGUE AND DIGITAL MEASURING INSTRUMENTS

Analogue instrument	Digital instrument
Uses a moving pointer.	Uses a numerical display.
Has a graduated scale.	Has an electronic display.
May experience parallax error.	Does not normally experience pointer parallax error.
Requires careful scale interpretation.	Displays numerical values directly.
Mechanical movement may be damaged by shock.	Electronic circuits may be damaged by electrical overload.
Can show continuous changes visually.	Updates readings at discrete intervals.
Basic passive versions may not need an internal battery.	Electronic measuring circuits normally require power.
May have lower input impedance in some designs.	Many digital voltmeters have high input impedance.

Practical comparison activity

A learner measures the DC voltage of a 12 V training battery using an analogue voltmeter and a digital multimeter.

The learner records both readings and compares:

- Ease of reading.
- Stability of the reading.
- Scale interpretation.
- Measurement resolution.
- Accuracy specifications of the instruments.

Important: A digital instrument is not automatically more accurate than every analogue instrument. Accuracy depends on instrument quality, calibration, resolution, operating conditions and the measurement range.

2.1.13 CONVERSION OF COIL-BASED INSTRUMENTS INTO AMMETERS

Definition of an ammeter

An ammeter is an electrical measuring instrument used to measure the magnitude of electric current flowing through an electrical circuit.

The SI unit of electric current is the ampere (A).

Characteristics of an ammeter

1. It is connected in series with the component or circuit whose current is being measured.
2. It has very low internal resistance.
3. It allows the circuit current to pass through it.
4. It is designed to cause minimum voltage drop in the circuit.
5. It is available in different current ranges.
6. It may be analogue or digital.

Why does an ammeter have low resistance?

An ammeter is connected in series with the circuit. Therefore, its resistance should be very small to avoid significantly changing the current being measured.

If an ammeter has a high resistance:

- It causes an excessive voltage drop.
- It reduces the current flowing through the circuit.
- It affects the accuracy of the measurement.
- It may interfere with the operation of the circuit.

Conversion of a galvanometer into an ammeter

A galvanometer is a sensitive instrument designed to measure small currents.

To convert it into an ammeter capable of measuring larger currents, a very low resistance called a **shunt resistor** is connected in parallel with the galvanometer.

Definition of a shunt resistor

A shunt resistor is a low-value resistance connected in parallel with a galvanometer to allow most of the current to bypass the galvanometer coil.

It enables the galvanometer to measure currents greater than its original full-scale deflection current.

Why is a shunt resistor used?

1. To extend the current measuring range.
2. To protect the delicate galvanometer coil.
3. To allow measurement of large currents.
4. To enable the instrument to measure different current ranges.
5. To reduce the current passing through the moving coil.

Principle of shunt connection

When a shunt resistor is connected in parallel with a galvanometer:

- The total current divides between the galvanometer and the shunt.
- A small portion passes through the galvanometer.
- The remaining current passes through the shunt.
- The voltage across the galvanometer equals the voltage across the shunt.

Therefore:

$$V_g = V_s$$

Using Ohm's law:

$$I_g R_g = I_s R_s$$

Where:

- I_g = galvanometer full-scale current.
- R_g = galvanometer resistance.
- I_s = shunt current.
- R_s = shunt resistance.

The total current is:

$$I = I_g + I_s$$

Therefore:

$$I_s = I - I_g$$

Substituting:

$$I_g R_g = (I - I_g) R_s$$

Hence, the shunt resistance is:

$$\boxed{R_s = \frac{I_g R_g}{I - I_g}}$$

Formula for shunt resistance

$$\boxed{R_s = \frac{I_g R_g}{I - I_g}}$$

This formula is used when converting a galvanometer into an ammeter with a specified maximum current range.

Worked example 1: Calculating shunt resistance

A galvanometer has an internal resistance of 50 Ω and a full-scale deflection current of 2 mA.

Calculate the shunt resistance required to convert it into an ammeter with a maximum range of 2 A.

Step 1: Identify the given information

$$R_g = 50\Omega$$

$$I_g = 2mA = 0.002A$$

$$I = 2A$$

Step 2: Write the formula

$$R_s = \frac{I_g R_g}{I - I_g}$$

Step 3: Substitute the values

$$R_s = \frac{0.002 \times 50}{2 - 0.002}$$

$$R_s = \frac{0.1}{1.998}$$

$$R_s = 0.05005\Omega$$

FINAL ANSWER

$$\boxed{R_s \approx 0.05\Omega}$$

Therefore, a shunt resistance of approximately 0.05 Ω is required.

Worked example 2: Determining the current range

A galvanometer has a resistance of 100 Ω and a full-scale current of 1 mA. It is connected in parallel with a shunt resistor of 0.1 Ω.

Determine the maximum current that can be measured.

Step 1: Given information

$$R_g = 100\Omega$$

$$I_g = 0.001A$$

$$R_s = 0.1\Omega$$

Step 2: Use the equal voltage principle

$$I_g R_g = I_s R_s$$

$$I_s = \frac{I_g R_g}{R_s}$$

Step 3: Substitute

$$I_s = \frac{0.001 \times 100}{0.1}$$

$$I_s = 1A$$

Step 4: Calculate the total current

$$I = I_g + I_s$$

$$I = 0.001 + 1$$

$$\boxed{I = 1.001A}$$

The maximum measurable current is 1.001 A.

2.1.14 CONVERSION OF COIL-BASED INSTRUMENTS INTO VOLTMETERS

Definition of a voltmeter

A voltmeter is an electrical measuring instrument used to measure the potential difference between two points in an electrical circuit.

The SI unit of voltage is the volt (V).

Characteristics of a voltmeter

1. It is connected in parallel across the component being measured.
2. It has very high internal resistance.
3. It draws very little current from the circuit.
4. It measures the potential difference between two points.
5. It is available in different voltage ranges.
6. It may be analogue or digital.

Why does a voltmeter have high resistance?

A voltmeter is connected in parallel with the component whose voltage is being measured.

It must have high resistance to draw very little current.

If a voltmeter has low resistance:

- It draws excessive current.
- It may affect the circuit voltage.
- It may cause incorrect measurements.
- It may overload the measuring instrument.

Conversion of a galvanometer into a voltmeter

A galvanometer can be converted into a voltmeter by connecting a high resistance called a **multiplier resistor** in series with the galvanometer coil.

Definition of a multiplier resistor

A multiplier resistor is a high-value resistance connected in series with a galvanometer to extend its voltage measuring range.

It limits the current flowing through the galvanometer to its full-scale deflection current.

Why is a multiplier resistor used?

1. To extend the voltage measuring range.
2. To limit the current through the galvanometer.
3. To protect the moving coil from excessive current.
4. To enable measurement of higher voltages.
5. To improve the suitability of the instrument for voltage measurement.

Principle of operation

When a multiplier resistor is connected in series with a galvanometer:

- The same current flows through both resistances.
- The total resistance increases.
- A large proportion of the applied voltage is dropped across the multiplier resistor.
- The current through the galvanometer remains within its rated full-scale value.

Using Ohm's law:

$$V = I_g(R_g + R_m)$$

Where:

- V = maximum voltage to be measured.
- I_g = full-scale galvanometer current.
- R_g = galvanometer resistance.
- R_m = multiplier resistance.

Rearranging:

$$\frac{V}{I_g} = R_g + R_m$$

Therefore:

$$\boxed{R_m = \frac{V}{I_g} - R_g}$$

Worked example 1: Calculating multiplier resistance

A galvanometer has an internal resistance of 100 Ω and a full-scale deflection current of 1 mA.

Calculate the multiplier resistance required to convert it into a voltmeter with a range of 100 V.

Step 1: Given information

$$R_g = 100\Omega$$

$$I_g = 1mA = 0.001A$$

$$V = 100V$$

Step 2: Write the formula

$$R_m = \frac{V}{I_g} - R_g$$

Step 3: Substitute

$$R_m = \frac{100}{0.001} - 100$$

$$R_m = 100000 - 100$$

$$R_m = 99900\Omega$$

FINAL ANSWER

$$\boxed{R_m = 99{,}900\Omega}$$

Or:

$$\boxed{R_m = 99.9k\Omega}$$

Therefore, a multiplier resistance of 99.9 kΩ is required.

Worked example 2: Determining voltmeter range

A galvanometer has a full-scale deflection current of 5 mA and internal resistance of 20 Ω. It is connected in series with a 980 Ω multiplier resistor.

Determine the maximum voltage range.

Step 1: Given information

$$I_g = 5mA = 0.005A$$

$$R_g = 20\Omega$$

$$R_m = 980\Omega$$

Step 2: Write the formula

$$V = I_g(R_g + R_m)$$

Step 3: Substitute

$$V = 0.005(20 + 980)$$

$$V = 0.005 \times 1000$$

$$\boxed{V = 5V}$$

The maximum voltage range is 5 V.

2.1.15 DIFFERENCES BETWEEN SHUNT AND MULTIPLIER RESISTORS

Shunt resistor	Multiplier resistor
Connected in parallel with the galvanometer.	Connected in series with the galvanometer.
Has very low resistance.	Has high resistance.
Used to convert a galvanometer into an ammeter.	Used to convert a galvanometer into a voltmeter.
Allows most current to bypass the coil.	Limits the current through the coil.
Extends the current range.	Extends the voltage range.
Carries the majority of the current being measured.	Carries the same current as the galvanometer.

Summary illustration

Ammeter conversion

Low resistance connected in parallel.

Voltmeter conversion

High resistance connected in series.

Important formula summary

Quantity	Formula
Shunt resistance	$R_s = \frac{I_g R_g}{I - I_g}$
Total current	$I = I_g + I_s$
Multiplier resistance	$R_m = \frac{V}{I_g} - R_g$
Voltmeter range	$V = I_g(R_g + R_m)$
Shunt current	$I_s = \frac{I_g R_g}{R_s}$

2.1.16 MULTIPLE-RANGE AMMETERS AND VOLTMETERS

A. Multiple-range ammeter

A multiple-range ammeter is an ammeter designed to measure different current ranges by using different shunt resistance arrangements.

For example, an ammeter may have:

- 0–1 A range.
- 0–5 A range.
- 0–10 A range.
- 0–20 A range.

Advantages:

1. Measures different current values.
2. Reduces the need for several separate ammeters.
3. Provides flexibility during electrical testing.

4. Helps protect the measuring movement when the correct range is selected.

B. Multiple-range voltmeter

A multiple-range voltmeter is designed to measure different voltage ranges using different series multiplier resistances.

For example:

- 0–10 V.
- 0–50 V.
- 0–100 V.
- 0–250 V.

Advantages:

1. Measures a wide range of voltages.
2. Reduces the number of separate instruments required.
3. Makes laboratory measurements more convenient.
4. Allows selection of a suitable range for different applications.

Rules for selecting measurement ranges

1. Estimate the expected value before selecting the range.
2. If the value is unknown, start with the highest suitable range.
3. Reduce the range gradually to obtain a clearer reading.
4. Do not exceed the instrument's rated maximum value.
5. Observe the instrument's category and voltage ratings.
6. Use the correct terminals.
7. Observe polarity when measuring DC using polarity-sensitive instruments.

2.1.17 ACCURACY, PRECISION, SENSITIVITY AND RESOLUTION

These are important concepts when selecting and using electrical measuring instruments.

A. Accuracy

Definition

Accuracy is the degree to which a measured value agrees with the true or accepted reference value.

An accurate instrument gives readings close to the actual value.

Example:

If the accepted voltage is 12.0 V and an instrument reads 11.98 V, the measurement is close to the reference value.

Factors affecting accuracy

- Calibration condition.
- Instrument quality.
- Temperature.
- Electrical interference.
- Incorrect range selection.
- Poor connection.
- Operator error.

B. Precision

Definition

Precision is the degree of agreement among repeated measurements taken under the same conditions.

An instrument is precise when repeated measurements produce similar results.

Example:

Measurements of 10.1 V, 10.1 V and 10.2 V show good repeatability.

C. Resolution

Definition

Resolution is the smallest change in a measured quantity that an instrument can detect or display.

Example:

A digital multimeter displaying 12.34 V has a resolution of 0.01 V on that selected range.

D. Sensitivity

Definition

Sensitivity is the amount of instrument response produced by a given change in the measured quantity.

For an analogue voltmeter, sensitivity may be expressed in ohms per volt (Ω/V).

E. Range

The range of an instrument is the minimum and maximum values that it can measure on a particular setting.

Example:

A voltmeter with a 0–100 V range can measure voltages from zero to 100 V within its specified operating conditions.

F. Repeatability

Repeatability is the ability of an instrument to provide similar readings when the same quantity is measured repeatedly under the same conditions.

Comparison of the terms

Term	Meaning
Accuracy	Closeness to the true value
Precision	Agreement between repeated measurements
Resolution	Smallest detectable or displayed change
Sensitivity	Response to changes in the measured quantity
Range	Minimum to maximum measurable value
Repeatability	Consistency of repeated measurements

2.1.18 ERRORS IN ELECTRICAL MEASUREMENTS

Definition of measurement error

Measurement error is the difference between the measured value and the true or accepted reference value of an electrical quantity.

Errors may arise from the measuring instrument, the measurement method, environmental conditions or the person taking the reading.

Formula for absolute error

$$\boxed{E_a = |V_m - V_t|}$$

Where:

- E_a = absolute error.
- V_m = measured value.
- V_t = true or accepted reference value.

Formula for percentage error

$$\boxed{E_p = \frac{|V_m - V_t|}{V_t} \times 100\%}$$

Worked example

A voltmeter measures a voltage of 48 V, while the accepted reference voltage is 50 V.

Calculate:

e) Absolute error.

f) Percentage error.

Solution

Given:

$$V_m = 48V$$

$$V_t = 50V$$

g) Absolute error:

$$E_a = |48 - 50|$$

$$\boxed{E_a = 2V}$$

b) Percentage error:

$$E_p = \frac{2}{50} \times 100$$

$$\boxed{E_p = 4\%}$$

Therefore, the absolute error is 2 V and the percentage error is 4%.

Types of measurement errors

1. Instrumental errors

These are errors caused by defects or imperfections in the measuring instrument.

Examples:

- Incorrect zero setting.
- Weak permanent magnet.
- Worn bearings.
- Damaged pointer.
- Incorrect calibration.
- Ageing components.

Correction methods:

- Calibrate the instrument.
- Adjust the zero setting.
- Replace damaged components.
- Maintain the instrument properly.
- Use a suitable measuring range.

2. Observational errors

These are errors caused by the person taking the measurement.

Examples:

- Reading the scale from an incorrect angle.
- Misinterpreting scale markings.
- Selecting the wrong range.
- Recording incorrect units.
- Making calculation mistakes.

Correction methods:

- Read the scale directly from the front.
- Use the correct scale.
- Check the selected range.
- Record measurements carefully.
- Repeat the measurement where necessary.

3. Environmental errors

These are errors caused by environmental conditions.

Examples:

- Temperature changes.
- External magnetic fields.
- Humidity.
- Vibration.
- Electrical interference.

Correction methods:

- Use instruments under specified environmental conditions.
- Shield instruments against unwanted magnetic fields where necessary.
- Avoid excessive vibration.
- Store instruments in suitable conditions.

- Use suitable instruments for the operating environment.

4. Random errors

These are unpredictable variations in readings that occur even when measurements are taken under apparently identical conditions.

Examples:

- Small fluctuations in supply voltage.
- Electrical noise.
- Slight variations in contact resistance.

Correction methods:

- Take repeated measurements.
- Calculate the average value.
- Improve the stability of the measurement conditions.
- Use appropriate filtering where necessary.

5. Systematic errors

These are errors that occur consistently in the same direction due to an identifiable cause.

Examples:

- A voltmeter that always reads 0.5 V too high.
- Incorrect calibration.
- A consistent zero offset.

Correction methods:

- Identify the cause.
- Calibrate the instrument against a suitable reference.
- Apply a justified correction.
- Replace faulty measuring equipment.

2.1.19 CALIBRATION OF ELECTRICAL MEASURING INSTRUMENTS

Definition

Calibration is the process of comparing the readings of a measuring instrument with those of a known reference standard under specified conditions to establish the measurement error or determine whether the instrument meets its required accuracy.

Calibration may also involve adjustment where the instrument is designed to permit adjustment.

Importance of calibration

1. Improves measurement reliability.
2. Helps identify instrument errors.
3. Supports accurate electrical testing.
4. Helps maintain quality standards.
5. Ensures readings are traceable to recognised measurement standards.
6. Helps identify instruments that require repair.
7. Improves confidence in measurement results.
8. Supports industrial quality control.

Equipment used in calibration

9. Reference digital multimeter.
10. Electrical calibrator.
11. Standard voltage source.
12. Standard current source.
13. Precision resistance standards.
14. Connecting leads.
15. Calibration records.
16. Temperature monitoring equipment where required.

General calibration procedure for an analogue coil-based instrument

Step 1: Inspect the instrument

- Check the physical condition.
- Examine the pointer.
- Check the terminals.
- Look for visible damage.

Step 2: Check the zero position

- Disconnect the instrument from the circuit.
- Place it in the correct operating position.
- Check whether the pointer rests at zero.
- Adjust the mechanical zero screw if the instrument has one and the manufacturer's instructions permit it.

Step 3: Select the correct range

Choose an appropriate measuring range.

Step 4: Connect the instrument to a reference source

Use a suitable calibrated reference source.

Step 5: Apply known values

Apply several known measurement values across the instrument's operating range.

Step 6: Record the readings

Compare the instrument readings with the reference values.

Step 7: Determine the errors

Calculate the difference between the indicated and reference values.

Step 8: Correct identified errors

Adjust the instrument where appropriate or arrange for repair.

Step 9: Repeat the test

Take further measurements to verify the results.

Step 10: Prepare a calibration record

Document:

- Instrument identification.

- Date of calibration.
- Reference equipment used.
- Applied values.
- Instrument readings.
- Errors identified.
- Corrections or adjustments made.
- Calibration outcome.

Important distinction: Zero adjustment and calibration

Zero adjustment	Calibration
Corrects the pointer's resting position.	Compares instrument readings against reference values.
Usually addresses zero offset.	Evaluates measurement performance across a range.
May be performed before use.	Performed at defined intervals or when required.
Does not establish overall accuracy.	Establishes errors and measurement traceability.

2.1.20 ERROR CORRECTION IN COIL-BASED MEASURING INSTRUMENTS

Error correction involves identifying and correcting errors that affect the accuracy of a coil-based measuring instrument.

A. Zero error

Definition: Zero error occurs when an instrument indicates a value other than zero when the measured quantity should be zero.

Types of zero error

1. Positive zero error: The pointer rests to the right of the zero mark.
2. Negative zero error: The pointer rests to the left of the zero mark.

Correction:

- Check the zero position before measurement.
- Use the mechanical zero adjustment screw where provided.
- If the zero error cannot be adjusted mechanically, determine the correction using a suitable reference method.
- Record the correction applied.

B. Parallax error

Definition: Parallax error is an observational error that occurs when an analogue scale is viewed from an angle rather than directly from the front.

Correction methods:

1. View the pointer directly from the front.
2. Position the eye perpendicular to the scale.
3. Use the mirror provided on some instruments.
4. Ensure the pointer is not being viewed from above or below.

C. Friction error

Friction error occurs when friction in the moving parts prevents the pointer from moving freely.

Causes:

- Worn bearings.
- Dust accumulation.
- Damaged pivots.
- Mechanical obstruction.

Correction:

- Clean the instrument appropriately.
- Service the bearings.
- Replace damaged mechanical components.
- Ensure the pointer moves freely.

D. Hysteresis error

Hysteresis error occurs when the instrument gives different readings depending on whether the measured quantity is increasing or decreasing.

It may occur in moving iron instruments due to magnetic properties of the iron components.

Correction:

- Use suitable magnetic materials.
- Maintain the instrument.
- Calibrate the instrument in both increasing and decreasing directions.
- Apply manufacturer-approved correction procedures.

E. Temperature error

Temperature error occurs when temperature changes affect the resistance of the coil or other instrument components.

Correction:

- Use suitable temperature compensation.
- Operate within the specified temperature range.
- Allow the instrument to stabilise.
- Recalibrate when required.

F. Magnetic interference error

This error occurs when external magnetic fields affect the magnetic field inside the instrument.

Correction:

- Use magnetic shielding where appropriate.
- Keep instruments away from strong external magnetic sources.
- Use instruments designed for the working environment.

Correction of measured readings

A correction is the value added algebraically to an indicated reading to compensate for an established measurement error.

$$\text{Corrected value} = \text{Indicated value} + \text{Correction}$$

Where:

$$\text{Correction} = \text{Reference value} - \text{Indicated value}$$

Worked example

An analogue ammeter indicates 4.8 A while a calibrated reference instrument indicates 5.0 A.

Determine the correction and corrected reading.

Solution:

$$\text{Correction} = 5.0 - 4.8$$

$$\boxed{+0.2A}$$

Corrected reading:

$$4.8 + 0.2 = 5.0A$$

Therefore, the corrected reading is 5.0 A.

2.1.21 SELECTION OF SUITABLE ELECTRICAL MEASURING INSTRUMENTS

Selecting the correct measuring instrument is essential for obtaining reliable readings and ensuring safety.

Factors to consider when selecting an instrument

1. Quantity to be measured

Determine whether the measurement involves:

- Current.
- Voltage.
- Resistance.
- Power.
- Energy.
- Frequency.
- Insulation resistance.

2. Type of electrical supply

Determine whether the circuit uses:

- Alternating current (AC).
- Direct current (DC).
- Both AC and DC.

3. Measurement range

Choose an instrument whose range covers the expected value.

4. Accuracy requirement

Use an instrument with suitable accuracy for the intended application.

5. Resolution

Select an instrument capable of displaying the required level of detail.

6. Internal resistance

- Ammeters should have very low resistance.
- Voltmeters should have very high resistance.

7. Safety rating

Consider:

- Maximum voltage.
- Measurement category.
- Current rating.
- Insulation condition.
- Input protection.

8. Environmental conditions

Consider:

- Temperature.
- Moisture.
- Dust.
- Vibration.
- Electromagnetic interference.

9. Portability

Handheld instruments are useful for fieldwork, while bench instruments are useful in laboratories.

10. Cost and availability

Select equipment that meets the technical requirements and is available within the project budget.

Appropriate instruments for different electrical quantities

Electrical quantity	Instrument	Unit
Current	Ammeter	Ampere (A)
Voltage	Voltmeter	Volt (V)
Resistance	Ohmmeter	Ohm (Ω)
Power	Wattmeter	Watt (W)
Energy	Energy meter	Kilowatt-hour (kWh)
Frequency	Frequency meter	Hertz (Hz)
Insulation resistance	Insulation resistance tester	Megaohm (MΩ)
Power factor	Power factor meter	No unit
Capacitance	Capacitance meter	Farad (F)
Temperature	Thermometer or suitable temperature meter	Degree Celsius (°C)

Examples of instrument selection in Kenyan electrical installations

Example 1: Measuring battery voltage

A technician installing a solar system in a school needs to measure the voltage of a 12 V battery.

Suitable instrument: Digital multimeter set to DC voltage.

Example 2: Measuring current in a motor circuit

A technician needs to measure the operating current of a motor without disconnecting the conductor.

Suitable instrument: A clamp meter with an appropriate AC or DC current function, depending on the motor circuit.

Example 3: Testing insulation resistance

An electrician needs to determine whether the insulation of an electrical cable is satisfactory.

Suitable instrument: Insulation resistance tester with the correct test voltage for the installation.

Example 4: Measuring electrical energy consumption

A school administrator needs to monitor electricity consumption.

Suitable instrument: Electrical energy meter.

Example 5: Measuring frequency

A technician needs to determine the frequency of an AC supply.

Suitable instrument: Frequency meter or a suitable digital multimeter with a frequency function and appropriate rating.

2.1.22 CONNECTING ELECTRICAL MEASURING INSTRUMENTS

Correct connection is essential for accurate measurements and personal safety.

A. Connecting an ammeter

An ammeter is connected in series with the component or circuit whose current is being measured.

Procedure:

1. Isolate the circuit before making connections.
2. Select a suitable current range.
3. Connect the ammeter in series.
4. Observe the correct polarity for DC.
5. Ensure the meter's terminals and leads are correctly rated.
6. Recheck the connections.
7. Energise the circuit under appropriate supervision.
8. Read and record the measurement.

Important: Never connect an ordinary ammeter directly across a voltage source. Its very low internal resistance can cause a dangerous short circuit.

B. Connecting a voltmeter

A voltmeter is connected in parallel across the component whose potential difference is being measured.

Procedure:

1. Select the correct AC or DC voltage function.
2. Select a suitable range.
3. Connect the voltmeter across the component.
4. Observe polarity for DC.

5. Confirm the connections.
6. Take the reading.
7. Record the result with the correct unit.

Important: A voltmeter should not be connected in series with the load in an ordinary voltage measurement.

C. Connecting an ohmmeter

An ohmmeter is used to measure electrical resistance.

Procedure:

1. Switch off and isolate the circuit.
2. Verify that the circuit is de-energised.
3. Discharge capacitors safely.
4. Select the resistance function.
5. Connect the test leads across the isolated component.
6. Read the resistance.
7. Record the result.

Important: Never measure resistance on an energised circuit.

D. Using a clamp meter

A clamp meter measures current by sensing the magnetic field produced by current flowing through a conductor.

Procedure:

1. Select the appropriate AC or DC current function.
2. Select a suitable range.
3. Open the clamp jaws.
4. Place the jaws around one conductor only.
5. Close the jaws fully.
6. Observe the reading.
7. Record the measured current.

If both line and neutral conductors are enclosed together, their magnetic fields normally cancel in a balanced circuit, producing an unsuitable current reading.

2.1.23 SAFE HANDLING AND STORAGE OF ELECTRICAL MEASURING INSTRUMENTS

Electrical measuring instruments are delicate and sometimes expensive equipment. They should be handled and stored properly to maintain accuracy and ensure safety.

Safe handling practices

1. Inspect the instrument before use.
2. Check the condition of test leads.
3. Select the correct measurement function.
4. Use the correct input terminals.
5. Begin with the highest suitable range where the value is unknown.
6. Observe the maximum voltage and current ratings.
7. Observe the instrument's measurement category.
8. Do not exceed the instrument's specified limits.

9. Keep instruments away from water and excessive moisture.
10. Avoid dropping or knocking instruments.
11. Do not use damaged test leads.
12. Follow the manufacturer's instructions.
13. Use appropriate personal protective equipment.
14. Isolate circuits before making or changing connections.
15. Verify the tester's operation using an appropriate proving unit before and after voltage testing where required by the safe isolation procedure.

Proper storage practices

1. Clean instruments after use.
2. Store them in protective cases.
3. Keep them in dry and dust-free places.
4. Remove batteries from instruments that will be stored for long periods if recommended by the manufacturer.
5. Avoid exposing instruments to excessive heat.
6. Keep test leads neatly arranged.
7. Store calibration certificates and records safely.
8. Keep instruments away from strong magnetic fields where relevant.
9. Protect instruments from mechanical shock.
10. Ensure that instruments are properly labelled and accounted for.

2.1.24 PRACTICAL APPLICATIONS OF MEASURING INSTRUMENTS IN KENYA

Electrical measuring instruments are used in many sectors of the Kenyan economy.

1. Domestic electrical installations

Used when:

- Testing household supply voltage.
- Checking socket outlets.
- Testing continuity.
- Identifying faulty appliances.
- Verifying electrical installations.

2. Schools and training institutions

Used in:

- Electrical technology workshops.
- Physics laboratories.
- Electronics training.
- Practical demonstrations.
- Electrical circuit experiments.

3. Solar photovoltaic installations

Used to:

- Measure solar panel voltage.
- Check battery voltage.
- Measure charging current.

- Test cable continuity.
- Diagnose faults in solar installations.

4. Industrial installations

Used to:

- Monitor motor current.
- Measure supply voltage.
- Check resistance.
- Test electrical control systems.
- Monitor electrical power.

5. Electricity distribution

Used by electrical technicians to:

- Check voltage levels.
- Measure current.
- Test transformers.
- Monitor electrical loads.
- Investigate supply problems.

6. Agricultural processing

Used in:

- Grain milling plants.
- Milk cooling installations.
- Irrigation pumping systems.
- Tea processing factories.
- Refrigeration systems.

7. Commercial buildings

Used to:

- Monitor electricity consumption.
- Test lighting circuits.
- Check electrical distribution systems.
- Inspect electrical equipment.

2.1.25 PRACTICAL COMPETENCY-BASED LEARNING ACTIVITIES

ACTIVITY 1: IDENTIFICATION OF ELECTRICAL MEASURING INSTRUMENTS

Learning task

Working in groups, learners examine available electrical measuring instruments.

Instructions:

1. Identify at least five measuring instruments.
2. State the electrical quantity measured by each instrument.
3. Identify the unit of measurement.
4. Explain how each instrument is connected.

5. Present findings to the class.

Expected competencies:

- Identification of instruments.
- Communication and collaboration.
- Critical thinking.
- Practical observation.

ACTIVITY 2: CONVERTING A GALVANOMETER INTO AN AMMETER

Learning task

Using a low-voltage educational circuit or simulation, demonstrate how a galvanometer can be converted into an ammeter.

Materials:

- Galvanometer or suitable training movement.
- Low-value shunt resistors.
- DC training power supply.
- Connecting leads.
- Digital multimeter.
- Drawing instruments.

Procedure:

1. Identify the galvanometer resistance.
2. Determine the full-scale deflection current.
3. Calculate the required shunt resistance.
4. Connect the shunt in parallel with the galvanometer.
5. Check the connections.
6. Compare the calculated and observed readings using an appropriate reference instrument.
7. Record the results.

Expected outcome: The learner should demonstrate understanding of current range extension using a shunt resistor.

ACTIVITY 3: CONVERTING A GALVANOMETER INTO A VOLTMETER

Learning task

Demonstrate how a galvanometer can be converted into a voltmeter using a multiplier resistor.

Procedure:

1. Determine the galvanometer resistance.
2. Establish the full-scale deflection current.
3. Select the required voltage range.
4. Calculate the multiplier resistance.
5. Connect the multiplier in series.
6. Verify the arrangement using a suitable low-voltage training circuit.
7. Record the results.

Expected outcome: The learner should be able to calculate and explain voltage range extension.

ACTIVITY 4: MEASURING ELECTRICAL QUANTITIES

Learning task

Use an analogue and digital multimeter to measure voltage, current and resistance in a low-voltage training circuit.

Procedure:

1. Identify the circuit components.
2. Select the appropriate instrument.
3. Connect the instrument correctly.
4. Take the measurements.
5. Record the readings.
6. Compare analogue and digital readings.
7. Discuss possible measurement errors.

Sample results table

Quantity	Analogue reading	Digital reading	Unit
Voltage			V
Current			A
Resistance			Ω

ACTIVITY 5: ERROR CORRECTION AND CALIBRATION

Learning task

Examine an analogue measuring instrument and determine whether its pointer is correctly aligned with the zero marking.

Procedure:

1. Inspect the instrument.
2. Check the pointer's resting position.
3. Identify any zero error.
4. Perform zero adjustment if permitted.
5. Compare readings against a suitable calibrated reference.
6. Record any remaining errors.
7. Discuss the importance of calibration.

2.1.27 IMPORTANT FORMULAE AND CALCULATIONS SUMMARY

The following formulae are important for Grade 11 Electricity Technology learners.

No.	Quantity	Formula
1	Ohm's law	$V = IR$

No.	Quantity	Formula
2	Electrical power	$P = VI$
3	PMMC deflecting torque	$T_d = NBAI$
4	Controlling torque	$T_c = k\theta$
5	PMMC equilibrium	$NBAI = k\theta$
6	Galvanometer figure of merit	$K = \frac{I_g}{n}$
7	Shunt resistance	$R_s = \frac{I_g R_g}{I - I_g}$
8	Total current	$I = I_g + I_s$
9	Multiplier resistance	$R_m = \frac{V}{I_g} - R_g$
10	Voltmeter range	$V = I_g(R_g + R_m)$
11	Absolute error	$E_a = \lvert V_m - V_t \rvert$
12	Percentage error	$E_p = \frac{\lvert V_m - V_t \rvert}{V_t} \times 100\%$
13	Corrected value	Indicated value + correction
14	Average reading	$\bar{x} = \frac{\text{Sum of readings}}{\text{Number of readings}}$

Additional worked examples

Example 1: Calculating galvanometer full-scale current

A galvanometer has a resistance of 200 Ω and a full-scale voltage drop of 0.2 V. Determine the full-scale current.

Using Ohm's law:

$$I_g = \frac{V_g}{R_g}$$

$$I_g = \frac{0.2}{200}$$

$$\boxed{I_g = 0.001A = 1mA}$$

Example 2: Calculating the shunt resistance

A galvanometer has a resistance of 80 Ω and a full-scale current of 5 mA. Calculate the shunt resistance required to convert it into a 5 A ammeter.

Given:

$$R_g = 80\Omega$$

$$I_g = 0.005A$$

$$I = 5A$$

Formula:

$$R_s = \frac{I_g R_g}{I - I_g}$$

Substituting:

$$R_s = \frac{0.005 \times 80}{5 - 0.005}$$

$$R_s = \frac{0.4}{4.995}$$

$$\boxed{R_s = 0.08008\Omega}$$

Example 3: Calculating multiplier resistance

A galvanometer has a resistance of 40 Ω and a full-scale current of 2 mA. Determine the multiplier resistance required for a 50 V voltmeter.

Given:

$$R_g = 40\Omega$$

$$I_g = 0.002A$$

$$V = 50V$$

Formula:

$$R_m = \frac{V}{I_g} - R_g$$

$$R_m = \frac{50}{0.002} - 40$$

$$R_m = 25000 - 40$$

$$\boxed{R_m = 24960\Omega}$$

Example 4: Calculating percentage error

A digital voltmeter reads 11.7 V while the reference value is 12 V. Determine the percentage error.

$$E_p = \frac{|11.7 - 12|}{12} \times 100$$

$$E_p = \frac{0.3}{12} \times 100$$

$$\boxed{E_p = 2.5\%}$$

2.1.28 SUMMARY OF THE SUB-STRAND

Concept	Main points
Measuring instrument	Device used to measure electrical quantities.
PMMC instrument	Uses a moving coil in a permanent magnetic field.
Galvanometer	Detects and measures small electrical currents.
Moving iron instrument	Uses the magnetic effect of current on soft iron.
Electrodynamometer	Uses interaction between fixed and moving coil magnetic fields.
Ammeter	Measures current and is connected in series.
Voltmeter	Measures voltage and is connected in parallel.

Concept	Main points
Shunt resistor	Low resistance connected in parallel to extend current range.
Multiplier resistor	High resistance connected in series to extend voltage range.
Analogue instrument	Displays readings using a moving pointer.
Digital instrument	Displays measurements numerically.
Accuracy	Closeness to the true value.
Precision	Agreement between repeated measurements.
Sensitivity	Response to changes in the measured quantity.
Resolution	Smallest detectable or displayed change.
Calibration	Comparison with a known reference standard.
Zero error	Instrument indicates a non-zero value when the measured quantity is zero.
Parallax error	Error caused by viewing a scale from an angle.
Clamp meter	Measures current by sensing the magnetic field around a conductor.
Insulation tester	Measures electrical insulation resistance.

2.1.29 REVISION EXERCISES AND ASSESSMENT

GRADE 11 ASSESSMENT

ELECTRICITY TECHNOLOGY

STRAND 2.0: ELECTRICAL MACHINES

SUB-STRAND 2.1: MEASURING INSTRUMENTS

SECTION A: 30 marks

SECTION B: 50 marks

TOTAL: 80 marks

SECTION A: MULTIPLE-CHOICE QUESTIONS (30 MARKS)

Instructions: Answer all questions. Choose the correct answer from the alternatives A, B, C and D. Each question carries 1 mark.

1. What is the main function of an electrical measuring instrument?

A. To generate electrical energy.

B. To determine the magnitude of electrical quantities.

C. To increase electrical resistance.

D. To store electrical energy.

2. Which instrument is used to measure electric current?

A. Voltmeter.

B. Ammeter.

C. Ohmmeter.

D. Wattmeter.

3. Which of the following instruments operates using a moving coil in a permanent magnetic field?

A. Moving iron instrument.

B. PMMC instrument.

C. Induction instrument.

D. Electrostatic instrument.

4. What is the main function of the permanent magnet in a PMMC instrument?

A. To produce a magnetic field.

B. To control the supply voltage.

C. To increase the coil resistance.

D. To measure electrical energy.

5. Which component of a PMMC instrument provides the controlling torque?

A. Pointer.

B. Permanent magnet.

C. Control spring.

D. Soft iron core.

6. The deflection of a PMMC instrument is directly proportional to:

A. Resistance.

B. Current.

C. Frequency.

D. Temperature.

7. Which instrument is commonly used to detect small electric currents?

A. Wattmeter.

B. Galvanometer.

C. Energy meter.

D. Frequency meter.

8. Which of the following instruments can measure both AC and DC?

A. Ordinary PMMC instrument.

B. Moving iron instrument.

C. DC galvanometer without rectification.

D. DC-only voltmeter.

9. What is the main function of a shunt resistor?

A. To increase voltage.

B. To extend the current measuring range.

C. To increase the coil's resistance.

D. To measure electrical power.

10. A shunt resistor is connected in which arrangement with a galvanometer?

A. Series.

B. Parallel.

C. Both terminals disconnected.

D. Across the power supply only.

11. Which type of resistor is used to convert a galvanometer into a voltmeter?

A. Shunt resistor.

B. Variable resistor.

C. Multiplier resistor.

D. Thermistor.

12. A multiplier resistor is connected in which arrangement?

A. Parallel.

B. Series.

C. Open circuit.

D. Across the galvanometer only.

13. Why should an ammeter have very low internal resistance?

A. To increase voltage drop.

B. To minimise its effect on circuit current.

C. To increase the power consumed.

D. To prevent current from flowing.

14. Why should a voltmeter have high internal resistance?

A. To draw very little current from the circuit.

B. To increase the circuit current.

C. To reduce the supply voltage.

D. To act as a fuse.

15. Which of the following is an advantage of a PMMC instrument?

A. It has a non-uniform scale.

B. It can directly measure AC without rectification.

C. It has a uniform scale.

D. It has very high power consumption.

16. What is the main function of the soft iron core in a PMMC instrument?

A. To produce a uniform radial magnetic field.

B. To increase the pointer weight.

C. To store electrical energy.

D. To reduce the supply frequency.

17. Which instrument uses two soft iron vanes in its repulsion-type arrangement?

A. PMMC instrument.

B. Moving iron instrument.

C. Digital voltmeter.

D. Energy meter.

18. Which of the following is a characteristic of a digital measuring instrument?

A. It uses only a mechanical pointer.

B. It displays readings numerically.

C. It cannot measure voltage.

D. It has no electronic components.

19. What is calibration?

A. Increasing the measuring range of an instrument.

B. Comparing an instrument with a known reference standard.

C. Cleaning an instrument only.

D. Replacing all internal components.

20. What is zero error?

A. An error occurring when the instrument reads zero at all times.

B. An error occurring when the instrument does not indicate zero when the measured quantity is zero.

C. An error caused by excessive voltage only.

D. An error caused by a short circuit.

21. Which error is caused by viewing an analogue scale from an angle?

A. Temperature error.

B. Friction error.

C. Parallax error.

D. Hysteresis error.

22. Which of the following instruments is suitable for measuring current without disconnecting a conductor?

A. Voltmeter.

B. Clamp meter.

C. Ohmmeter.

D. Galvanometer.

23. What is the SI unit of electrical resistance?

A. Volt.

B. Ampere.

C. Ohm.

D. Watt.

24. Which instrument is suitable for measuring insulation resistance?

A. Ammeter.

B. Voltmeter.

C. Insulation resistance tester.

D. Frequency meter.

25. An ammeter is connected in which arrangement with the load?

A. Parallel.

B. Series.

C. Across the supply only.

D. Open circuit.

26. A voltmeter is connected in which arrangement with the load?

A. Series.

B. Parallel.

C. In the protective earth conductor only.

D. In an open circuit.

27. Which of the following best describes accuracy?

A. Agreement between repeated measurements.

B. Closeness of a measured value to the true value.

C. Smallest value displayed.

D. Maximum instrument range.

28. A galvanometer has a full-scale current of 2 mA and 100 scale divisions. What is its figure of merit?

A. 0.2 mA/division.

B. 0.02 mA/division.

C. 2 mA/division.

D. 20 mA/division.

29. Which of the following is an appropriate procedure when measuring resistance?

A. Measure resistance while the circuit is energised.

B. Connect the ohmmeter across an isolated component.

C. Connect the ohmmeter in series with an AC supply.

D. Use the current terminal for every resistance measurement.

30. Why should electrical measuring instruments be stored in protective cases?

A. To increase their measuring range.

B. To protect them from dust, moisture and mechanical damage.

C. To increase their internal resistance.

D. To change their calibration values.

SECTION B: STRUCTURED QUESTIONS (50 MARKS)

Instructions: Answer all questions. Show all working in calculation questions. Use appropriate electrical diagrams where necessary.

QUESTION 1: FUNDAMENTALS OF MEASURING INSTRUMENTS (8 MARKS)

a) Define an electrical measuring instrument. (2 marks)

b) State three reasons why electrical measuring instruments are important in electrical technology. (3 marks)

c) Name three electrical quantities that can be measured using electrical measuring instruments. (3 marks)

QUESTION 2: COIL-BASED MEASURING INSTRUMENTS (8 MARKS)

a) Explain the principle of operation of a Permanent Magnet Moving Coil (PMMC) instrument. (3 marks)

b) State three components of a PMMC instrument and explain the function of each. (3 marks)

c) State two advantages of PMMC instruments. (2 marks)

QUESTION 3: CONVERSION OF MEASURING INSTRUMENTS (10 MARKS)

a) Explain how a galvanometer is converted into an ammeter. (2 marks)

b) A galvanometer has an internal resistance of 100 Ω and a full-scale deflection current of 2 mA. Calculate the shunt resistance required to convert it into an ammeter with a maximum range of 5 A. (4 marks)

c) Explain how a galvanometer is converted into a voltmeter. (2 marks)

d) State two differences between a shunt resistor and a multiplier resistor. (2 marks)

QUESTION 4: DIGITAL AND ANALOGUE MEASURING INSTRUMENTS (8 MARKS)

a) Define a digital measuring instrument. (2 marks)

b) State three differences between analogue and digital measuring instruments. (3 marks)

c) A galvanometer has a resistance of 50 Ω and a full-scale deflection current of 1 mA. Calculate the multiplier resistance required to convert it into a 20 V voltmeter. (3 marks)

QUESTION 5: CALIBRATION AND ERROR CORRECTION (8 MARKS)

a) Define calibration of an electrical measuring instrument. (2 marks)

b) State three types of errors that may occur when using electrical measuring instruments. (3 marks)

c) An ammeter indicates 9.6 A while a calibrated reference instrument indicates 10 A. Calculate the percentage error. (3 marks)

QUESTION 6: SELECTION, USE AND MAINTENANCE OF MEASURING INSTRUMENTS (8 MARKS)

a) Identify four electrical measuring instruments and state the quantity measured by each. (4 marks)

b) State two precautions to observe when using an electrical measuring instrument. (2 marks)

c) State two practices that should be followed when storing electrical measuring instruments. (2 marks)

2.1.30 ANSWERS AND MARKING SCHEME

SECTION A: MULTIPLE-CHOICE ANSWERS

Question	Answer	Question	Answer	Question	Answer
1	B	11	C	21	C
2	B	12	B	22	B
3	B	13	B	23	C
4	A	14	A	24	C
5	C	15	C	25	B
6	B	16	A	26	B
7	B	17	B	27	B
8	B	18	B	28	B
9	B	19	B	29	B
10	B	20	B	30	B

SECTION B: SUGGESTED MARKING SCHEME

QUESTION 1 (8 MARKS)

a) An electrical measuring instrument is a device used to determine the magnitude of an electrical quantity such as current, voltage or resistance. (2)

b) Any three:

- Testing electrical circuits.
- Identifying electrical faults.
- Maintaining electrical equipment.
- Promoting electrical safety.
- Monitoring energy consumption.
- Supporting electrical research and experiments. (3)

c) Any three:

- Current.
- Voltage.

- Resistance.
- Power.
- Frequency.
- Electrical energy. (3)

QUESTION 2 (8 MARKS)

a) Explanation of PMMC operation:

- Current flows through a moving coil placed in a permanent magnetic field. (1)
- The interaction between the magnetic fields produces a deflecting torque, causing the coil to rotate. (1)
- The pointer moves until the deflecting torque balances the controlling torque of the springs. (1)

b) Any three components and functions:

Component	Function
Permanent magnet	Produces a magnetic field.
Moving coil	Carries current and experiences a turning force.
Control spring	Provides controlling torque.
Pointer	Indicates the measured value.
Soft iron core	Produces a uniform radial magnetic field.
Damping arrangement	Reduces pointer oscillation.

c) Any two:

- High accuracy.
- High sensitivity.
- Uniform scale.
- Low power consumption.
- Good damping characteristics. (2)

QUESTION 3 (10 MARKS)

a) A galvanometer is converted into an ammeter by connecting a low resistance called a shunt resistor in parallel with the galvanometer. (2)

b) Given:

$$R_g = 100\Omega$$

$$I_g = 2mA = 0.002A$$

$$I = 5A$$

Formula:

$$R_s = \frac{I_g R_g}{I - I_g}$$

Substitution:

$$R_s = \frac{0.002 \times 100}{5 - 0.002}$$

$$R_s = \frac{0.2}{4.998}$$

$$\boxed{R_s = 0.04002\Omega}$$

(4 marks: formula 1, substitution 1, calculation 1, answer with unit 1.)

c) A galvanometer is converted into a voltmeter by connecting a high resistance called a multiplier resistor in series with the galvanometer. (2)

d) Any two differences:

Shunt resistor	Multiplier resistor
Connected in parallel.	Connected in series.
Has low resistance.	Has high resistance.
Extends current range.	Extends voltage range.

QUESTION 4 (8 MARKS)

a) A digital measuring instrument is an electronic device that measures an electrical quantity and displays the result numerically on a digital screen. (2)

b) Any three differences:

Analogue	Digital
Uses a moving pointer.	Uses a numerical display.
Uses a graduated scale.	Uses an electronic display.
May experience parallax error.	Does not normally experience pointer parallax error.
Requires careful scale reading.	Displays numerical readings directly.

c) Given:

$$R_g = 50\Omega$$

$$I_g = 1mA = 0.001A$$

$$V = 20V$$

Formula:

$$R_m = \frac{V}{I_g} - R_g$$

Substitution:

$$R_m = \frac{20}{0.001} - 50$$

$$R_m = 20000 - 50$$

$$\boxed{R_m = 19950\Omega}$$

(3 marks: formula 1, substitution 1, answer 1.)

QUESTION 5 (8 MARKS)

a) Calibration is the process of comparing an instrument's readings with a known reference standard under specified conditions to establish its measurement error. (2)

b) Any three:

- Zero error.
- Parallax error.
- Friction error.
- Temperature error.
- Hysteresis error.
- Random error.
- Instrumental error.
- Environmental error. (3)

c) Given:

$$V_m = 9.6A$$

$$V_t = 10A$$

Percentage error:

$$E_p = \frac{|V_m - V_t|}{V_t} \times 100$$

$$E_p = \frac{|9.6 - 10|}{10} \times 100$$

$$E_p = \frac{0.4}{10} \times 100$$

$$\boxed{E_p = 4\%}$$

(3 marks: formula 1, substitution 1, answer 1.)

QUESTION 6 (8 MARKS)

a) Any four:

Instrument	Quantity measured
Ammeter	Current
Voltmeter	Voltage
Ohmmeter	Resistance
Wattmeter	Power
Energy meter	Electrical energy
Frequency meter	Frequency
Insulation resistance tester	Insulation resistance
Power factor meter	Power factor

b) Any two:

- Select the correct measuring range.
- Use the correct terminals.
- Observe the instrument's ratings.
- Inspect test leads before use.
- Isolate the circuit before making connections.
- Use appropriate protective equipment.

- Connect the instrument correctly. (2)

c) Any two:

- Store instruments in protective cases.
- Keep them in dry and dust-free places.
- Protect them from mechanical shock.
- Store test leads neatly.
- Follow battery storage recommendations.
- Keep calibration records safely. (2)

2.1.31 TEACHER'S GUIDANCE AND RECOMMENDED LEARNING RESOURCES

Recommended teaching and learning resources

8. Analogue ammeters.
9. Analogue voltmeters.
10. Galvanometers.
11. Moving iron instruments.
12. Digital multimeters.
13. Clamp meters.
14. Insulation resistance testers.
15. Wattmeters.
16. Electrical energy meters.
17. Shunt resistors.
18. Multiplier resistors.
19. Low-voltage DC power supplies.
20. Connecting wires.
21. Electrical measuring instrument charts.
22. Computer simulations.
23. Digital projectors.
24. Electrical training boards.

Recommended teaching methods

- Demonstration.
- Guided discovery.
- Group discussions.
- Practical experiments.
- Project-based learning.
- Problem-solving activities.
- Peer teaching.
- Digital research.
- Field visits.
- Practical measurement exercises.

Recommended assessment methods

Assessment method	Competency assessed
Oral questioning	Understanding of operating principles
Written tests	Knowledge of measuring instruments
Practical demonstration	Correct use of instruments

Assessment method	Competency assessed
Calculation exercises	Shunt and multiplier calculations
Observation	Safety and equipment handling
Group project	Communication and collaboration
Portfolio	Practical progress and skill development
Peer assessment	Evaluation and improvement of measurement techniques

GRADE 11 ELECTRICITY TECHNOLOGY

STRAND 2.0: ELECTRICAL MACHINES

SUB-STRAND 2.2: DC GENERATORS

Introduction to the sub-strand

Electrical energy is required in homes, schools, hospitals, industries, farms and commercial establishments. In Kenya, electricity is supplied mainly through the national grid, but generators are also used in places where grid power is unavailable, unreliable or insufficient. Examples include standby generators in hospitals, generators on construction sites, and small generators used in workshops and remote facilities.

A **DC generator** is an electrical machine that converts mechanical energy into direct-current (DC) electrical energy through electromagnetic induction.

In this sub-strand, learners explore how DC generators operate, identify their components, investigate the characteristics of different types, calculate generated electromotive force (EMF), select suitable generators for particular applications and practise safe operation and maintenance.

2.2.4 Meaning and basic concepts of a DC generator

A. Definition of a DC generator

A **direct-current generator (DC generator)** is a rotating electrical machine that converts mechanical energy supplied by a prime mover into direct-current electrical energy by electromagnetic induction.

A prime mover is a machine or device that supplies mechanical power to rotate the generator. Examples include:

- A diesel engine.
- A petrol engine.
- A steam turbine.
- A water turbine.
- An electric motor used in a laboratory demonstration.
- A wind turbine coupled to a suitable mechanical drive.

Examples of DC generator applications:

1. Charging batteries in specialised installations.
2. Supplying DC power in workshops and laboratories.
3. Supplying excitation current to alternators in some power stations.
4. Electroplating and electrolysis processes.
5. DC welding applications using suitable generator sets.
6. Supplying DC power in some older industrial installations.

B. Electrical energy and mechanical energy

A DC generator operates through the conversion of energy.

- **Mechanical energy:** Energy supplied by the rotating shaft.
- **Magnetic energy:** Magnetic field established by permanent magnets or field windings.
- **Electrical energy:** Energy produced when conductors cut magnetic flux.

The energy conversion can be represented as:

Mechanical energy → DC electrical energy

The generator does not create energy. It converts mechanical energy into electrical energy, with some energy lost through heat, friction, magnetic effects and other losses.

C. Difference between a DC generator and a DC motor

Although a DC generator and a DC motor may have similar construction, their functions are different.

DC generator	DC motor
Converts mechanical energy into electrical energy.	Converts electrical energy into mechanical energy.
Requires a prime mover to rotate its shaft.	Requires electrical supply to produce rotation.
Produces an induced EMF at its terminals.	Develops back EMF as its armature rotates.
Operates according to electromagnetic induction.	Operates according to the motor principle.
Used to supply electrical power.	Used to drive mechanical loads.

Important: A DC machine can operate as either a generator or a motor depending on how energy is supplied and used.

2.2.5 Principle of operation of a DC generator

A. Electromagnetic induction

A DC generator operates on the principle of **electromagnetic induction**.

Electromagnetic induction is the production of an electromotive force (EMF) in a conductor when it cuts magnetic flux or when the magnetic flux linking the conductor changes.

When a conductor moves across a magnetic field, an EMF is induced in it. If the conductor forms part of a closed circuit, an electric current flows.

The principle is associated with Faraday's law of electromagnetic induction.

B. Conditions necessary for electromagnetic induction

For an EMF to be induced in a conductor:

7. There must be a magnetic field.
8. There must be relative movement between the conductor and the magnetic field, or a changing magnetic flux linking the conductor.
9. The conductor must cut magnetic lines of force.
10. The rate of cutting magnetic flux determines the magnitude of induced EMF.

The magnitude of induced EMF increases when:

- The speed of rotation increases.
- The magnetic field strength increases.
- The number of turns in the coil increases.
- The effective length of conductor cutting the magnetic field increases.

C. How a DC generator works

The operation takes place as follows:

1. A prime mover rotates the generator shaft.
2. The shaft rotates the armature within the magnetic field produced by the field system.
3. The armature conductors cut magnetic flux as they rotate.
4. An EMF is induced in the armature conductors.

5. The direction of induced EMF in each conductor changes as it moves through successive magnetic poles.
6. The commutator reverses the connections of the armature coils to the external circuit at the appropriate moments.
7. Carbon brushes maintain electrical contact with the rotating commutator.
8. Current is collected at the brushes and supplied to the external load.
9. The output at the generator terminals is unidirectional DC.

D. Role of the commutator

The commutator is one of the most important components that distinguishes a conventional DC generator from a simple AC generator.

- The EMF induced in a rotating armature coil is alternating.
- The commutator acts as a mechanical rectifier.
- It changes the connection of the rotating coil to the external circuit every half-turn.
- This makes the current collected at the brushes flow in one direction in the external circuit.
- The resulting output is pulsating DC, although it can be made smoother by using a suitable number of armature coils and commutator segments.

Remember: The commutator does not generate electricity. It helps convert the alternating EMF induced in the armature into a unidirectional output at the brushes.

E. Fleming's right-hand rule

Fleming's right-hand rule is used to determine the direction of induced current in a conductor moving in a magnetic field.

Hold the thumb, forefinger and middle finger of the right hand mutually at right angles.

- **Thumb:** Indicates the direction of motion of the conductor.
- **Forefinger:** Indicates the direction of the magnetic field, from North to South.
- **Middle finger:** Indicates the direction of the induced conventional current.

This rule is useful when studying the direction of induced current in generator conductors.

F. Factors affecting the generated EMF

The generated EMF depends mainly on:

1. **Magnetic flux per pole:** A stronger magnetic field increases the generated EMF.
2. **Speed of rotation:** Increasing the rotational speed increases the rate at which conductors cut magnetic flux.
3. **Number of armature conductors:** More conductors connected in series in each parallel path increase the generated EMF.
4. **Number of poles:** The number of magnetic poles influences the amount of flux cut per revolution.
5. **Armature winding arrangement:** Lap and wave windings have different numbers of parallel paths.

2.2.6 Main parts of a DC generator and their functions

A DC generator consists of stationary and rotating parts. The stationary section establishes and supports the magnetic field, while the rotating section carries the armature conductors.

A. Yoke or outer frame

Definition: The yoke is the outer body of a DC generator that supports and protects the internal components.

Functions:

- Provides mechanical support to the generator.
- Protects internal components from physical damage.
- Holds the pole cores and pole shoes in position.
- Provides a low-reluctance path for magnetic flux.
- Helps maintain the correct alignment of the magnetic system.

Materials commonly used include cast iron and steel, depending on the size and design of the machine.

B. Pole cores

Pole cores are magnetic structures fixed to the inside of the yoke.

Functions:

- Support the field windings.
- Carry magnetic flux.
- Direct magnetic flux towards the armature.
- Provide a magnetic path between the field windings and armature.

C. Pole shoes

Pole shoes are widened ends of the pole cores facing the armature.

Functions:

- Spread magnetic flux over a larger area.
- Reduce magnetic reluctance.
- Produce a more uniform magnetic field across the air gap.
- Support the field coils.

D. Field windings

Definition: Field windings are insulated copper coils wound around the pole cores to produce the magnetic field when electric current flows through them.

Functions:

- Produce the main magnetic field.
- Establish magnetic flux across the air gap.
- Control the magnetic strength of the generator.
- Help regulate the generated EMF.

Field windings may be connected as:

- Series field windings.
- Shunt field windings.
- Compound field windings.

E. Permanent magnets

Permanent magnets are materials that retain their magnetism without requiring continuous electrical excitation.

Functions:

- Produce the magnetic field in small DC generators.
- Eliminate the need for a separate field supply.
- Simplify the construction of small dynamo generators.

They are commonly found in small DC dynamos, educational models and some compact devices.

F. Armature core

Definition: The armature core is the rotating iron or steel part on which the armature windings are mounted.

Functions:

- Provides mechanical support for the armature windings.
- Provides a magnetic path for flux.
- Rotates within the magnetic field.
- Helps concentrate magnetic flux through the armature conductors.

The core is usually made of thin laminated steel sheets.

Why is the armature core laminated?

- To reduce eddy current losses.
- To reduce heating.
- To improve the efficiency of the generator.
- To minimise unnecessary power losses.

G. Armature winding

Definition: Armature windings are insulated conductors placed in slots on the armature core where EMF is induced during rotation.

Functions:

- Cut magnetic flux during rotation.
- Have EMF induced in them.
- Carry the generated current.
- Transfer generated electrical energy to the commutator.

Armature windings may be arranged as:

1. Lap winding.
2. Wave winding.

H. Commutator

Definition: A commutator is a cylindrical arrangement of insulated copper segments mounted on the armature shaft and connected to the armature windings.

Functions:

- Converts the alternating EMF in the armature into unidirectional output at the brushes.
- Provides a connection between rotating armature coils and stationary brushes.
- Maintains the correct direction of current in the external circuit.
- Collects generated current from the armature winding through the brushes.

The commutator segments are insulated from one another using mica or another suitable insulating material.

I. Carbon brushes

Definition: Carbon brushes are stationary conducting blocks that make sliding contact with the rotating commutator.

Functions:

- Collect current from the commutator.
- Transfer current to the external circuit.
- Maintain electrical contact with the rotating commutator.
- Allow current to enter or leave the rotating armature circuit.

Carbon is commonly used because it provides suitable electrical contact and reduces wear on the commutator compared with many harder conducting materials.

J. Brush holders and springs

Functions:

- Hold brushes in the correct position.
- Apply suitable pressure to maintain contact with the commutator.
- Allow brushes to move as they wear.
- Support reliable current collection.

K. Shaft

The shaft is a mechanical component that supports the rotating armature and transfers mechanical power from the prime mover.

Functions:

- Supports the armature core and commutator.
- Transfers rotational movement.
- Connects the generator to the prime mover.
- Maintains the alignment of rotating components.

L. Bearings

Bearings support the rotating shaft.

Functions:

- Reduce friction.
- Support smooth rotation.
- Maintain correct shaft alignment.
- Reduce vibration and mechanical wear.

M. End covers and end brackets

Functions:

- Support the bearings.
- Protect internal parts.
- Maintain the position of the shaft.
- Provide structural support to the generator.

N. Terminals

Generator terminals are the points where electrical connections are made.

Functions:

- Provide connection to the external load.
- Allow measurement of terminal voltage.
- Provide connection to the field circuit where required.
- Indicate the positive and negative output terminals.

Summary of generator components

Component	Main function
Yoke	Supports and protects the generator.
Pole core	Carries magnetic flux and supports field coils.
Pole shoe	Spreads magnetic flux.
Field winding	Produces the magnetic field.
Permanent magnet	Provides magnetic flux without electrical excitation.
Armature core	Supports the armature conductors.
Armature winding	Carries conductors in which EMF is induced.
Commutator	Provides unidirectional output at the brushes.
Carbon brushes	Collect current from the commutator.
Shaft	Transfers mechanical rotation.
Bearings	Support the rotating shaft.
Terminals	Connect the generator to the external circuit.

2.2.7 Types of DC generators

DC generators are classified according to the method used to produce their magnetic field.

There are two main categories:

1. Separately excited DC generators.
2. Self-excited DC generators.

A. Separately excited DC generator

Definition: A separately excited DC generator is a generator whose field winding receives current from an independent external DC supply.

Characteristics:

- The field current is supplied separately.
- The field strength can be controlled independently of the load current.
- The terminal voltage can be regulated by adjusting the field current.
- It can provide good voltage control under varying load conditions.
- It requires an additional source of DC excitation.

Applications:

- Laboratory experiments.

- Testing of electrical machines.
- Special industrial DC supplies.
- Controlled DC power systems.

B. Self-excited DC generator

Definition: A self-excited DC generator is a generator whose field winding receives its excitation current from the generator's own output.

The field winding is connected in one of three main ways:

1. Series-wound generator.
2. Shunt-wound generator.
3. Compound-wound generator.

Self-excitation usually depends on residual magnetism, correct field connection and suitable field-circuit resistance.

C. Series-wound DC generator

Definition: A series-wound DC generator is a generator in which the field winding is connected in series with the armature and external load.

Connection arrangement:

The armature, series field winding and external load are connected in one series circuit.

Therefore:

$$I_a = I_{se} = I_L$$

Where:

- I_a = armature current.
- I_{se} = series field current.
- I_L = load current.

Characteristics of a series generator

1. At no load, the generator produces very little voltage because the series field receives little or no current.
2. As load current increases, field current also increases.
3. Increasing field current strengthens the magnetic flux.
4. The generated EMF increases as the magnetic flux increases, until magnetic saturation occurs.
5. Beyond the saturation region, further increases in current produce only small increases in generated EMF.
6. At high loads, voltage drops caused by armature resistance, series-field resistance and armature reaction become significant.

Applications:

- Special-purpose DC supplies.
- Some older DC booster applications.
- Specialised welding and industrial applications where the generator is designed for the required load characteristic.

Advantages:

- Simple field-current arrangement.

- Field strength automatically increases with load current.
- Can produce a rising voltage characteristic over part of its operating range.

Disadvantages:

- Poor voltage regulation for ordinary loads.
- Very low no-load voltage.
- Terminal voltage changes considerably with load.
- Not suitable for general-purpose constant-voltage supply.

D. Shunt-wound DC generator

Definition: A shunt-wound DC generator is a generator whose field winding is connected in parallel with the armature terminals.

Connection arrangement:

The shunt field winding is connected across the generator terminals. It therefore receives a voltage approximately equal to the terminal voltage.

The shunt field winding has many turns of relatively fine wire and a high resistance compared with the series field winding.

Current relationship:

$$I_a = I_L + I_{sh}$$

Where:

- I_a = armature current.
- I_L = load current.
- I_{sh} = shunt field current.

Shunt field current is:

$$I_{sh} = \frac{V}{R_{sh}}$$

Where:

- V = terminal voltage.
- R_{sh} = shunt field resistance.

Characteristics of a shunt generator

7. It produces voltage even when the load is disconnected, provided it has successfully built up its field.
8. The field current is determined mainly by terminal voltage and field resistance.
9. As load current increases, terminal voltage generally decreases slightly.
10. The voltage drop is caused by armature resistance, brush contact drop and armature reaction.
11. The decrease in terminal voltage reduces shunt field current.
12. Reduced field current weakens the magnetic flux and may cause a further decrease in generated EMF.

Applications:

- Battery charging systems designed for DC output.
- DC lighting systems in suitable installations.
- Laboratory DC supplies.

- Older DC power distribution systems.
- Small industrial DC loads.

Advantages:

- Fairly constant terminal voltage over a suitable load range.
- Suitable for applications requiring reasonably stable DC voltage.
- Simple voltage control through field resistance adjustment.

Disadvantages:

- Terminal voltage falls as load increases.
- Poor regulation compared with a suitably controlled separately excited generator.
- Requires residual magnetism for voltage build-up.
- May fail to build up voltage if field connections or operating conditions are incorrect.

E. Compound-wound DC generator

Definition: A compound-wound DC generator is a generator that has both series and shunt field windings.

The two field windings work together to produce a magnetic field that gives the generator improved voltage characteristics under changing load conditions.

Types of compound generators

1. Cumulative compound generator.
2. Differential compound generator.

i. Cumulative compound generator

In a cumulative compound generator, the magnetic fields produced by the series and shunt windings assist one another.

Characteristics:

- The series field strengthens the shunt field as load current increases.
- It helps compensate for voltage drops within the generator.
- It can maintain nearly constant terminal voltage over a designed load range.
- Depending on the degree of compounding, terminal voltage may remain constant, rise slightly or fall slightly with increasing load.

Applications:

- DC distribution systems.
- Industrial DC supplies.
- Older DC lighting and power installations.
- Applications requiring relatively stable DC terminal voltage.

ii. Differential compound generator

In a differential compound generator, the magnetic field produced by the series winding opposes the magnetic field produced by the shunt winding.

Characteristics:

- As load current increases, the series field opposes the shunt field more strongly.
- The resultant magnetic flux decreases.
- Generated EMF decreases as load current increases.

- Terminal voltage falls more rapidly than in an ordinary shunt generator.

Applications:

- Special-purpose DC supplies requiring a falling voltage characteristic.
- Certain specialised welding applications.

F. Long-shunt and short-shunt compound generators

Compound generators are also classified according to the connection of the shunt field winding.

Long-shunt compound generator

- The shunt field winding is connected across the generator terminals.
- It is therefore in parallel with the armature and series-field combination.
- The series field carries the armature current in this arrangement.

Short-shunt compound generator

- The shunt field winding is connected across the armature only.
- The series field is connected in series with the external load.
- The shunt field receives the voltage across the armature.

Comparison of DC generator types

Type	Field connection	Load voltage behaviour	Main use
Separately excited	Independent DC source	Can be controlled through separate excitation	Laboratory and controlled supplies
Series	Series with armature and load	Rises initially with load, then may fall	Special-purpose applications
Shunt	Parallel with armature terminals	Falls gradually as load increases	Fairly constant-voltage DC supply
Cumulative compound	Series and shunt fields assist	Nearly constant or slightly rising/falling	Industrial DC supply
Differential compound	Series and shunt fields oppose	Falls significantly with load	Special-purpose falling-voltage supply

2.2.8 Load characteristics of DC generators

A. Meaning of load characteristics

Load characteristics are the relationships between the terminal voltage and load current of a generator as the load changes while the generator operates under specified conditions.

They show how well a generator maintains its terminal voltage when connected to different loads.

The most common characteristic used for comparison is the **external characteristic**, which is a graph of terminal voltage against load current.

B. Important characteristics

3. **Open-circuit characteristic (OCC):** Shows the relationship between generated EMF and field current when the generator is running without an external load at constant speed.
4. **Internal characteristic:** Shows the relationship between generated EMF and armature current under load.
5. **External characteristic:** Shows the relationship between terminal voltage and load current.

C. Load characteristic of a series generator

- At no load, the series field current is almost zero.
- The generator therefore produces very little voltage, apart from residual voltage.
- As load current increases, the series field current increases.
- The magnetic flux becomes stronger.
- Generated EMF rises.
- After magnetic saturation, the rise in EMF becomes smaller.
- At high load currents, internal voltage drops may cause terminal voltage to decrease.

D. Load characteristic of a shunt generator

- At no load, the generator has an established field and produces terminal voltage.
- As the load increases, armature current increases.
- Armature resistance causes an internal voltage drop.
- Armature reaction weakens the effective magnetic flux.
- The generated EMF and terminal voltage reduce.
- The voltage may fall more rapidly at heavy loads.

E. Load characteristic of a cumulative compound generator

A cumulative compound generator can be designed to have different voltage characteristics.

Under-compounded generator

- The series field does not fully compensate for internal voltage drops.
- Terminal voltage decreases slightly as load increases.

Flat-compounded generator

- The series field compensates approximately for internal voltage drops.
- Terminal voltage remains almost constant over the designed load range.

Over-compounded generator

- The series field produces more compensation than required.
- Terminal voltage increases slightly as load increases.

F. Load characteristic of a differential compound generator

- At no load, the generator produces its normal voltage.
- When load current increases, series field current increases.
- The series field opposes the shunt field.
- Resultant flux decreases.
- Generated EMF decreases.
- Terminal voltage falls considerably.

G. Factors affecting load characteristics

6. Armature resistance.
7. Field winding resistance.
8. Armature reaction.
9. Brush contact voltage drop.
10. Speed of rotation.
11. Magnetic saturation.
12. Type of field connection.
13. Load current.

14. Temperature of the windings.
15. Mechanical condition of the generator.

H. Importance of studying load characteristics

- Helps select a suitable generator for an application.
- Helps determine voltage stability.
- Assists in estimating generator performance.
- Helps identify the safe operating load.
- Supports proper generator maintenance.
- Helps compare different generator designs.

2.2.9 Generated EMF equation of a DC generator

A. Meaning of generated EMF

Generated electromotive force (EMF) is the electrical potential difference induced in the armature conductors as they rotate and cut magnetic flux.

It is measured in volts (V).

The generated EMF depends on:

- Number of poles.
- Flux per pole.
- Total number of armature conductors.
- Speed of armature rotation.
- Number of parallel paths in the armature winding.

B. Formula for generated EMF

The average generated EMF of a DC generator is given by:

$$\boxed{E_g = \frac{P\Phi ZN}{60A}}$$

Where:

Symbol	Meaning	Unit
E_g	Generated EMF	Volts (V)
P	Number of poles	No unit
Φ	Magnetic flux per pole	Weber (Wb)
Z	Total number of armature conductors	No unit
N	Armature speed	Revolutions per minute (rpm)
A	Number of parallel paths	No unit

Important: The symbol A in the formula represents the number of parallel paths, not the unit ampere.

C. Number of parallel paths

The number of parallel paths depends on the armature winding arrangement.

Lap winding

$$A = P$$

In a simplex lap winding, the number of parallel paths is equal to the number of poles.

Wave winding

$$A = 2$$

In a simplex wave winding, there are two parallel paths regardless of the number of poles.

Therefore:

For lap winding:

$$E_g = \frac{P\Phi ZN}{60P}$$

$$\boxed{E_g = \frac{\Phi ZN}{60}}$$

For wave winding:

$$\boxed{E_g = \frac{P\Phi ZN}{120}}$$

These are the standard average EMF equations for simplex lap and wave windings. (nec-license.gitbook.io)

D. Derivation of the EMF equation

Let:

- P = number of poles.
- Φ = flux per pole in webers.
- Z = total number of armature conductors.
- N = speed in rpm.
- A = number of parallel paths.

Step 1: Flux cut by one conductor in one complete revolution:

$$\text{Flux cut} = P\Phi$$

Step 2: Time taken for one revolution:

$$t = \frac{60}{N} \text{ seconds}$$

Step 3: Average EMF induced in one conductor:

$$e = \frac{\text{Flux cut}}{\text{Time}}$$

$$e = \frac{P\Phi N}{60}$$

Step 4: Number of conductors in series in each parallel path:

$$\frac{Z}{A}$$

Step 5: Generated EMF across the armature terminals:

$$E_g = e \times \frac{Z}{A}$$

Substituting:

$$\boxed{E_g = \frac{P\Phi ZN}{60A}}$$

E. Worked example 1: Calculating generated EMF

A four-pole DC generator has 600 armature conductors. It is wave-wound and rotates at 1,000 rpm. If the flux per pole is 0.02 Wb, calculate the generated EMF.

Solution

Given:

- $P = 4$
- $Z = 600$
- $N = 1000$ rpm
- $\Phi = 0.02$ Wb
- $A = 2$, because it is wave-wound.

Formula:

$$E_g = \frac{P\Phi ZN}{60A}$$

Substitution:

$$E_g = \frac{4 \times 0.02 \times 600 \times 1000}{60 \times 2}$$

$$E_g = \frac{48000}{120}$$

$$\boxed{E_g = 400 \text{ V}}$$

Answer: The generated EMF is 400 V.

F. Worked example 2: Lap-wound generator

A six-pole lap-wound DC generator has 720 conductors. The flux per pole is 0.015 Wb and the armature rotates at 800 rpm. Calculate the generated EMF.

Solution

Given:

- $P = 6$
- $Z = 720$
- $\Phi = 0.015$ Wb
- $N = 800$ rpm
- $A = P = 6$

$$E_g = \frac{P\Phi ZN}{60A}$$

$$E_g = \frac{6 \times 0.015 \times 720 \times 800}{60 \times 6}$$

$$E_g = \frac{51840}{360}$$

$$\boxed{E_g = 144\ \text{V}}$$

Answer: The generated EMF is 144 V.

G. Worked example 3: Finding speed

A four-pole wave-wound DC generator has 400 conductors and produces 200 V. If the flux per pole is 0.025 Wb, calculate its speed.

Solution

Given:

- $E_g = 200\ \text{V}$
- $P = 4$
- $Z = 400$
- $\Phi = 0.025\ \text{Wb}$
- $A = 2$

Formula:

$$E_g = \frac{P\Phi ZN}{60A}$$

Making N the subject:

$$N = \frac{60AE_g}{P\Phi Z}$$

Substitution:

$$N = \frac{60 \times 2 \times 200}{4 \times 0.025 \times 400}$$

$$N = \frac{24000}{40}$$

$$\boxed{N = 600\ \text{rpm}}$$

H. Relationship between generated EMF, flux and speed

For a given generator:

$$E_g = K\Phi N$$

Where K is a constant depending on the construction and winding arrangement.

This means:

- If flux remains constant, generated EMF is directly proportional to speed.
- If speed remains constant, generated EMF is directly proportional to flux.
- If both flux and speed increase, generated EMF increases.
- If both flux and speed decrease, generated EMF decreases.

I. Worked example 4: Change in speed and flux

A generator produces 120 V at a speed of 800 rpm and flux of 0.02 Wb per pole. Determine the new EMF when the speed increases to 1,000 rpm and flux increases to 0.025 Wb per pole.

Solution

Using:

$$\frac{E_{g2}}{E_{g1}} = \frac{\Phi_2 N_2}{\Phi_1 N_1}$$

$$E_{g2} = E_{g1} \times \frac{\Phi_2 N_2}{\Phi_1 N_1}$$

$$E_{g2} = 120 \times \frac{0.025 \times 1000}{0.02 \times 800}$$

$$E_{g2} = 120 \times 1.5625$$

$$\boxed{E_{g2} = 187.5 \text{ V}}$$

2.2.10 Frequency of induced EMF in a DC generator

Although a DC generator delivers unidirectional output at its terminals, the EMF induced in an individual armature coil is alternating.

The frequency of the induced alternating EMF is given by:

$$\boxed{f = \frac{PN}{120}}$$

Where:

- f = frequency in hertz (Hz).
- P = number of poles.
- N = speed in rpm.

Worked example

A four-pole DC generator rotates at 1,500 rpm. Calculate the frequency of the alternating EMF induced in its armature coils.

Solution

$$f = \frac{PN}{120}$$

$$f = \frac{4 \times 1500}{120}$$

$$\boxed{f = 50 \text{ Hz}}$$

Answer: The frequency of the alternating EMF induced in the armature coils is 50 Hz.

Important distinction: This is the internal electrical frequency of the induced EMF. The commutator makes the output at the brushes unidirectional; it is not an ordinary 50 Hz AC output.

2.2.11 Generated EMF and terminal voltage

The generated EMF is not always equal to the terminal voltage available to the load.

When current flows through the armature, some voltage is lost due to the resistance of the armature winding and the brush contacts.

For a generator:

$$\boxed{V = E_g - I_a R_a - V_b}$$

Where:

- V = terminal voltage.
- E_g = generated EMF.
- I_a = armature current.
- R_a = armature resistance.
- V_b = total brush contact voltage drop.

If brush drop is ignored:

$$\boxed{V = E_g - I_a R_a}$$

Worked example

A DC generator produces a generated EMF of 250 V. The armature current is 40 A and armature resistance is 0.25 Ω. Calculate the terminal voltage, ignoring brush voltage drop.

Solution

$$V = E_g - I_a R_a$$

$$V = 250 - (40 \times 0.25)$$

$$V = 250 - 10$$

$$\boxed{V = 240 \text{ V}}$$

Answer: The terminal voltage is 240 V.

2.2.12 Power and efficiency of a DC generator

A. Electrical output power

The electrical power delivered to the external load is:

$$\boxed{P_{out} = VI_L}$$

Where:

- P_{out} = output power in watts.
- V = terminal voltage.
- I_L = load current.

B. Power developed in the armature

The electrical power developed within the armature is:

$$\boxed{P_g = E_g I_a}$$

Where:

- P_g = power developed in the armature.

- E_g = generated EMF.
- I_a = armature current.

C. Mechanical input power

The mechanical input power is the power supplied by the prime mover to the generator shaft.

$$P_{in} = T\omega$$

Where:

- T = torque in newton metres (Nm).
- ω = angular speed in radians per second.

Angular speed is:

$$\omega = \frac{2\pi N}{60}$$

Therefore:

$$\boxed{P_{in} = \frac{2\pi NT}{60}}$$

D. Efficiency of a DC generator

Definition: Efficiency is the ratio of useful electrical output power to mechanical input power, expressed as a percentage.

$$\boxed{\eta = \frac{P_{out}}{P_{in}} \times 100\%}$$

Where:

- η = efficiency.
- P_{out} = useful electrical output power.
- P_{in} = mechanical input power.

E. Worked example: Calculating output power

A DC generator supplies a load at 220 V and 15 A. Calculate the output power.

Solution

$$P_{out} = VI_L$$

$$P_{out} = 220 \times 15$$

$$\boxed{P_{out} = 3300 \text{ W} = 3.3 \text{ kW}}$$

F. Worked example: Calculating efficiency

A generator receives 5 kW of mechanical power and supplies 4 kW of electrical power. Calculate its efficiency.

Solution

$$\eta = \frac{P_{out}}{P_{in}} \times 100\%$$

$$\eta = \frac{4000}{5000} \times 100$$

$$\boxed{\eta = 80\%}$$

G. Losses in a DC generator

Not all mechanical input power is converted into useful electrical output power. Some energy is lost in the generator.

1. Copper losses

These occur due to resistance in the windings.

Examples:

- Armature copper loss: $I_a^2 R_a$.
- Shunt field copper loss: $I_{sh}^2 R_{sh}$.
- Series field copper loss: $I_{se}^2 R_{se}$.

2. Iron or core losses

These occur in the magnetic core.

They include:

- Hysteresis loss.
- Eddy current loss.

3. Mechanical losses

These arise from mechanical movement.

Examples:

- Bearing friction.
- Brush friction.
- Windage caused by air resistance.

4. Stray load losses

These are additional losses that occur under operating load and are not always easily classified under the other categories.

Ways of reducing generator losses

- Use good-quality laminated magnetic cores.
- Use conductors of suitable cross-sectional area.
- Maintain proper brush pressure.
- Lubricate bearings as recommended.
- Keep the generator clean and well ventilated.
- Avoid overloading.
- Maintain correct operating speed.

2.2.13 Selection of a suitable DC generator

The selection of a DC generator depends on the electrical requirements and operating conditions of the application.

A. Factors to consider when selecting a DC generator

1. Output voltage

The generator must provide the voltage required by the load.

Examples:

- A 12 V battery-charging system requires a generator designed for the appropriate charging voltage.
- A 24 V DC system requires a generator with suitable voltage ratings.

2. Current rating

The generator must be capable of supplying the required load current without overheating.

3. Power rating

The generator should have a power rating that meets the load demand.

$$P = VI$$

4. Type of load

Consider whether the load is:

- Resistive.
- Inductive.
- Electronic.
- Variable.
- Continuous or intermittent.

5. Voltage regulation

Applications requiring stable voltage may need a suitably regulated generator.

6. Speed of operation

The generator must be compatible with the speed of the prime mover.

7. Efficiency

A generator with good efficiency reduces energy wastage and operating costs.

8. Cost and availability of spare parts

The purchase price, maintenance requirements and availability of replacement parts should be considered.

9. Operating environment

Consider:

- Temperature.
- Dust.
- Moisture.
- Ventilation.
- Vibration.
- Corrosive conditions.

10. Safety and protection

The generator should have suitable protection against overcurrent, overheating and mechanical hazards.

B. Selection according to application

Application	Suitable type or consideration	Reason
Laboratory DC supply	Separately excited generator	Field current can be adjusted independently.
Fairly constant-voltage DC supply	Shunt generator	Provides reasonably stable voltage over a suitable load range.
Industrial DC distribution	Cumulative compound generator	Can be designed for improved voltage regulation.
Special-purpose falling-voltage supply	Differential compound generator	Produces a falling voltage characteristic.
Small educational dynamo	Permanent-magnet DC generator	Simple construction and no separate field supply.
Battery charging	Properly rated and regulated DC generator	Charging voltage and current must suit the battery.

Note: In many modern installations, electronic rectifiers, DC power supplies and alternators with rectifiers have replaced conventional DC generators. The generator type should therefore be selected according to the actual technical and economic requirements.

C. Worked selection example

A small workshop requires a DC generator to supply equipment that needs a fairly constant DC voltage as the load changes. Which type would be suitable?

Answer:

A cumulative compound DC generator is a suitable choice where a traditional DC generator is required.

Reasons:

1. It has both series and shunt field windings.
2. The series field assists the shunt field.
3. It can compensate for internal voltage drops.
4. It can be designed to maintain nearly constant terminal voltage over its operating range.

2.2.14 Reading and interpreting a DC generator nameplate

A. Meaning of a nameplate

A **nameplate** is a metal or durable label attached to an electrical machine showing its important technical specifications and operating ratings.

B. Common information on a DC generator nameplate

Nameplate information	Meaning
Manufacturer	Company that made the generator.
Model number	Identifies the generator model.
Rated voltage	Normal operating terminal voltage.
Rated current	Maximum specified continuous output current under stated conditions.
Rated power	Specified output power.

Nameplate information	Meaning
Rated speed	Normal operating speed in rpm.
Field voltage	Voltage required by the field winding where specified.
Field current	Rated field current.
Duty rating	Indicates the permitted operating duty.
Insulation class	Indicates the thermal capability of the insulation system.
Serial number	Identifies the particular machine.

C. Importance of reading a nameplate

- Helps identify the correct operating voltage.
- Prevents overloading.
- Helps select suitable cables and protective devices.
- Assists in choosing a suitable prime mover.
- Supports correct maintenance.
- Helps identify replacement parts.
- Provides important safety information.

D. Example of nameplate interpretation

Consider a hypothetical generator with the following nameplate details:

Specification	Rating
Rated output voltage	220 V
Rated output current	20 A
Rated power	4.4 kW
Rated speed	1,500 rpm
Field voltage	110 V
Insulation class	F
Duty	Continuous

The generator is designed to provide 220 V DC at a rated output current of 20 A and a rated output power of 4.4 kW under its specified operating conditions.

Verify the relationship:

$$P = VI$$

$$P = 220 \times 20 = 4400 \text{ W}$$

$$P = 4.4 \text{ kW}$$

The nameplate power is therefore consistent with the voltage and current ratings.

2.2.15 Practical use of DC generators

DC generators have been used in many areas of electrical technology. Their applications depend on their output characteristics, power rating and design.

A. Applications in Kenyan settings

1. Educational institutions

- Used in electrical workshops for demonstrations.
- Used to teach electromagnetic induction.
- Used in practical experiments on electrical machines.
- Used for measuring generated voltage and current.

2. Technical training institutions

- Used for electrical machine testing.
- Used for studying load characteristics.
- Used for demonstrating generator efficiency.
- Used for learning generator maintenance.

3. Industrial workshops

- Used in specialised DC power systems.
- Used in certain electrochemical processes.
- Used in some legacy industrial installations.
- Used for specialised welding systems.

4. Battery charging

- Used in suitable DC charging systems.
- Used where controlled DC charging is required.
- Used in some specialised off-grid installations.

5. Renewable energy training

- Used in small demonstration wind or water turbine systems.
- Used to demonstrate mechanical-to-electrical energy conversion.
- Used to study DC output from small generating machines.

6. Agricultural and rural applications

- Used in training demonstrations involving small water turbines.
- Used in specialised battery-charging arrangements.
- Used in educational projects involving small mechanical energy systems.

B. Importance of DC generators in day-to-day life

- They demonstrate the conversion of mechanical energy into electrical energy.
- They provide DC electrical power for suitable applications.
- They support electrical engineering education and practical training.
- They are useful in specialised industrial processes.
- They help learners understand electromagnetic induction.
- They support the development of technical skills.
- They contribute to understanding electricity generation and energy conversion.

2.2.16 Safety precautions when operating DC generators

DC generators contain rotating components and electrical circuits. Incorrect operation may cause electric shock, burns, mechanical injury, fire or damage to the machine.

A. Before starting the generator

1. Inspect the generator for physical damage.
2. Ensure that the generator is mounted securely.
3. Check that all electrical connections are tight.
4. Inspect the armature and field winding connections.
5. Check the condition of the brushes and commutator.
6. Ensure that ventilation openings are clear.
7. Check that the prime mover is in good condition.
8. Confirm that the generator voltage and current ratings are suitable for the intended load.
9. Ensure that the load is disconnected or arranged as required by the manufacturer's starting procedure.
10. Confirm that protective devices are correctly installed.

B. During operation

1. Never touch exposed live terminals.
2. Keep hands and clothing away from rotating shafts and couplings.
3. Do not exceed the rated speed.
4. Do not overload the generator.
5. Monitor terminal voltage and load current.
6. Observe unusual vibration or noise.
7. Watch for excessive heating.
8. Avoid operating the generator in wet conditions unless specifically designed for them.
9. Do not adjust connections while the generator is running unless the procedure is specifically designed for safe live adjustment.
10. Keep unauthorised persons away from the equipment.

C. After operation

1. Disconnect the load using the correct procedure.
2. Stop the prime mover.
3. Isolate the electrical supply or field circuit as required.
4. Allow the generator to cool before maintenance.
5. Clean the external surfaces.
6. Inspect the brushes and commutator.
7. Record any faults observed.
8. Store tools and accessories safely.

D. Personal protective equipment (PPE)

Appropriate PPE may include:

- Safety boots.
- Protective clothing.
- Safety goggles.
- Suitable gloves for the particular maintenance task.
- Hearing protection where noise levels require it.

Important safety rule: Never open, dismantle or repair a generator while it is rotating or connected to an electrical supply. Isolate the equipment, prevent accidental restarting and verify that it is safe before beginning work.

2.2.17 Maintenance of DC generators

Definition: Maintenance is the process of inspecting, cleaning, servicing and repairing equipment to ensure that it operates safely and efficiently.

A. Routine maintenance activities

Component	Maintenance activity
Brushes	Inspect for wear, cracks and correct contact pressure.
Commutator	Keep clean and inspect for roughness, burning and excessive sparking.
Bearings	Check condition and lubricate according to manufacturer's instructions.
Armature	Inspect for overheating, damage and loose connections.
Field windings	Check insulation and electrical continuity.
Terminals	Tighten connections and inspect for corrosion.
Cooling system	Remove dust and ensure proper ventilation.
Shaft	Check alignment and mechanical condition.
Frame	Clean and inspect for damage or corrosion.

B. Common faults and their remedies

Fault	Possible cause	Remedy
Generator fails to build up voltage	Loss of residual magnetism or incorrect field connection	Check field circuit and follow approved voltage build-up procedure.
Low terminal voltage	Low speed, weak field or excessive load	Check speed, field circuit and load.
Excessive sparking at brushes	Incorrect brush position, poor contact or damaged commutator	Inspect and correct brush and commutator condition.
Overheating	Overloading, poor ventilation or winding fault	Reduce load, improve ventilation and test windings.
Unusual noise	Worn bearings or mechanical misalignment	Inspect bearings and alignment.
Excessive vibration	Loose mounting or unbalanced rotating parts	Secure mounting and inspect rotating assembly.
Low output current	High circuit resistance or poor connections	Inspect connections and load circuit.

C. Importance of proper maintenance

- Increases the service life of the generator.
- Improves operating efficiency.
- Reduces unexpected breakdowns.
- Improves safety.
- Reduces repair costs.
- Maintains reliable electrical output.
- Helps identify faults before they become serious.

2.2.18 Practical activities for competency development

Activity 1: Identifying parts of a DC generator

Learning intention: Identify the main components of a DC generator and explain their functions.

Materials and resources:

- A small DC generator or educational model.
- A labelled diagram.
- Screwdrivers and suitable tools.
- Safety goggles.
- Component identification chart.

Procedure:

9. Observe the generator externally.
10. Identify the frame, shaft and terminals.
11. Under supervision, examine the internal parts of an isolated generator.
12. Identify the field windings.
13. Locate the armature core and winding.
14. Identify the commutator and brushes.
15. Record the function of each component.
16. Reassemble the generator according to the manufacturer's instructions.

Expected learning evidence:

- Correct identification of generator components.
- Explanation of the function of each component.
- Safe handling and assembly of equipment.

Activity 2: Demonstrating electromagnetic induction

Learning intention: Explain how movement in a magnetic field induces EMF.

Materials:

- Bar magnet.
- Insulated copper wire coil.
- Sensitive galvanometer.
- Connecting leads.

Procedure:

17. Connect the coil to the galvanometer.
18. Move the magnet towards the coil.
19. Observe the galvanometer deflection.
20. Stop moving the magnet.
21. Observe the galvanometer reading.
22. Move the magnet away from the coil.
23. Observe the direction of deflection.
24. Discuss the relationship between movement and induced EMF.

Observation:

- Movement of the magnet produces an induced EMF.

- No relative movement produces no change in flux linkage and no induced EMF in this demonstration.
- Reversing the direction of movement reverses the direction of induced EMF.

Activity 3: Investigating the load characteristics of DC generators

Learning intention: Compare the voltage behaviour of different types of DC generators under changing load conditions.

Materials:

- DC shunt generator model or laboratory generator set.
- Series generator model where available.
- Compound generator model where available.
- DC voltmeter.
- DC ammeter.
- Variable load bank.
- Tachometer.
- Connecting leads.

Procedure:

1. Inspect the generator and its nameplate.
2. Connect the measuring instruments correctly.
3. Run the generator at the specified speed.
4. Record the no-load terminal voltage.
5. Connect the load according to the approved laboratory procedure.
6. Increase the load gradually.
7. Record the terminal voltage and load current at each step.
8. Repeat the test for other generator types where available.
9. Plot terminal voltage against load current.
10. Compare the graphs and explain the differences.

Expected learning evidence:

- Correct connection of measuring instruments.
- Accurate recording of readings.
- Correct plotting of graphs.
- Explanation of the load characteristics of each generator.

Safety: The teacher or laboratory technician must supervise the activity. Never exceed the generator's rated current, voltage, speed or the load bank's rating.

Activity 4: Calculating generated EMF

Learners are provided with the number of poles, flux per pole, armature conductors, speed and winding type.

They should:

1. Identify the known quantities.
2. Determine the number of parallel paths.
3. Select the correct EMF formula.
4. Substitute the values.
5. Calculate the generated EMF.
6. State the answer with the correct unit.

Activity 5: Interpreting a generator nameplate

Learners examine a generator nameplate or a sample specification sheet.

They should identify:

- Rated voltage.
- Rated current.
- Rated power.
- Rated speed.
- Field voltage.
- Manufacturer.
- Model number.
- Duty rating.

They should then explain how each specification affects the safe operation of the machine.

Important formula summary

Quantity	Formula
Generated EMF	$E_g = \frac{P\Phi ZN}{60A}$
Lap-wound generator	$E_g = \frac{\Phi ZN}{60}$
Wave-wound generator	$E_g = \frac{P\Phi ZN}{120}$
Induced EMF frequency	$f = \frac{PN}{120}$
Shunt field current	$I_{sh} = \frac{V}{R_{sh}}$
Shunt generator armature current	$I_a = I_L + I_{sh}$
Series generator current	$I_a = I_{se} = I_L$
Terminal voltage	$V = E_g - I_a R_a - V_b$
Output power	$P_{out} = VI_L$
Armature power developed	$P_g = E_g I_a$
Mechanical input power	$P_{in} = \frac{2\pi NT}{60}$
Efficiency	$\eta = \frac{P_{out}}{P_{in}} \times 100\%$

REVISION QUESTIONS

SECTION A: MULTIPLE-CHOICE QUESTIONS

30 marks

Instructions: Answer all questions. Choose the correct answer from the alternatives A, B, C and D.

1. What is the main function of a DC generator?

A. To convert electrical energy into mechanical energy.
B. To convert mechanical energy into electrical energy.
C. To convert chemical energy into heat energy.
D. To convert light energy into mechanical energy.

2. The operating principle of a DC generator is based on:

A. Electrostatic induction.
B. Electromagnetic induction.
C. Chemical reaction.
D. Thermal expansion.

3. Which component of a DC generator provides the mechanical support for its internal parts?

A. Carbon brush.
B. Commutator.
C. Yoke.
D. Armature winding.

4. Which part of a DC generator produces the main magnetic field?

A. Field winding.
B. Carbon brush.
C. Shaft.
D. Bearing.

5. The main function of the armature winding is to:

A. Support the generator frame.
B. Produce mechanical rotation.
C. Carry conductors in which EMF is induced.
D. Lubricate the shaft.

6. Which component acts as a mechanical rectifier in a conventional DC generator?

A. Pole shoe.
B. Commutator.
C. Bearing.
D. Yoke.

7. Carbon brushes are used in a DC generator to:

A. Increase the speed of rotation.
B. Produce magnetic flux.
C. Collect current from the commutator.
D. Support the armature core.

8. Which component supports the rotating shaft and reduces friction?

A. Pole core.
B. Bearing.
C. Field coil.
D. Terminal.

9. The direction of induced current in a generator conductor can be determined using:

A. Fleming's left-hand rule.
B. Fleming's right-hand rule.
C. Ohm's law.
D. Kirchhoff's voltage law.

10. Which of the following is a prime mover for a DC generator?

A. Voltmeter.
B. Ammeter.
C. Diesel engine.
D. Resistor.

11. In a separately excited DC generator, the field winding receives current from:

A. The external load only.
B. An independent DC source.
C. The commutator only.
D. The armature resistance.

12. In a series-wound DC generator, the field winding is connected:

A. In parallel with the armature and load.
B. In series with the armature and load.
C. Across an independent supply.
D. In parallel with the brushes only.

13. In a shunt-wound DC generator, the field winding is connected:

A. In series with the load.
B. Across the generator terminals.
C. Across the prime mover.
D. In series with the commutator segments.

14. A compound-wound DC generator has:

A. Only permanent magnets.
B. Only series field windings.
C. Both series and shunt field windings.
D. No field winding.

15. In a cumulative compound generator, the series field:

A. Opposes the shunt field.
B. Assists the shunt field.
C. Cancels the armature current.
D. Prevents rotation.

16. Which type of DC generator has a very low voltage at no load because its series field current is almost zero?

A. Series generator.
B. Shunt generator.
C. Separately excited generator.
D. Cumulative compound generator.

17. Which generator is commonly associated with fairly constant terminal voltage over a suitable load range?

A. Series generator.
B. Shunt generator.

C. Differential compound generator.
D. Unexcited generator.

18. The number of parallel paths in a simplex lap-wound DC generator is equal to:

A. Two.
B. Half the number of poles.
C. The number of poles.
D. Twice the number of conductors.

19. The number of parallel paths in a simplex wave-wound DC generator is:

A. Two.
B. Four.
C. Equal to the number of poles.
D. Equal to the number of armature conductors.

20. Which of the following is the correct generated EMF equation of a DC generator?

A. $E_g = \frac{60A}{P\Phi ZN}$

B. $E_g = \frac{P\Phi ZN}{60A}$

C. $E_g = \frac{VI}{R}$

D. $E_g = \frac{P}{VI}$

21. In the generated EMF equation, the symbol Φ represents:

A. Speed of rotation.
B. Flux per pole.
C. Armature resistance.
D. Number of conductors.

22. A DC generator has four poles and rotates at 1,500 rpm. What is the frequency of the EMF induced in its armature coils?

A. 25 Hz.
B. 40 Hz.
C. 50 Hz.
D. 60 Hz.

23. A generator has a generated EMF of 200 V and an armature current of 10 A. If armature resistance is 0.5 Ω and brush drop is ignored, what is its terminal voltage?

A. 195 V.
B. 200 V.
C. 205 V.
D. 210 V.

24. A generator supplies 220 V at 10 A. Calculate its electrical output power.

A. 220 W.
B. 1,100 W.
C. 2,200 W.
D. 22,000 W.

25. A generator receives 5 kW mechanical input power and delivers 4 kW electrical output power. Its efficiency is:

A. 60%.
B. 70%.
C. 80%.
D. 90%.

26. Which of the following is an iron loss in a DC generator?

A. Bearing friction.
B. Eddy current loss.
C. Brush friction.
D. Armature copper loss.

27. Laminations in the armature core are mainly used to reduce:

A. Mechanical vibration.
B. Eddy current losses.
C. Brush pressure.
D. Load current.

28. Which instrument is used to measure the rotational speed of a DC generator?

A. Ammeter.
B. Voltmeter.
C. Tachometer.
D. Ohmmeter.

29. Which of the following should be checked before operating a DC generator?

A. Whether the brushes are removed.
B. Whether the generator is overloaded.
C. Whether electrical connections are secure.
D. Whether the ventilation openings are blocked.

30. Why is it important to read the nameplate of a DC generator?

A. To determine the colour of the machine.
B. To identify its operating ratings and specifications.
C. To increase its rotational speed.
D. To change its winding arrangement.

Section A: Answer key

Question	Answer	Question	Answer	Question	Answer
1	B	11	B	21	B
2	B	12	B	22	C
3	C	13	B	23	A
4	A	14	C	24	C
5	C	15	B	25	C
6	B	16	A	26	B
7	C	17	B	27	B
8	B	18	C	28	C
9	B	19	A	29	C
10	C	20	B	30	B

SECTION B: STRUCTURED QUESTIONS

50 marks

Instructions: Answer all questions. Show all working in calculation questions and give appropriate units.

Question 1: Principle and construction of a DC generator (8 marks)

a) Define a DC generator. (2 marks)

b) State the principle on which a DC generator operates. (1 mark)

c) Explain how a DC generator produces electrical energy. (3 marks)

d) State two functions of the commutator. (2 marks)

Question 2: Components and their functions (8 marks)

a) Name four main components of a DC generator. (2 marks)

b) Explain the function of each of the following components: (4 marks)

   i. Armature winding.

   ii. Field winding.

   iii. Carbon brushes.

   iv. Bearings.

c) State two reasons why the armature core is laminated. (2 marks)

Question 3: Types and load characteristics of DC generators (8 marks)

a) Differentiate between a separately excited generator and a self-excited generator. (2 marks)

b) State two differences between a series-wound generator and a shunt-wound generator. (2 marks)

c) Explain the load characteristics of a cumulative compound generator. (2 marks)

d) State two applications of DC generators. (2 marks)

Question 4: Generated EMF calculations (10 marks)

A four-pole wave-wound DC generator has 600 armature conductors. The generator rotates at 1,200 rpm and the flux per pole is 0.025 Wb.

a) State the generated EMF equation of a DC generator. (2 marks)

b) Determine the number of parallel paths in the armature winding. (1 mark)

c) Calculate the generated EMF. (4 marks)

d) Calculate the frequency of the EMF induced in the armature coils. (3 marks)

Question 5: Power, efficiency and generator selection (8 marks)

A DC generator supplies a workshop load at 220 V and 20 A. The mechanical input power supplied by the prime mover is 5.5 kW.

a) Calculate the electrical output power. (2 marks)

b) Calculate the efficiency of the generator. (3 marks)

c) Give three factors to consider when selecting a DC generator for a workshop. (3 marks)

Question 6: Safety, maintenance and application (8 marks)

a) State four safety precautions to observe when operating a DC generator. (4 marks)

b) Explain two maintenance activities that should be carried out on a DC generator. (2 marks)

c) State two benefits of proper maintenance of a DC generator. (2 marks)

SUGGESTED MARKING SCHEME: SECTION B

Question 1 (8 marks)

a) A DC generator is an electrical machine that converts mechanical energy into direct-current electrical energy through electromagnetic induction. (2 marks)

b) Electromagnetic induction. (1 mark)

c) Explanation:

- A prime mover rotates the generator shaft. (1)
- The armature conductors cut magnetic flux and an EMF is induced. (1)
- The commutator and brushes collect the generated current and supply unidirectional output to the external circuit. (1)

d) Functions of the commutator:

- Converts the alternating EMF in the armature into unidirectional output at the brushes. (1)
- Provides connection between the rotating armature winding and stationary brushes. (1)

Question 2 (8 marks)

a) Any four:

- Yoke.
- Pole core.
- Pole shoe.
- Field winding.
- Armature core.
- Armature winding.
- Commutator.
- Carbon brushes.
- Shaft.
- Bearings.

Award ½ mark each, maximum 2 marks.

b) Functions:

i. Armature winding: Carries conductors in which EMF is induced. (1)

ii. Field winding: Produces the main magnetic field. (1)

iii. Carbon brushes: Collect current from the commutator and transfer it to the external circuit. (1)

iv. Bearings: Support the rotating shaft and reduce friction. (1)

c) Reasons for laminating the armature core:

- Reduces eddy current losses. (1)
- Reduces heating in the core. (1)

Question 3 (8 marks)

- Separately excited generator: Field current is supplied by an independent external DC source. (1)
- Self-excited generator: Field current is supplied from the generator's own output. (1)

b) Any two differences:

- Series field winding is connected in series with the armature and load, while shunt field winding is connected in parallel with the generator terminals. (1)
- Series generator has very low no-load voltage, while a shunt generator can build up and produce no-load voltage. (1)
- The series field assists the shunt field. (1)
- It compensates for internal voltage drops and can maintain nearly constant terminal voltage over a designed load range. (1)

e) Any two applications:

- Battery charging in suitable installations. (1)
- Electrical engineering laboratory experiments. (1)
- Specialised industrial DC supplies. (1)
- Electroplating and electrolysis. (1)

Maximum 2 marks.

Question 4 (10 marks)

$$E_g = \frac{P\Phi ZN}{60A}$$

(2 marks)

c) Wave winding has two parallel paths.

$$A = 2$$

(1 mark)

d) Given:

- $P = 4$
- $\Phi = 0.025$ Wb
- $Z = 600$
- $N = 1200$ rpm
- $A = 2$

Substitution:

$$E_g = \frac{4 \times 0.025 \times 600 \times 1200}{60 \times 2}$$

$$E_g = \frac{72000}{120}$$

$$\boxed{E_g = 600 \text{ V}}$$

Suggested allocation:

- Correct formula and substitution (2 marks).
- Correct calculation (1 mark).
- Correct answer with unit (1 mark).

d) Frequency formula:

$$f = \frac{PN}{120}$$

Substitution:

$$f = \frac{4 \times 1200}{120}$$

$$\boxed{f = 40 \text{ Hz}}$$

Suggested allocation:

- Correct formula (1 mark).
- Substitution (1 mark).
- Correct answer and unit (1 mark).

Question 5 (8 marks)

b) Output power:

$$P_{out} = VI$$

$$P_{out} = 220 \times 20$$

$$\boxed{P_{out} = 4400 \text{ W} = 4.4 \text{ kW}}$$

(2 marks)

b) Efficiency:

$$\eta = \frac{P_{out}}{P_{in}} \times 100\%$$

$$\eta = \frac{4400}{5500} \times 100$$

$$\boxed{\eta = 80\%}$$

Suggested allocation:

- Correct formula (1 mark).
- Correct substitution (1 mark).
- Correct answer (1 mark).

e) Any three:

- Required output voltage. (1)
- Required load current. (1)
- Power rating. (1)
- Type of load. (1)
- Voltage regulation. (1)
- Efficiency. (1)
- Operating speed. (1)
- Cost and availability of spare parts. (1)

Maximum 3 marks.

Question 6 (8 marks)

c) Any four safety precautions:

- Avoid touching exposed live terminals. (1)

- Keep hands and clothing away from rotating parts. (1)
- Avoid overloading the generator. (1)
- Ensure electrical connections are secure. (1)
- Do not exceed the rated speed. (1)
- Ensure proper ventilation. (1)
- Wear appropriate PPE. (1)
- Isolate the generator before maintenance. (1)

Maximum 4 marks.

b) Any two maintenance activities, explained:

- Inspect and replace worn brushes to maintain reliable contact. (1)
- Clean and inspect the commutator to reduce sparking and poor contact. (1)
- Inspect and lubricate bearings according to manufacturer's instructions. (1)
- Check winding insulation and electrical connections. (1)

Maximum 2 marks.

f) Any two benefits:

- Increases the service life of the generator. (1)
- Reduces unexpected breakdowns. (1)
- Improves efficiency. (1)
- Improves safety and reliability. (1)

Maximum 2 marks.

STRAND 2.0: ELECTRICAL MACHINES

SUB-STRAND 2.3: SINGLE-PHASE AC GENERATORS

1.0 INTRODUCTION TO SINGLE-PHASE AC GENERATORS

1.1 Meaning of an electrical generator

An electrical generator is an electromechanical device that converts mechanical energy into electrical energy through the process of electromagnetic induction.

- A generator requires mechanical energy to rotate its moving components.
- The rotation produces a changing magnetic flux linkage in the conductors.
- The changing magnetic flux linkage induces an electromotive force (e.m.f.).
- When an electrical load is connected, the induced e.m.f. causes current to flow through the external circuit.

Mechanical energy may be supplied by:

- Petrol engines.
- Diesel engines.
- Steam turbines.
- Water turbines.
- Wind turbines.
- Other mechanical prime movers.

Examples of generators used in Kenya

1. Standby generators used in hospitals and schools.
2. Diesel generators used in factories and commercial buildings.
3. Petrol generators used in homes and small businesses.
4. Hydroelectric generators used in electricity-generating stations.
5. Wind-driven generators used in wind power installations.

1.2 Meaning of a single-phase AC generator

A single-phase AC generator, also called a **single-phase alternator**, is an electrical machine that converts mechanical energy into single-phase alternating electrical energy using electromagnetic induction.

It produces an alternating voltage whose magnitude and direction change periodically with time. The generated voltage is usually sinusoidal.

1.3 Meaning of alternating current (AC)

Alternating current is an electric current that periodically changes both its magnitude and direction.

Unlike direct current (DC), which flows in one direction, alternating current reverses its direction at regular intervals.

Characteristics of alternating current

- Changes direction periodically.
- Its magnitude varies with time.
- It has a frequency measured in hertz (Hz).
- It may have a sinusoidal waveform.
- It can be transformed to different voltage levels using transformers.
- It is suitable for transmission and distribution over electrical power networks.

1.4 Meaning of single-phase electrical supply

A single-phase electrical supply is an AC electrical system consisting of one alternating voltage waveform.

In a typical single-phase domestic installation, the supply has:

- **Live conductor:** Carries the supply voltage to the load.
- **Neutral conductor:** Provides the normal return path for current.
- **Earth conductor:** Provides a protective path during electrical faults.

In Kenya, the nominal domestic supply is approximately **230 V, 50 Hz**.

2.0 WORKING PRINCIPLE OF A SINGLE-PHASE AC GENERATOR

2.1 Electromagnetic induction

A single-phase AC generator works on the principle of **electromagnetic induction**.

Electromagnetic induction is the process by which an electromotive force is induced in a conductor when the magnetic flux linking the conductor changes.

This principle was discovered through the work of Michael Faraday.

2.2 Faraday's laws of electromagnetic induction

Faraday's laws explain how voltage is induced in an electrical conductor.

First law

Whenever the magnetic flux linking a conductor or coil changes, an electromotive force is induced in the conductor.

If the conductor forms part of a closed circuit, an induced current flows.

Second law

The magnitude of the induced electromotive force is directly proportional to the rate of change of magnetic flux linkage.

Mathematically:

$$e = -N\frac{d\Phi}{dt}$$

Where:

- e = instantaneous induced e.m.f. in volts (V).
- N = number of turns in the coil.
- Φ = magnetic flux in webers (Wb).
- t = time in seconds (s).
- The negative sign represents Lenz's law.

2.3 Lenz's law

Lenz's law states that the direction of an induced electromotive force or current is such that it opposes the change in magnetic flux that produces it.

Importance of Lenz's law

1. Explains the direction of induced current.
2. Demonstrates the conservation of energy.
3. Explains why mechanical effort is required to rotate a generator under electrical load.
4. Helps determine the direction of induced current using Fleming's right-hand rule.

2.4 How a single-phase AC generator produces alternating current

The generation of alternating current takes place as follows:

1. A rectangular coil of insulated copper wire is placed between the north and south poles of a magnet.
2. The coil is mounted on a shaft that allows it to rotate.
3. A prime mover supplies mechanical energy to rotate the shaft.
4. As the coil rotates, its sides cut through the magnetic field.
5. The magnetic flux linking the coil changes continuously.
6. An electromotive force is induced in the coil according to Faraday's law.
7. The induced e.m.f. is transferred to the external circuit through slip rings and carbon brushes in a rotating-armature arrangement.
8. During the first half of the rotation, current flows in one direction through the external circuit.
9. During the next half of the rotation, the direction of induced e.m.f. reverses.
10. The continuous reversal produces alternating current.

Important observation: Slip rings allow the alternating voltage generated in the rotating coil to be connected to the stationary external circuit without mechanically reversing the connections.

2.5 Stages of voltage generation during coil rotation

Consider a rectangular coil rotating uniformly in a magnetic field. The generation of voltage can be explained using four main positions.

Position 1: 0° (zero position)

- The plane of the coil is perpendicular to the magnetic field.
- The coil sides move parallel to the magnetic field lines.
- There is no effective cutting of magnetic flux.
- The induced e.m.f. is zero.

Position 2: 90° (maximum position)

- The plane of the coil is parallel to the magnetic field.
- The coil sides cut the magnetic field lines at right angles.
- The rate of change of flux linkage is maximum.
- The induced e.m.f. reaches its maximum positive value.

Position 3: 180° (zero position)

- The coil completes half a revolution.
- The conductors are again moving parallel to the magnetic field.
- The induced e.m.f. becomes zero.
- The direction of the induced e.m.f. is about to reverse.

Position 4: 270° (maximum negative position)

- The coil continues rotating.
- The conductors cut the magnetic field in the opposite direction.
- The induced e.m.f. reaches its maximum negative value.
- Current flows in the opposite direction through the external circuit.

After completing 360°, the coil returns to its starting position, and the cycle repeats.

2.6 Alternating voltage waveform

The voltage generated by a single-phase AC generator is normally represented by a sine wave.

Characteristics of the waveform

- **Positive half-cycle:** Voltage has positive values.
- **Negative half-cycle:** Voltage has negative values.
- **Zero crossing:** Voltage is momentarily zero.
- **Peak value:** Maximum instantaneous voltage.
- **Period:** Time taken to complete one full cycle.
- **Frequency:** Number of complete cycles produced per second.

The instantaneous voltage is expressed as:

$$e = E_{\max}\sin\theta$$

Or:

$$e = E_{\max}\sin\omega t$$

Where:

- e = instantaneous voltage (V).
- $E_{\max}$ = maximum or peak voltage (V).
- θ = angular position in degrees or radians.
- ω = angular velocity in rad/s.
- t = time in seconds.

2.7 Fleming's right-hand rule

Fleming's right-hand rule is used to determine the direction of induced current in a conductor moving through a magnetic field.

Hold the thumb, first finger and middle finger of the right hand at right angles to one another.

- **Thumb:** Direction of motion of the conductor.
- **First finger:** Direction of magnetic field (North to South).
- **Middle finger:** Direction of induced conventional current.

Application: It helps determine the direction of current generated when a conductor moves through a magnetic field.

3.0 CONSTRUCTION OF A SINGLE-PHASE AC GENERATOR

3.1 General construction

A single-phase AC generator consists of several components that work together to convert mechanical energy into electrical energy.

The main components include:

1. Stator.
2. Rotor.
3. Armature winding.
4. Field winding or permanent magnets.
5. Slip rings.
6. Carbon brushes.
7. Shaft.

8. Bearings.
9. Frame or casing.
10. Cooling fan.
11. Terminal box.
12. Voltage regulator or excitation system, where fitted.

3.2 Stator

The stator is the stationary part of an AC generator.

Construction

- Made from a strong steel or cast-metal frame.
- Contains a laminated steel core.
- Has slots that accommodate insulated copper windings.
- The windings are arranged to produce the required single-phase output.

Functions

1. Supports the stationary electrical windings.
2. Provides a path for magnetic flux.
3. Houses the armature winding in many alternator designs.
4. Provides mechanical support for internal components.
5. Helps dissipate heat generated during operation.

3.3 Rotor

The rotor is the rotating part of an AC generator.

Construction

- Mounted on a rotating shaft.
- Made from magnetic steel or laminated steel.
- May contain field windings or permanent magnets.
- Supported by bearings.
- Rotates inside or relative to the stator.

Functions

1. Produces or carries the rotating magnetic field.
2. Provides the mechanical movement required for generation.
3. Enables the magnetic flux linking the stator winding to change.
4. Helps induce alternating voltage in the armature winding.

3.4 Armature winding

An armature winding is a coil or arrangement of insulated conductors in which the generated electromotive force is induced.

In many practical alternators, the armature winding is located on the stator.

Construction

- Made from insulated copper conductors.
- Wound into coils.
- Placed in slots in the laminated core.
- Connected to the output terminals.

Functions

1. Provides conductors in which e.m.f. is induced.
2. Carries the generated electrical current.
3. Supplies electrical energy to the connected load.
4. Determines, together with the magnetic field and speed, the generated voltage.

3.5 Field winding

A field winding is a coil of insulated wire used to produce a magnetic field when electric current flows through it.

Construction

- Made from insulated copper wire.
- Wound around magnetic poles or rotor cores.
- Supplied with direct current in an electrically excited alternator.

Functions

1. Produces the magnetic field required for generation.
2. Establishes magnetic flux.
3. Allows adjustment of generated voltage by controlling field excitation.
4. Provides the magnetic field that links the armature winding.

3.6 Permanent magnets

Permanent magnets are magnetic materials that produce a magnetic field without requiring an external electrical supply.

Examples

- Neodymium magnets.
- Ferrite magnets.
- Other suitable permanent magnetic materials.

Functions

1. Provide magnetic flux for electromagnetic induction.
2. Eliminate the need for a separate field excitation supply.
3. Are commonly used in small generators and compact alternators.
4. Simplify generator construction.

3.7 Slip rings

Slip rings are continuous circular conducting rings mounted on the rotating shaft and electrically connected to the ends of a rotating winding.

Construction

- Usually made from copper or another conducting material.
- Mounted on an insulated shaft.
- Connected to the rotating coil.
- Contacted by stationary carbon brushes.

Functions

1. Transfer electrical energy between a rotating winding and the external circuit.
2. Maintain continuous electrical contact during rotation.

3. Allow alternating voltage to be obtained from a rotating armature.
4. Prevent twisting of connecting wires during rotation.

Important distinction: In a rotating-field alternator, slip rings may instead supply DC excitation current to the rotating field winding. Some modern machines use brushless excitation.

3.8 Carbon brushes

Carbon brushes are stationary conducting contacts that maintain electrical contact with rotating slip rings.

Construction

- Usually made from carbon or graphite.
- Held in brush holders.
- Pressed against slip rings using springs.
- Connected to the stationary electrical circuit.

Functions

1. Transfer current between stationary and rotating parts.
2. Maintain electrical contact during rotation.
3. Provide a connection to the external circuit in rotating-armature machines.
4. Transfer excitation current in some rotating-field machines.

Maintenance requirements

- Inspect for excessive wear.
- Remove accumulated carbon dust.
- Check brush spring pressure.
- Ensure proper contact with slip rings.
- Replace worn brushes with suitable replacements.

3.9 Shaft

The shaft is a strong cylindrical metal component that connects the rotor to the prime mover.

Functions

1. Transmits mechanical power to the rotor.
2. Supports rotating components.
3. Maintains alignment during rotation.
4. Transfers torque from the driving engine.

3.10 Bearings

Bearings are mechanical components that support a rotating shaft and reduce friction.

Functions

- Support the rotor shaft.
- Allow smooth rotation.
- Reduce mechanical friction.
- Maintain correct alignment.
- Reduce wear on rotating components.

3.11 Frame and casing

The frame is the outer supporting structure of the generator.

Functions

1. Protects internal components from physical damage.
2. Supports the stator and other parts.
3. Provides mechanical strength.
4. Helps protect users from accidental contact with moving or live parts.
5. May provide ventilation openings for cooling.

3.12 Cooling fan

A cooling fan is used to circulate air around the generator to remove heat.

Functions

- Prevents overheating.
- Maintains suitable operating temperatures.
- Improves the efficiency and reliability of the generator.
- Protects insulation from excessive heat damage.

3.13 Terminal box

The terminal box is an enclosure containing the electrical connection points of the generator.

Functions

1. Provides access to the output terminals.
2. Allows safe connection to electrical loads.
3. Houses terminal links and connection arrangements where applicable.
4. Protects electrical connections from accidental contact.

3.14 Voltage regulator

An automatic voltage regulator (AVR) is an electronic control device used to maintain the generator output voltage within an acceptable range.

Functions

1. Monitors output voltage.
2. Adjusts field excitation in suitable alternators.
3. Helps maintain stable terminal voltage when the load changes.
4. Protects electrical equipment from excessive voltage variations.

4.0 TYPES OF SINGLE-PHASE AC GENERATOR CONSTRUCTION

4.1 Rotating-armature type

In a rotating-armature generator, the armature winding rotates within a stationary magnetic field.

Characteristics

- The armature winding is mounted on the rotor.
- The magnetic field is stationary.
- Slip rings and carbon brushes transfer generated current to the external circuit.
- Commonly used in simple demonstration generators and some small machines.

Advantages

1. Simple construction for small applications.
2. Useful for demonstrating electromagnetic induction.
3. Easy to understand and study.

4. Can use permanent magnets.

Disadvantages

1. Generated current passes through brushes and slip rings.
2. Brushes may wear out.
3. Electrical insulation of the rotating winding is more difficult at high voltages.
4. Not generally preferred for large-capacity alternators.

4.2 Rotating-field type

In a rotating-field generator, the field system rotates while the armature winding remains stationary.

Characteristics

- Field winding is mounted on the rotor.
- Armature winding is mounted on the stator.
- The rotor is supplied with DC excitation or uses an appropriate permanent-magnet arrangement.
- The generated output is taken from stationary stator terminals.

Advantages

1. High-voltage insulation is easier because the armature winding is stationary.
2. Output connections are simpler.
3. The output current does not have to pass through rotating brushes.
4. Suitable for higher power ratings.
5. Easier cooling of the stationary armature winding.

Disadvantages

1. Requires a field excitation system in electrically excited designs.
2. Construction can be more complex.
3. Requires accurate rotor balancing.
4. Excitation components require maintenance in some designs.

Key learning point: Many practical alternators use the rotating-field arrangement because it makes it easier and safer to obtain electrical output from stationary terminals.

5.0 FACTORS AFFECTING THE GENERATED E.M.F.

The magnitude of the e.m.f. generated by a single-phase AC generator depends on several factors.

5.1 Magnetic flux

Magnetic flux is the total magnetic field passing through a given surface.

- Increasing magnetic flux increases the induced e.m.f., provided other factors remain constant.
- Stronger magnets or increased field excitation can increase the magnetic flux.
- Weak magnetic flux results in lower generated voltage.

5.2 Number of turns

The number of turns refers to the total number of loops of conductor in the armature winding.

- Increasing the number of turns increases the generated e.m.f.
- Fewer turns produce lower e.m.f.
- The insulation and arrangement of the windings must be appropriate for the operating voltage.

5.3 Rotational speed

Rotational speed is the rate at which the rotor turns.

- Increasing rotational speed increases the rate of change of magnetic flux.
- This increases the generated voltage.
- Reducing speed decreases the generated voltage.
- Excessive speed may damage the generator.

5.4 Frequency

Frequency is the number of complete alternating cycles produced per second.

- Higher rotational speed generally produces a higher frequency for a given number of poles.
- A higher number of poles produces a higher frequency at a given rotational speed.

5.5 Winding arrangement

The arrangement and distribution of the armature winding influence the generated e.m.f.

A properly designed winding improves the waveform and electrical performance of the generator.

6.0 E.M.F. EQUATION OF A SINGLE-PHASE AC GENERATOR

6.1 Meaning of induced e.m.f.

Induced electromotive force is the voltage produced in a conductor or coil when the magnetic flux linking it changes.

The e.m.f. equation helps determine the generated voltage using the magnetic flux, number of turns and frequency.

6.2 Derivation of the generated e.m.f. equation

Consider a coil rotating uniformly in a magnetic field.

The magnetic flux linking the coil changes continuously as the coil rotates.

The instantaneous induced e.m.f. is determined by the rate of change of flux linkage.

For a simple concentrated, full-pitch winding, the winding factor may be taken as 1.

Generated e.m.f. equation

$$E = 4.44 k_w f \Phi T$$

Where:

- E = generated RMS e.m.f. in volts (V).
- k_w = winding factor.
- f = frequency in hertz (Hz).
- Φ = magnetic flux per pole in webers (Wb).
- T = number of series turns per phase.

Important: The equation gives the RMS e.m.f. per phase. In a single-phase generator, the phase voltage is the generated single-phase voltage.

Source note: The supplied notes had a blank or incomplete mathematical derivation in this section. The missing intermediate derivation steps are therefore not reproduced as though they were in the original material.

6.3 Worked example 1: Calculating generated e.m.f.

A single-phase AC generator has 200 turns in its armature winding. The magnetic flux per pole is 0.02 Wb, and the frequency is 50 Hz. Assuming a winding factor of 1, calculate the generated RMS e.m.f.

Solution

Given:

- $T = 200$
- $\Phi = 0.02\,Wb$
- $f = 50\,Hz$
- $k_w = 1$

Formula:

$$E = 4.44 k_w f \Phi T$$

Substitute:

$$E = 4.44 \times 1 \times 50 \times 0.02 \times 200$$

$$E = 888\,V$$

Answer: 888 V

6.4 Worked example 2: Calculating the number of turns

A generator produces an RMS e.m.f. of 230 V at 50 Hz. The flux per pole is 0.025 Wb. Assuming a winding factor of 1, calculate the number of series turns.

Solution

Given:

- $E = 230\,V$
- $f = 50\,Hz$
- $\Phi = 0.025\,Wb$
- $k_w = 1$

Formula:

$$E = 4.44 k_w f \Phi T$$

Making T the subject:

$$T = \frac{E}{4.44 k_w f \Phi}$$

Substituting:

$$T = \frac{230}{4.44 \times 1 \times 50 \times 0.025}$$

$$T = \frac{230}{5.55}$$

$$T = 41.44$$

Approximately:

$$T = 41 \text{ turns}$$

In practical winding design, the selected number of turns must be a whole number and the resulting voltage checked against the design requirements.

6.5 Worked example 3: Calculating magnetic flux

A single-phase alternator has 500 series turns per phase and generates 230 V at 50 Hz. Assuming a winding factor of 1, determine the magnetic flux per pole.

Solution

Formula:

$$E = 4.44 k_w f \Phi T$$

Making Φ the subject:

$$\Phi = \frac{E}{4.44 k_w f T}$$

Substitute:

$$\Phi = \frac{230}{4.44 \times 1 \times 50 \times 500}$$

$$\Phi = \frac{230}{111000}$$

$$\Phi = 0.00207\, Wb$$

Answer: $0.00207\, Wb$

7.0 FREQUENCY OF A SINGLE-PHASE AC GENERATOR

7.1 Meaning of frequency

Frequency is the number of complete cycles of alternating voltage produced by a generator in one second.

It is measured in hertz (Hz).

One hertz means one complete cycle per second.

7.2 Frequency equation

The frequency of an alternator is determined by the number of magnetic poles and the rotational speed.

$$f = \frac{PN}{120}$$

Where:

- f = frequency in hertz.
- P = number of magnetic poles.
- N = rotor speed in revolutions per minute (rpm).
- 120 = constant arising from the conversion between minutes, seconds and pole pairs.

7.3 Worked example 4: Calculating frequency

A four-pole alternator rotates at 1,500 rpm. Calculate its frequency.

Solution

Given:

- $P = 4$
- $N = 1500\,rpm$

Formula:

$$f = \frac{PN}{120}$$

Substitute:

$$f = \frac{4 \times 1500}{120}$$

$$f = \frac{6000}{120}$$

$$f = 50\,Hz$$

Answer: 50 Hz

7.4 Worked example 5: Calculating rotor speed

A six-pole generator produces a frequency of 50 Hz. Determine the required rotational speed.

Solution

Formula:

$$f = \frac{PN}{120}$$

Making N the subject:

$$N = \frac{120f}{P}$$

Substitute:

$$N = \frac{120 \times 50}{6}$$

$$N = 1000\,rpm$$

Answer: 1,000 rpm

7.5 Synchronous speed

Synchronous speed is the rotational speed of the magnetic field in an AC machine.

For a synchronous generator, the rotor runs at synchronous speed.

$$N_s = \frac{120f}{P}$$

The speed must be controlled to maintain the required output frequency.

7.6 Relationship between speed, poles and frequency

Number of poles	Speed (rpm)	Frequency (Hz)
2	3,000	50
4	1,500	50
6	1,000	50

Number of poles	Speed (rpm)	Frequency (Hz)
8	750	50
10	600	50
12	500	50

Observations

- Increasing the number of poles reduces the rotational speed required to generate the same frequency.
- Increasing the speed increases frequency when the number of poles remains constant.
- For a 50 Hz supply, the speed must be controlled according to the number of poles.

8.0 CHARACTERISTICS OF A SINGLE-PHASE AC GENERATOR UNDER DIFFERENT LOAD CONDITIONS

8.1 Meaning of electrical load

An electrical load is any electrical device or equipment that consumes electrical energy supplied by a generator.

The load converts electrical energy into another form of energy such as:

- Light energy.
- Heat energy.
- Mechanical energy.
- Sound energy.
- Chemical energy.

Examples of electrical loads in Kenya

- Electric bulbs.
- Television sets.
- Refrigerators.
- Water pumps.
- Electric irons.
- Computers.
- Fans.
- Electric motors.

8.2 Meaning of load conditions

Load conditions refer to the electrical demands placed on a generator by the connected equipment.

The load condition determines the amount of current drawn from the generator and influences its terminal voltage, power output, temperature and efficiency.

The main load conditions are:

1. No-load condition.
2. Light-load condition.
3. Full-load condition.
4. Overload condition.

8.3 No-load condition

A generator operates under no-load condition when it is running but no electrical load is connected to its output terminals.

Characteristics

- The generator produces an induced e.m.f.
- There is almost no current supplied to an external load.
- The terminal voltage is approximately equal to the generated e.m.f.
- The generator experiences mechanical and electrical losses even though no external load is supplied.
- The prime mover supplies mechanical power to overcome rotational losses.

Example: A standby generator running during testing without any appliances connected.

8.4 Light-load condition

A light-load condition occurs when the generator supplies a relatively small amount of current compared with its rated capacity.

Characteristics

- The generator supplies a small current.
- The terminal voltage is usually close to the no-load voltage.
- The temperature rise is generally low.
- Fuel or mechanical energy consumption is relatively low.
- The generator operates below its rated output.

Example: A 5 kVA generator supplying a few LED bulbs and a television.

8.5 Full-load condition

A full-load condition occurs when the generator supplies its rated electrical load under the specified operating conditions.

Characteristics

- The generator supplies its rated current.
- The output power is within the rated capacity.
- The temperature rises due to winding and other losses.
- The prime mover supplies sufficient mechanical power.
- The generator operates according to its designed performance limits.

Example: A 5 kVA generator supplying a total load close to 5 kVA at the specified power factor.

8.6 Overload condition

Overload occurs when the electrical demand exceeds the rated capacity of the generator.

Characteristics

- Excessive current may flow through the windings.
- The windings may overheat.
- Terminal voltage may drop.
- Insulation may deteriorate.
- Protective devices may disconnect the generator.
- Continuous overloading may damage the generator.

Example: Connecting several heavy electrical appliances to a generator rated for a much smaller load.

8.7 Comparison of generator load conditions

Condition	Current supplied	Terminal voltage	Operating effect
No load	Almost zero	Near no-load voltage	Mainly internal losses
Light load	Small	Usually close to rated voltage	Low heating
Full load	Rated current	Within rated limits	Normal rated operation
Overload	Above rated current	May fall significantly	Excessive heating and possible damage

8.8 Factors determining the load condition of a generator

The load condition of a single-phase AC generator can be determined by considering the following factors.

1. Load current

- Current measures the amount of electrical charge flowing through a circuit per unit time.
- A higher load current generally indicates a greater demand for electrical power.
- The measured current is compared with the generator's rated current.

2. Load voltage

- Voltage is the electrical potential difference between two points.
- A generator's terminal voltage may change as the load changes.
- A significant voltage drop may indicate overloading, inadequate excitation or an operating fault.

3. Apparent power

Apparent power is the product of RMS voltage and RMS current in a single-phase AC circuit.

$$S = VI$$

Where:

- S = apparent power in volt-amperes (VA).
- V = RMS voltage in volts.
- I = RMS current in amperes.

Apparent power is commonly expressed in kilovolt-amperes (kVA).

$$S(kVA) = \frac{VI}{1000}$$

Worked example 6: Determining apparent power

A single-phase generator supplies a voltage of 230 V and a current of 15 A. Calculate its apparent power.

Solution

Formula:

$$S = VI$$

Substitute:

$$S = 230 \times 15$$

$$S = 3450\,VA$$

Convert to kVA:

$$S = \frac{3450}{1000} = 3.45\,kVA$$

Answer: 3.45 kVA

4. Power factor

Power factor is the ratio of real power to apparent power in an AC circuit.

$$PF = \frac{P}{S}$$

Where:

- PF = power factor.
- P = real power in watts.
- S = apparent power in volt-amperes.

For a sinusoidal single-phase AC circuit:

$$P = VI\cos\phi$$

Where $\cos\phi$ represents the power factor.

5. Connected appliances

The total demand of the electrical appliances connected to the generator helps determine the load condition.

For example:

- A few energy-saving bulbs produce a light load.
- A refrigerator and several computers produce a higher load.
- Several electric heaters may create a heavy load.

8.9 Types of electrical loads according to power factor

Electrical loads can also be classified according to their effect on the phase relationship between voltage and current.

A. Resistive loads

Resistive loads are electrical loads in which voltage and current are approximately in phase.

Examples:

- Incandescent bulbs.
- Electric irons.
- Electric heaters.
- Resistance cookers.

Characteristics:

1. Current and voltage reach their maximum values at approximately the same time.
2. The power factor is approximately unity.
3. Real electrical power is converted mainly into heat or light.

B. Inductive loads

Inductive loads are electrical loads in which current lags behind voltage.

Examples:

- Electric motors.
- Transformers.
- Refrigerators.
- Water pumps.
- Air-conditioning compressors.

Characteristics:

1. Current lags behind voltage.
2. They require magnetic fields for operation.
3. They usually have a lagging power factor.
4. They may cause a greater voltage drop in a generator under load.

C. Capacitive loads

Capacitive loads are electrical loads in which current leads voltage.

Examples:

- Capacitor banks.
- Certain electronic power-factor correction systems.
- Capacitive circuits.

Characteristics:

1. Current leads voltage.
2. They store energy in an electric field.
3. They have a leading power factor.
4. They can influence the voltage regulation of an alternator.

8.10 Effect of load changes on generator performance

When the load connected to a generator changes, its operating characteristics may also change.

When load increases:

1. The current supplied by the generator increases.
2. Armature winding losses increase.
3. Voltage drop in the internal impedance increases.
4. Terminal voltage may decrease.
5. The prime mover must supply more mechanical power.
6. The generator temperature may rise.
7. Fuel consumption may increase in engine-driven generators.

When load decreases:

1. Load current decreases.
2. Armature copper losses decrease.
3. The terminal voltage may rise towards its no-load value.
4. The mechanical input power required decreases.
5. Generator heating generally reduces.

8.11 Voltage regulation of a single-phase AC generator

Voltage regulation is the change in terminal voltage between no-load and full-load conditions, expressed as a percentage of the full-load terminal voltage, with speed and excitation held constant.

$$\%VR = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

Where:

- V_{NL} = no-load terminal voltage.
- V_{FL} = full-load terminal voltage.

Worked example 7: Calculating voltage regulation

A single-phase generator produces 240 V at no load and 220 V at full load. Calculate its percentage voltage regulation.

Solution

Formula:

$$\%VR = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

Substitute:

$$\%VR = \frac{240 - 220}{220} \times 100$$

$$= \frac{20}{220} \times 100$$

$$\%VR = 9.09\%$$

Answer: 9.09%

Interpretation

The generator has a voltage regulation of approximately 9.09%. Its terminal voltage decreases by 20 V when moving from no-load to full-load conditions.

A low positive voltage regulation generally indicates better voltage stability.

Note: Depending on the load power factor and generator design, voltage regulation may be positive, zero or negative.

8.12 Efficiency of a single-phase AC generator

Efficiency is the ratio of useful electrical output power to mechanical input power, expressed as a percentage.

$$\eta = \frac{\text{Electrical output power}}{\text{Mechanical input power}} \times 100$$

Worked example 8

A generator receives 5,000 W of mechanical power and produces 4,250 W of electrical output power. Calculate its efficiency.

Solution

Formula:

$$\eta = \frac{\text{Output power}}{\text{Input power}} \times 100$$

Substitute:

$$\eta = \frac{4250}{5000} \times 100$$

$$\eta = 85\%$$

Answer: 85%

8.13 Losses in a single-phase AC generator

A generator does not convert all the mechanical input energy into useful electrical energy. Some energy is lost during operation.

1. Copper losses

- Occur due to resistance in the windings.
- Cause heating of the copper conductors.
- Increase with the square of the current.

$$P_{cu} = I^2R$$

Where:

- P_{cu} = copper power loss in watts.
- I = current in amperes.
- R = winding resistance in ohms.

2. Iron losses

These occur in the magnetic core.

They include:

- **Hysteresis losses:** Caused by repeated magnetisation and demagnetisation of the iron core.
- **Eddy current losses:** Caused by circulating currents induced in the core.

Laminated steel cores help reduce eddy current losses.

3. Mechanical losses

These include:

- Bearing friction.
- Air resistance.
- Friction between moving components.

4. Stray-load losses

These are additional losses caused by leakage magnetic fields and other effects associated with loaded operation.

Methods of reducing generator losses

1. Use good-quality copper conductors.
2. Use laminated magnetic cores.
3. Maintain bearings properly.
4. Ensure proper ventilation.
5. Avoid overloading.
6. Use appropriate magnetic materials.
7. Keep the generator clean and correctly aligned.

9.0 INTERPRETATION OF A SINGLE-PHASE AC GENERATOR NAMEPLATE

9.1 Meaning of a nameplate

A nameplate is a metal or durable printed information plate fixed to an electrical machine to provide essential technical specifications and operating details.

The nameplate enables an operator, technician or electrician to identify the generator's rated performance and operating requirements.

9.2 Information commonly displayed on a generator nameplate

1. Manufacturer's name

Identifies the company that manufactured the generator.

2. Model number

Identifies the specific generator model and helps in obtaining the correct spare parts and technical information.

3. Serial number

A unique identification number used for:

- Warranty claims.
- Maintenance records.
- Manufacturer support.
- Equipment identification.

4. Rated voltage

The voltage at which the generator is designed to operate under specified conditions.

Example: 230 V.

5. Rated frequency

The number of electrical cycles produced per second.

Example: 50 Hz.

6. Rated power

The maximum continuous output capacity specified by the manufacturer under stated operating conditions.

It may be expressed in:

- Watts (W).
- Kilowatts (kW).
- Volt-amperes (VA).
- Kilovolt-amperes (kVA).

7. Rated current

The current the generator is designed to supply under its specified rated conditions.

8. Power factor

Indicates the relationship between real power and apparent power.

A common rated power factor for some generators is 0.8.

9. Rated speed

The rotational speed at which the generator is designed to operate.

Example: 3,000 rpm for a two-pole, 50 Hz alternator.

10. Insulation class

Indicates the thermal rating of the insulating materials used in the generator windings.

Examples include:

- Class B.
- Class F.
- Class H.

11. Ingress Protection (IP) rating

Indicates the degree of protection provided by the enclosure against the entry of solid objects and water.

12. Phase

Indicates the electrical output arrangement.

Examples:

- Single phase.
- Three phase.

13. Duty rating

Indicates the operating conditions for which the generator is designed.

Examples:

- Continuous duty.
- Standby duty.
- Prime power duty.

14. Fuel type

For an engine-driven generator, the nameplate or accompanying specifications may indicate:

- Petrol.
- Diesel.
- Natural gas.
- Other approved fuel.

9.3 Sample generator nameplate

The following is an illustrative nameplate for learning purposes, not an actual manufacturer's specification.

AC GENERATOR

SAMPLE NAMEPLATE

SINGLE-PHASE ALTERNATOR

Specification	Details

Manufacturer	ABC Electrical Machines
Model	ABC-5000
Rated output	5 kVA
Rated voltage	230 V
Rated frequency	50 Hz
Rated current	21.7 A
Power factor	1.0
Number of phases	1
Rated speed	3,000 rpm
Insulation class	F
Duty	Continuous (illustrative)

Illustrative training example only. Actual ratings must be obtained from the manufacturer's nameplate.

9.4 How to interpret the sample nameplate

Question 1: What is the rated voltage?

Answer: 230 V.

This means the generator is designed to supply a nominal output voltage of 230 volts.

Question 2: What is the rated frequency?

Answer: 50 Hz.

This means the generator produces 50 complete cycles per second at the specified operating speed.

Question 3: What is the rated output power?

Answer: 5 kVA.

This is the generator's rated apparent power capacity.

Question 4: What is the rated current?

Answer: 21.7 A.

This is approximately the rated current for a 5 kVA, 230 V single-phase generator.

Formula:

$$S = VI$$

Making I the subject:

$$I = \frac{S}{V}$$

Substitute:

$$I = \frac{5000}{230}$$

$$I = 21.74\,A$$

Approximately:

$$I = 21.7\,A$$

Question 5: How many phases does the generator produce?

Answer: One phase.

Question 6: What is the rated speed?

Answer: 3,000 rpm.

This is the operating speed required for a two-pole, 50 Hz alternator.

9.5 Importance of reading generator nameplates

1. Helps users select a generator suitable for their electrical requirements.
2. Prevents overloading.
3. Helps determine the appropriate load current.
4. Provides information required during maintenance.
5. Helps technicians identify the correct replacement parts.
6. Indicates the correct operating voltage and frequency.
7. Promotes safe operation.
8. Helps in comparing different generator models.

10.0 APPLICATIONS OF SINGLE-PHASE AC GENERATORS IN DAILY LIFE

Single-phase AC generators are widely used in homes, schools, businesses, industries and other institutions.

10.1 Domestic applications

- Providing backup electricity during power interruptions.
- Powering household lighting systems.
- Operating television sets and computers.
- Supplying electricity to refrigerators.
- Powering small water pumps.
- Supporting domestic activities in areas without reliable grid electricity.

10.2 Educational institutions

- Providing backup electricity in schools.
- Powering computer laboratories.
- Supplying electricity to administrative offices.
- Supporting practical lessons in electricity technology.
- Powering projectors and teaching equipment.

10.3 Hospitals and health facilities

- Providing standby power during electricity interruptions.
- Supporting lighting systems.
- Powering selected medical equipment within the generator's capacity.
- Supporting refrigeration of medicines and vaccines where appropriate.
- Supporting communication and monitoring systems.

Important: Critical medical equipment must be supplied through properly designed backup systems, with suitable transfer arrangements and power quality.

10.4 Commercial applications

- Powering shops and supermarkets.
- Operating point-of-sale systems.
- Supplying electricity to small offices.

- Powering security lighting.
- Supporting communication equipment.

10.5 Agricultural applications

- Powering water pumps.
- Supporting irrigation systems.
- Powering small agricultural processing machines.
- Providing electricity to poultry and livestock facilities.
- Supporting agricultural storage and cooling equipment.

10.6 Construction and workshop applications

- Powering drilling machines.
- Operating grinding machines.
- Supporting welding equipment where the generator is suitably rated.
- Powering lighting at construction sites.
- Supplying electricity to portable workshop tools.

10.7 Rural electrification

Small generators can provide electricity in remote areas where connection to the national electricity grid is difficult or unavailable.

Examples include:

- Remote homes.
- Rural health centres.
- Small businesses.
- Community facilities.
- Agricultural establishments.

10.8 Renewable energy applications

Some renewable energy systems use generators to convert mechanical energy into electrical energy.

Wind energy

Wind rotates turbine blades, which drive a generator to produce electrical energy.

Hydroelectric energy

Moving water rotates a turbine connected to an electrical generator.

Biogas systems

An engine fuelled by biogas can drive an alternator to generate electricity.

11.0 SAFE OPERATION OF A SINGLE-PHASE AC GENERATOR

11.1 Meaning of electrical safety

Electrical safety refers to the practices and precautions used to prevent electrical accidents, injuries, equipment damage and loss of life when working with electrical machines.

Generators involve electrical and mechanical hazards. They must therefore be operated according to manufacturer instructions and relevant electrical safety requirements.

11.2 Safety precautions before starting a generator

1. Read the manufacturer's operating instructions.

2. Inspect the generator for physical damage.
3. Ensure the generator is placed on a firm, level surface.
4. Check the fuel level.
5. Check the engine oil level.
6. Inspect electrical cables for damage.
7. Ensure all connections are secure.
8. Confirm that the load is within the generator's rated capacity.
9. Ensure the generator is in a well-ventilated outdoor location.
10. Keep flammable materials away from the generator.
11. Ensure that protective devices are in good condition.
12. Do not operate a generator in wet conditions unless it has been specifically designed and installed for those conditions.

11.3 Safety precautions during operation

1. Never operate a petrol or diesel generator indoors, in a house, classroom or enclosed room.
2. Keep the generator away from doors, windows and air intakes to prevent carbon monoxide entering buildings.
3. Avoid touching exposed electrical terminals.
4. Do not operate the generator with wet hands.
5. Do not refuel a hot or running generator.
6. Avoid overloading the generator.
7. Do not remove protective covers while the machine is operating.
8. Keep children and unauthorised persons away.
9. Listen for unusual sounds and observe abnormal vibrations.
10. Monitor the output voltage and frequency where appropriate.
11. Ensure adequate cooling and ventilation.
12. Use suitable cables and connectors rated for the generator output.

11.4 Safety precautions after operation

1. Disconnect electrical loads using the correct procedure.
2. Switch off the generator according to the manufacturer's instructions.
3. Allow hot components to cool.
4. Inspect for signs of overheating.
5. Check for fuel or oil leaks.
6. Store the generator in a secure, dry and well-ventilated location.
7. Keep maintenance records.

11.5 Common hazards associated with generators

Hazard	Possible effect	Preventive measure
Electric shock	Injury or death	Proper insulation and earthing
Carbon monoxide	Poisoning or death	Operate outdoors
Hot surfaces	Burns	Allow cooling before handling
Fuel leakage	Fire	Inspect fuel system
Excessive noise	Hearing damage	Use appropriate hearing protection
Rotating parts	Physical injury	Keep guards in place
Overloading	Overheating and damage	Observe rated capacity
Wet connections	Electric shock	Keep connections dry and protected

Important: Carbon monoxide is a poisonous, odourless and colourless gas produced by fuel-burning engines. Never operate an engine-driven generator indoors or in an enclosed space.

11.6 Earthing and electrical protection

Earthing is an important protective measure in generator installations.

- The generator frame may require connection to an appropriate protective earthing system.
- The neutral-earth arrangement must follow the generator manufacturer's instructions and the applicable electrical installation design.
- An appropriately selected circuit breaker protects against overcurrent.
- A residual current device (RCD) may provide additional protection against certain earth-leakage faults.
- Cables must have suitable current-carrying capacity.
- Generator connections to building installations must be made through suitable changeover equipment by a qualified electrician.

Never connect a generator directly to a building circuit in a way that can back-feed the utility supply.

12.0 BASIC MAINTENANCE OF A SINGLE-PHASE AC GENERATOR

12.1 Meaning of generator maintenance

Generator maintenance refers to the routine inspection, servicing, cleaning, testing and repair of a generator to ensure reliable, safe and efficient operation.

12.2 Importance of generator maintenance

1. Improves reliability.
2. Extends the service life of the generator.
3. Prevents unexpected breakdowns.
4. Reduces maintenance and repair costs.
5. Improves operating efficiency.
6. Prevents overheating.
7. Reduces the risk of electrical faults.
8. Maintains the required output voltage and frequency.
9. Promotes safe operation.
10. Helps identify faults before they become serious.

12.3 Routine maintenance activities

A. Cleaning

- Remove dust and dirt from the external casing.
- Keep ventilation openings clear.
- Remove accumulated debris.
- Clean components according to manufacturer instructions.

B. Inspection of electrical connections

- Check terminals for looseness.
- Inspect cables for damaged insulation.
- Look for signs of corrosion.
- Check terminal connections for overheating.
- Ensure electrical covers are properly fitted.

C. Inspection of brushes and slip rings

For machines fitted with brushes and slip rings:

- Check the brushes for excessive wear.
- Inspect the slip rings for scoring or damage.
- Remove carbon dust using an approved method.
- Check brush pressure.
- Replace worn components with suitable replacements.

D. Inspection of bearings

- Listen for unusual bearing noises.
- Check for excessive vibration.
- Lubricate only where required by the manufacturer.
- Replace worn bearings.

E. Engine maintenance

For engine-driven generators:

- Check engine oil.
- Inspect the air filter.
- Check the fuel system.
- Inspect the cooling system.
- Replace oil and filters according to the service schedule.

F. Electrical testing

A qualified technician may perform:

- Output voltage testing.
- Frequency testing.
- Insulation resistance testing.
- Continuity testing.
- Earthing and protective-device testing.
- Load testing.

12.4 Suggested generator maintenance schedule

Maintenance activity	Suggested frequency
Visual inspection	Before each use
Check fuel and oil	Before each use
Clean ventilation openings	Regularly
Inspect electrical cables	Before each use
Check battery condition, if fitted	According to manufacturer
Inspect brushes, if fitted	According to service schedule
Check bearings	According to service schedule
Change engine oil	According to manufacturer
Comprehensive service	According to manufacturer

12.5 Common faults in single-phase AC generators

Fault	Possible cause	Recommended action
Generator fails to produce voltage	Loss of excitation, wiring fault or damaged winding	Arrange qualified diagnosis
Low output voltage	Low speed, overload or excitation fault	Check load and operating speed
Unstable voltage	Speed variation or AVR fault	Inspect governor and AVR
Excessive heating	Overloading or poor ventilation	Reduce load and improve cooling
Excessive vibration	Loose mounting or imbalance	Inspect mounting and rotating parts
Unusual noise	Worn bearings or loose components	Stop and inspect
No output current	Open circuit or faulty connections	Inspect circuit safely
Frequent tripping	Overload or electrical fault	Identify and correct the fault

Safety note: Electrical fault-finding, winding testing and repairs must be carried out by appropriately trained personnel with the generator isolated and made safe.

13.0 PRACTICAL ACTIVITIES AND COMPETENCY DEVELOPMENT

Activity 1: Demonstrating electromagnetic induction

Objective: To demonstrate how movement of a conductor in a magnetic field produces an induced e.m.f.

Materials

- Bar magnet.
- Coil of insulated copper wire.
- Sensitive galvanometer.
- Connecting wires.

Procedure

1. Connect the coil to the galvanometer.
2. Hold the bar magnet near the coil.
3. Move the magnet towards the coil.
4. Observe the galvanometer reading.
5. Stop the magnet.
6. Move the magnet away from the coil.
7. Reverse the direction of movement.
8. Record the observations.

Expected observations

- The galvanometer deflects when the magnet moves towards the coil.
- The galvanometer returns to zero when the magnet stops moving.
- The galvanometer deflects in the opposite direction when the magnet moves away.

Conclusion

An e.m.f. is induced when the magnetic flux linking the coil changes. Reversing the direction of relative movement reverses the direction of induced current.

Activity 2: Identifying generator components

Objective: To identify the main components of a single-phase AC generator.

Materials

- Small demonstration AC generator.
- Generator component model.
- Identification chart.
- Appropriate hand tools.

Procedure

1. Observe the external structure of the generator.
2. Identify the terminal box.
3. Identify the stator and rotor.
4. Locate the armature winding.
5. Locate the field winding or permanent magnets.
6. Identify slip rings and brushes, where fitted.
7. Identify the shaft and bearings.
8. Record the functions of each component.
9. Reassemble the demonstration machine under supervision.

Expected outcome

The learner identifies the constructional components and explains their functions.

Activity 3: Investigating the effect of load on generator output

Objective: To investigate how load changes affect the terminal voltage and current of a single-phase AC generator.

Materials

- Suitable low-voltage AC generator or protected laboratory alternator.
- AC voltmeter.
- AC ammeter.
- Suitable resistive load bank.
- Connecting cables.
- Protective equipment.

Procedure

1. Ensure the generator is correctly installed and protected.
2. Start the generator according to the manufacturer's instructions.
3. Measure the no-load terminal voltage.
4. Record the reading.
5. Connect a suitable small resistive load.
6. Measure voltage and current.
7. Increase the load gradually within the machine's safe rated capacity.
8. Record the voltage and current at each load level.
9. Compare the results.

Sample observation table

Load condition	Voltage (V)	Current (A)

Load condition	Voltage (V)	Current (A)
No load	230	0
Light load	228	2
Medium load	225	5
Higher load	220	8

Illustrative readings only. Actual results depend on the generator and test conditions.

Conclusion

The terminal voltage of a generator may decrease as load current increases, depending on the generator's internal impedance, power factor and voltage regulation.

Activity 4: Reading a generator nameplate

Objective: To interpret technical information on a generator nameplate.

Procedure

1. Observe a generator nameplate.
2. Identify the manufacturer.
3. Record the rated voltage.
4. Record the frequency.
5. Identify the rated output.
6. Determine the rated current where possible.
7. Identify the phase arrangement.
8. Explain the meaning of the operating speed.
9. Present the findings to the class.

Activity 5: Virtual simulation of AC generation

Learners can use a suitable interactive electromagnetic induction simulation to investigate:

- Rotation of a coil.
- Direction of magnetic field.
- Induced voltage.
- Effect of rotational speed.
- Effect of magnetic field strength.
- Alternating voltage waveform.

Suggested digital resource: PhET Interactive Simulations. Search for *Faraday's Electromagnetic Lab*.

14.0 COMPETENCY-BASED EDUCATION (CBE) INTEGRATION

14.1 Specific learning outcomes

By the end of this sub-strand, the learner should be able to:

1. Explain the working principle of a single-phase AC generator.
2. Describe the construction of the components of a single-phase AC generator.
3. Analyse the characteristics of a single-phase AC generator under different load conditions.
4. Apply the e.m.f. equation to determine the output voltage of a single-phase AC generator.
5. Interpret information on a single-phase AC generator nameplate.
6. Appreciate the application of AC generators in day-to-day life.

14.2 Core competencies developed

Core competency	Application in this sub-strand
Communication and collaboration	Discussing generator operation and sharing findings
Critical thinking and problem-solving	Calculating generated voltage and diagnosing faults
Creativity and imagination	Developing simple models of AC generators
Digital literacy	Using virtual simulations and digital learning re-sources
Learning to learn	Researching generator technologies
Self-efficacy	Performing practical tasks and interpreting results
Citizenship	Appreciating safe and responsible electricity use

14.3 Pertinent and contemporary issues (PCIs)

1. Safety and accident prevention

Learners develop awareness of electrical hazards, fire risks and safe generator operation.

2. Environmental conservation

Learners appreciate the need to reduce fuel wastage, noise pollution and harmful emissions.

3. Energy conservation

Learners understand the importance of selecting generators that match the electrical load.

4. Occupational health and safety

Learners practise safe handling of electrical tools and equipment.

5. Entrepreneurship

Learners explore opportunities in generator installation, maintenance, repair and sales.

6. Climate change awareness

Learners appreciate cleaner energy technologies such as wind and hydropower generation.

14.4 Values promoted

- Responsibility.
- Integrity.
- Respect.
- Cooperation.
- Diligence.
- Environmental stewardship.
- Safety consciousness.

14.5 Suggested learning resources

1. Single-phase AC generator.
2. Small electric dynamo.
3. Permanent magnets.
4. Insulated copper wire.
5. Galvanometer.
6. AC voltmeter.
7. AC ammeter.

8. Electrical load bank.
9. Generator nameplate samples.
10. Digital simulation software.
11. Electrical safety equipment.
12. Generator component charts.
13. Textbooks and reference materials.

15.0 SUMMARY OF IMPORTANT CONCEPTS AND FORMULAE

Concept	Meaning or formula
Electrical generator	Converts mechanical energy into electrical energy
Electromagnetic induction	Production of e.m.f. due to changing magnetic flux linkage
Faraday's law	$e = -N\frac{d\Phi}{dt}$
Instantaneous voltage	$e = E_{\max}\sin\omega t$
RMS voltage	$E = \frac{E_{\max}}{\sqrt{2}}$ for a sinusoidal waveform
Generated e.m.f.	$E = 4.44k_w f\Phi T$
Frequency	$f = \frac{PN}{120}$
Synchronous speed	$N_s = \frac{120f}{P}$
Apparent power	$S = VI$
Real power	$P = VI\cos\phi$
Power factor	$PF = \frac{P}{S}$
Voltage regulation	$\%VR = \frac{V_{NL}-V_{FL}}{V_{FL}} \times 100$
Efficiency	$\eta = \frac{\text{Output power}}{\text{Input power}} \times 100$
Copper loss	$P_{cu} = I^2R$

PART II: TOPICAL REVISION QUESTIONS

STRAND 2.0: ELECTRICAL MACHINES

SUB-STRAND 2.3: SINGLE-PHASE AC GENERATORS

SECTION A: 30 MARKS

SECTION A: MULTIPLE-CHOICE QUESTIONS

30 MARKS | Answer all questions. Each question carries 1 mark.

1. A single-phase AC generator is an electrical machine that converts:

A. Electrical energy into mechanical energy.

B. Mechanical energy into electrical energy.

C. Chemical energy into heat energy.

D. Electrical energy into chemical energy.

2. The working principle of a single-phase AC generator is based on:

A. Electrostatic induction.

B. Electromagnetic induction.

C. Chemical reaction.

D. Magnetic attraction only.

3. Which scientist is associated with the discovery of electromagnetic induction?

A. Isaac Newton.

B. James Watt.

C. Michael Faraday.

D. Albert Einstein.

4. An electromotive force is induced in a coil when:

A. The coil is kept stationary in an unchanged magnetic field.

B. The resistance of the coil is increased.

C. The magnetic flux linking the coil changes.

D. The coil is disconnected from the circuit.

5. Which component of an AC generator provides the mechanical rotation required for generation?

A. Carbon brush.

B. Prime mover.

C. Terminal box.

D. Galvanometer.

6. The stationary part of an electrical generator is called the:

A. Rotor.

B. Shaft.

C. Stator.

D. Slip ring.

7. The rotating component of a generator is known as the:

A. Stator.

B. Rotor.

C. Terminal.

D. Brush holder.

8. The main function of the armature winding is to:

A. Support the generator frame.

B. Produce mechanical rotation.

C. Provide conductors in which e.m.f. is induced.

D. Reduce fuel consumption.

9. Which component provides the magnetic field in a generator?

A. Bearing.

B. Field winding.

C. Terminal box.

D. Cooling fan.

10. The main function of slip rings in a rotating-armature AC generator is to:

A. Convert AC into DC.

B. Transfer electrical energy between rotating and stationary circuits.

C. Increase the rotational speed.

D. Reduce magnetic flux.

11. Carbon brushes are used in an AC generator to:

A. Support the rotor.

B. Maintain electrical contact with slip rings.

C. Produce magnetic flux.

D. Reduce the number of poles.

12. A generator produces alternating current because:

A. Its magnetic field is permanently switched off.

B. The direction of induced e.m.f. reverses periodically.

C. Its resistance changes continuously.

D. Its rotor remains stationary.

13. The negative sign in Faraday's law represents:

A. Fleming's left-hand rule.

B. Lenz's law.

C. Ohm's law.

D. Kirchhoff's law.

14. The frequency of an AC generator is measured in:

A. Volts.

B. Amperes.

C. Hertz.

D. Ohms.

15. A four-pole alternator rotates at 1,500 rpm. What frequency does it produce?

A. 25 Hz.

B. 40 Hz.

C. 50 Hz.

D. 60 Hz.

16. The frequency of an alternator is determined by:

A. Resistance and voltage.

B. Number of poles and rotational speed.

C. Current and power factor only.

D. Number of brushes and slip rings.

17. A generator has 100 turns, a flux of 0.01 Wb per pole and a frequency of 50 Hz. Assuming a winding factor of 1, its RMS generated e.m.f. is:

A. 111 V.

B. 222 V.

C. 444 V.

D. 555 V.

18. The RMS value of a sinusoidal alternating voltage is equal to:

A. The maximum voltage multiplied by 22.

B. The maximum voltage divided by 22.

C. Twice the maximum voltage.

D. Half the maximum voltage multiplied by 22.

19. A generator operating without an external electrical load is said to be under:

A. Full-load condition.

B. Overload condition.

C. No-load condition.

D. Short-circuit condition.

20. When the electrical load connected to a generator increases, the armature current generally:

A. Decreases.

B. Increases.

C. Remains permanently zero.

D. Becomes independent of the load.

21. Which of the following is an example of a resistive load?

A. Electric heater.

B. Induction motor.

C. Transformer.

D. Refrigerator compressor.

22. In a predominantly inductive AC load, the current:

A. Leads voltage.

B. Lags voltage.

C. Is always zero.

D. Is always equal to voltage.

23. Voltage regulation of an AC generator compares:

A. Input current and output current.

B. No-load voltage and full-load voltage.

C. Rotor speed and shaft diameter.

D. Magnetic flux and winding resistance.

24. A generator has a no-load voltage of 240 V and a full-load voltage of 220 V. Its voltage regulation is approximately:

A. 5.00%.

B. 8.00%.

C. 9.09%.

D. 10.00%.

25. A generator supplies 230 V and 10 A. Its apparent power is:

A. 230 VA.

B. 1,150 VA.

C. 2,300 VA.

D. 23,000 VA.

26. Which information is normally obtained from a generator nameplate?

A. Operator's home address.

B. Rated voltage and frequency.

C. Daily fuel purchase records.

D. Number of electrical appliances in a building.

27. A generator nameplate indicates 230 V, 50 Hz and 5 kVA. The 5 kVA value represents the:

A. Rated apparent power.

B. Rated frequency.

C. Rated rotational speed.

D. Rated insulation resistance.

28. Which of the following practices is safest when operating a petrol generator?

A. Operating it inside a closed classroom.

B. Refuelling while the engine is running.

C. Operating it outdoors in a well-ventilated location.

D. Touching exposed terminals during operation.

29. Laminated steel cores are used in AC generators mainly to reduce:

A. Fuel losses.

B. Eddy current losses.

C. Bearing friction.

D. Mechanical vibration.

30. Which of the following is a common application of a single-phase AC generator in Kenya?

A. Producing fertilisers.

B. Providing backup electricity to schools and homes.

C. Purifying drinking water chemically.

D. Manufacturing copper conductors.

SECTION B: STRUCTURED QUESTIONS

50 MARKS

6 Questions

Answer all questions. Show all calculations and include appropriate units.

QUESTION 1: Working Principle of an AC Generator (8 marks)

a) Define a single-phase AC generator. (2 marks)

b) State two energy transformations that take place during the operation of a single-phase AC generator. (2 marks)

c) Explain four steps involved in the generation of alternating current when a coil rotates in a magnetic field. (4 marks)

QUESTION 2: Construction of a Single-Phase AC Generator (8 marks)

a) Differentiate between the stator and rotor of an AC generator. (2 marks)

b) State the function of each of the following components: (4 marks)

i. Armature winding.

ii. Field winding.

iii. Slip rings.

iv. Carbon brushes.

c) State two advantages of using a rotating-field arrangement in an AC generator. (2 marks)

QUESTION 3: E.M.F. and Frequency Calculations (8 marks)

a) State Faraday's law of electromagnetic induction. (2 marks)

b) A single-phase AC generator has 300 series turns per phase. The magnetic flux per pole is 0.015 Wb, and the frequency is 50 Hz. Assuming a winding factor of 1, calculate the generated RMS e.m.f. (3 marks)

c) A four-pole alternator rotates at 1,500 rpm. Calculate its operating frequency. (3 marks)

QUESTION 4: Generator Load Characteristics (8 marks)

a) Define the term electrical load as applied to an AC generator. (2 marks)

b) Distinguish between no-load and full-load conditions of a generator. (2 marks)

c) State four effects of increasing the electrical load on the performance of a single-phase AC generator. (4 marks)

QUESTION 5: Nameplate Interpretation and Applications (9 marks)

Study the following illustrative generator nameplate and answer the questions that follow.

SINGLE-PHASE AC GENERATOR

Specification	Rating
Rated voltage	230 V
Rated frequency	50 Hz
Rated apparent power	4.6 kVA
Rated power factor	1.0
Rated speed	3,000 rpm
Number of phases	1

a) State the rated voltage of the generator. (1 mark)

b) Determine the rated current of the generator. (3 marks)

c) State the meaning of the 50 Hz rating. (2 marks)

d) Give three applications of single-phase AC generators in Kenya. (3 marks)

QUESTION 6: Safety and Maintenance (9 marks)

a) State four safety precautions that should be observed when operating a petrol-driven AC generator. (4 marks)

b) Explain three maintenance activities carried out on a single-phase AC generator. (3 marks)

c) State two possible effects of operating a generator beyond its rated capacity. (2 marks)

STRAND 3.0: ELECTRICAL INSTALLATION

SUB-STRAND 3.1: WIRING SYSTEMS AND REGULATIONS

1.0 Introduction to Electrical Wiring Systems

Electrical wiring is an important part of every building because it enables electrical energy to be distributed safely from the supply source to lighting points, socket outlets, switches and other electrical appliances.

In Kenya, electrical wiring is used in residential houses, schools, hospitals, offices, hotels, workshops, factories, farms and commercial buildings.

The choice of a wiring system depends on the type of building, the electrical load, environmental conditions, safety requirements, cost and the appearance of the installation.

1.1 Definition of an electrical wiring system

An **electrical wiring system** is an arrangement of electrical conductors, cables, protective devices, accessories and supporting materials used to distribute electrical energy safely from the source of supply to points of use.

1.2 Main purposes of electrical wiring systems

An electrical wiring system is installed to:

1. Distribute electrical energy from the main supply to different parts of a building.
2. Provide connections to lighting points, socket outlets and electrical equipment.
3. Protect conductors against mechanical damage.
4. Reduce the risk of electric shock, fire and other electrical accidents.
5. Provide a neat and organised arrangement of electrical cables.
6. Make inspection, testing, repair and maintenance easier.
7. Ensure reliable operation of electrical appliances.
8. Allow future modification and extension of electrical installations where appropriate.

1.3 Important terms used in electrical wiring

1. Conductor

A conductor is a material that allows electric current to flow through it easily. Copper and aluminium are commonly used in electrical installations.

2. Cable

A cable is an assembly of one or more insulated conductors, which may have additional protective coverings or sheaths.

3. Insulation

Insulation is a non-conducting material surrounding a conductor to prevent unwanted contact between conductors and between a conductor and its surroundings.

4. Wiring accessory

A wiring accessory is a device used to control, connect or distribute electrical energy in an installation.

Examples include:

- Switches.
- Socket outlets.

- Lamp holders.
- Ceiling roses.
- Junction boxes.
- Plugs.
- Connector blocks.

5. Wiring enclosure

A wiring enclosure is a protective structure through which electrical cables are routed. Examples include conduits, trunking and cable ducts.

6. Electrical installation

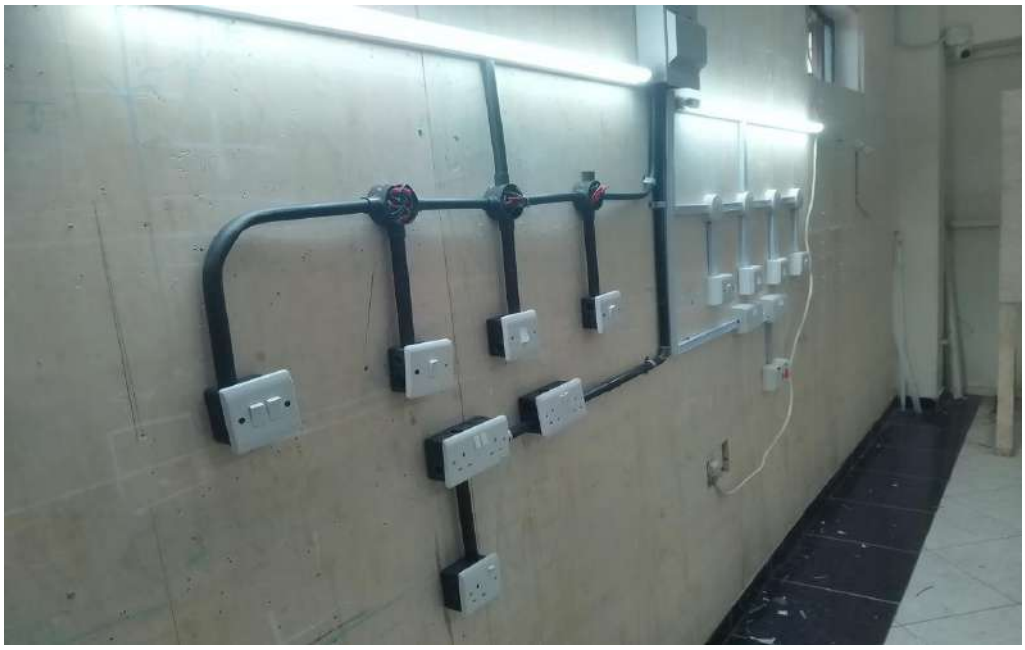
An electrical installation is the complete arrangement of wiring, electrical equipment, accessories and protective devices used to receive, distribute and use electrical energy within premises.

7. Circuit

An electrical circuit is a complete path through which electric current flows from a source, through electrical equipment and back to the source.

8. Distribution board

A distribution board is an enclosure containing protective and switching devices used to distribute electrical power to different circuits in a building.



2.0 Classification of Electrical Wiring Systems

Electrical wiring systems can be classified according to the method used to support, protect and route the cables.

The common wiring systems include:

1. PVC-sheathed wiring.
2. PVC conduit wiring.
3. Metal conduit wiring.
4. Mini-trunking wiring.
5. Trunking wiring.

6. Surface wiring.
7. Concealed wiring.
8. Cable tray and cable ladder systems.
9. Flexible conduit wiring.

The choice of a system depends on the conditions under which the installation will operate.

2.1 PVC-Sheathed Wiring System

Definition

PVC-sheathed wiring is a wiring system in which insulated electrical conductors are enclosed within a protective polyvinyl chloride (PVC) outer sheath.

PVC is a synthetic plastic material commonly used for insulating and protecting electrical cables.

Construction and features

A PVC-sheathed cable normally consists of:

1. **Conductive core:** Usually made of copper or aluminium, depending on the cable type.
2. **Insulation:** Surrounds each conductor and prevents electrical contact.
3. **Outer sheath:** Provides additional protection against moisture, abrasion and other environmental conditions, according to the cable rating.
4. **Cable identification:** Markings on the cable indicate information such as conductor size, voltage rating and manufacturer.

Installation method

1. Measure and mark the cable route.
2. Select the correct cable size and type for the circuit.
3. Route the cable along the approved path.
4. Secure the cable using suitable clips or supports at appropriate intervals.
5. Protect the cable where it passes through walls, floors or other vulnerable areas.
6. Make connections inside suitable accessories or enclosures.
7. Carry out inspection and electrical tests before energising the installation.

Applications

PVC-sheathed cables are commonly used:

- In domestic electrical installations.
- In schools and offices.
- In lighting and socket circuits.
- In surface or concealed installations where the cable type and installation method are suitable.
- In fixed wiring within buildings.

Advantages

1. Relatively economical.
2. Easy to handle and install.

3. Available in different conductor sizes.
4. Provides electrical insulation.
5. Suitable for many ordinary building installations.
6. Available in different conductor configurations.

Disadvantages

1. Can be damaged by sharp objects.
2. Some PVC cable types are unsuitable for prolonged exposure to direct sunlight.
3. Can deteriorate under excessive heat.
4. May be damaged by chemicals that are incompatible with PVC.
5. Requires additional protection where mechanical damage is likely.

2.2 PVC Conduit Wiring System

Definition

PVC conduit wiring is a wiring system in which insulated electrical cables are drawn through rigid or flexible PVC tubes called conduits.

The conduit protects the cables from mechanical damage and helps organise the wiring route.

Main components

1. **PVC conduit:** A tube through which electrical cables pass.
2. **Bends:** Used to change the direction of the conduit route.
3. **Couplers:** Used to join two conduit lengths.
4. **Inspection bends:** Provide access for drawing in or inspecting cables.
5. **Adaptors:** Connect conduits to boxes or other fittings.
6. **Junction boxes:** Provide enclosed points for joining or branching conductors where permitted.
7. **Switch boxes:** House switches and their connections.
8. **Saddles or clips:** Secure conduits to walls or ceilings.
9. **Draw-in boxes:** Provide access for pulling cables through longer or complicated routes.

Types of PVC conduit

a) Rigid PVC conduit

- Has a fixed shape.
- Used for straight routes and installations requiring firm support.
- Can be cut and joined using compatible fittings.

b) Flexible PVC conduit

- Can bend around obstacles.
- Useful where movement or awkward routing is expected.
- Must be selected according to its mechanical, temperature and environmental rating.

Installation procedure

1. Study the wiring layout diagram.
2. Identify and mark the conduit route.
3. Measure the required conduit lengths.
4. Cut the conduit using an appropriate cutting tool.
5. Remove rough edges and burrs.
6. Bend the conduit using the correct technique and suitable equipment.
7. Fix conduit clips or saddles securely.
8. Join conduit lengths using suitable couplers and fittings.
9. Install draw-in boxes and accessory boxes where necessary.
10. Check that the route is continuous and free from obstruction.
11. Draw the correctly sized insulated conductors through the conduit.
12. Make connections in suitable enclosures.
13. Inspect, test and record the results before energising.

Applications

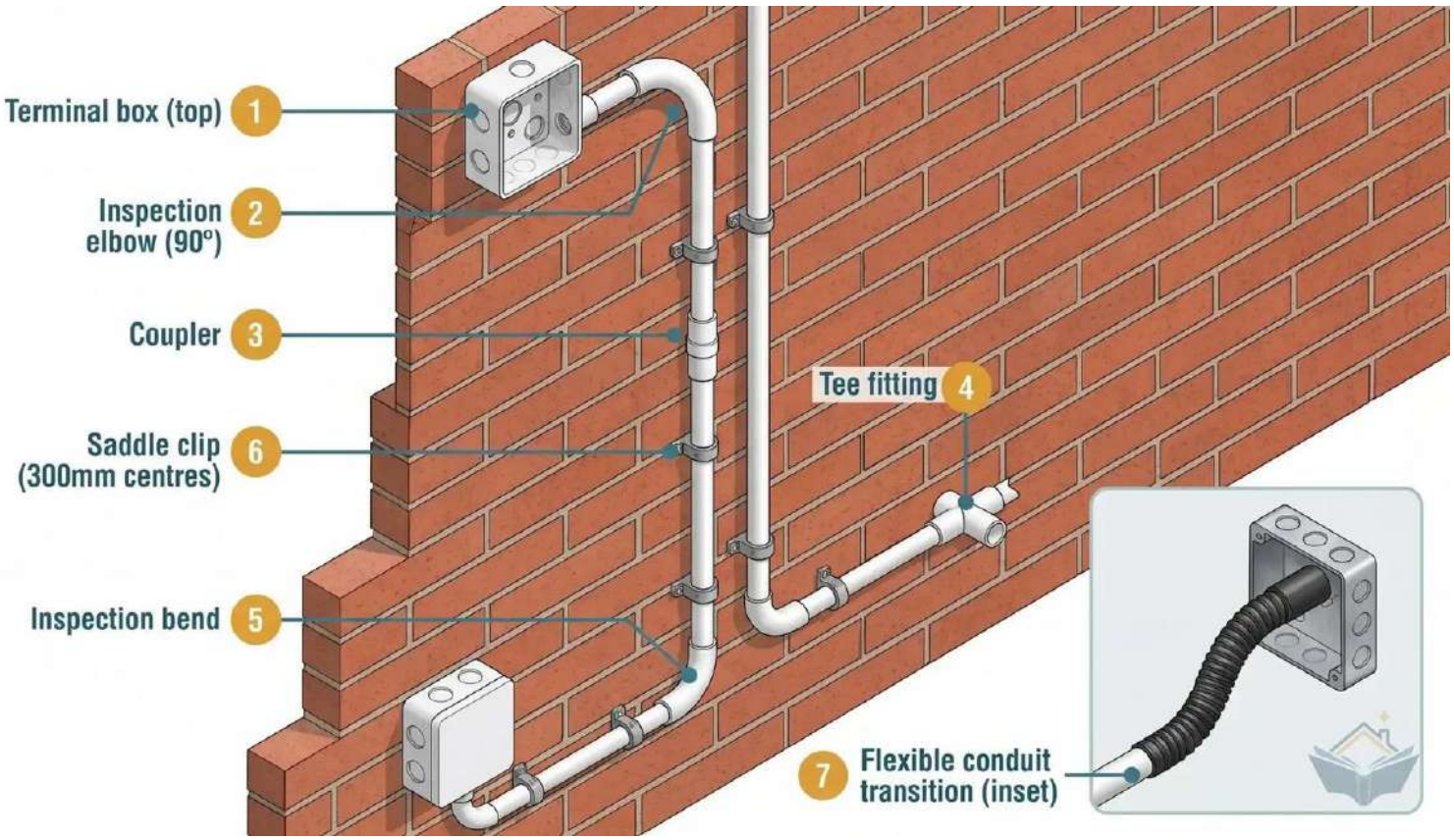
- Domestic buildings.
- Schools and hospitals.
- Offices.
- Commercial premises.
- Workshops.
- Locations where cables require additional protection.

Advantages

1. Provides good protection against mechanical damage.
2. Does not corrode like ordinary steel conduit.
3. Lightweight and easy to handle.
4. Suitable for many indoor installations.
5. Provides a neat appearance.
6. Allows cables to be replaced or added when the design and conduit capacity permit.

Disadvantages

1. May soften or deform when exposed to excessive heat.
2. Can become brittle under unsuitable environmental conditions.
3. Requires suitable fittings and careful installation.
4. May be damaged by impact if not adequately protected.
5. Some types are unsuitable for outdoor exposure unless specifically rated for that use.



2.3 Metal Conduit Wiring System

Definition

Metal conduit wiring is a wiring system in which insulated electrical conductors are enclosed inside metal tubes for protection and cable routing.

The conduit is commonly made from galvanised steel or another suitable metal.

Main components

1. Metal conduit.
2. Couplers.
3. Metal bends.
4. Inspection elbows.
5. Junction boxes.
6. Locknuts.
7. Bushes.
8. Saddles and clips.
9. Adaptors.
10. Earthing and bonding accessories where required.

Installation procedure

1. Study the wiring diagram.
2. Mark the required conduit route.
3. Measure and cut the metal conduit.
4. Remove sharp edges and burrs.

5. Thread the conduit ends where threaded fittings are used.
6. Bend the conduit using an appropriate bending tool.
7. Fix the conduit firmly to the building structure.
8. Install suitable boxes and fittings.
9. Ensure continuity of the protective conductor and bonding arrangements.
10. Draw in the insulated cables.
11. Make connections in suitable enclosures.
12. Test the installation before it is energised.

Applications

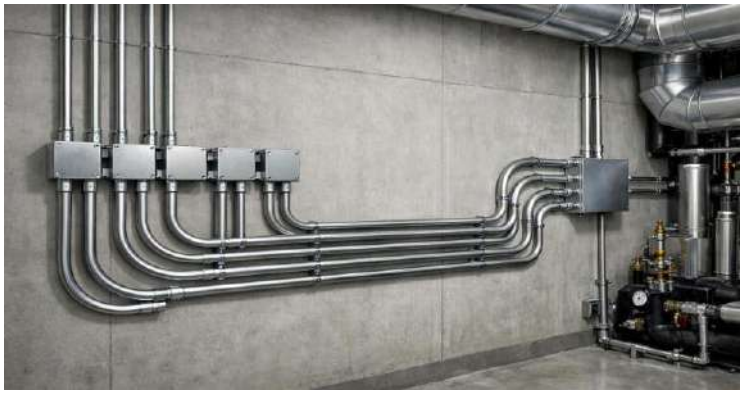
- Factories.
- Industrial workshops.
- Commercial buildings.
- Garages.
- Workshops with a high risk of mechanical damage.
- Certain outdoor or exposed installations using appropriately rated materials.

Advantages

1. Offers strong mechanical protection.
2. Suitable for harsh environments when correctly selected.
3. Provides a durable cable-routing system.
4. Can be used in industrial installations.
5. Offers a neat and organised installation.

Disadvantages

1. More expensive than many PVC systems.
2. Requires specialised tools and skills.
3. Heavier and more difficult to handle.
4. Can corrode if the metal and protective finish are unsuitable.
5. Requires effective earthing and bonding arrangements.



2.4 Mini-Trunking Wiring System

Definition

Mini-trunking wiring is a system in which insulated electrical cables are enclosed in small rectangular or square plastic channels fixed to walls, ceilings or other suitable surfaces.

The trunking normally has a base and a removable cover.

Main components

1. **Trunking base:** The part fixed to the wall or ceiling.
2. **Cover:** Closes the trunking and protects the cables.
3. **Internal bends:** Used to change direction within the trunking.
4. **External bends:** Used for outside corners.
5. **Flat angles:** Used for changes in direction on a flat surface.
6. **Tees:** Used to create branch routes.
7. **End caps:** Close the ends of the trunking.
8. **Couplers:** Join two trunking lengths.
9. **Fixing screws or suitable adhesive:** Secure the trunking according to the manufacturer's instructions.

Installation procedure

1. Study the wiring layout.
2. Determine the position of the trunking route.
3. Measure the required lengths.
4. Cut the trunking base and cover to size.
5. Remove rough edges.
6. Fix the trunking base to the surface.
7. Install suitable bends, tees and other fittings.
8. Lay the insulated cables inside the trunking without overcrowding.
9. Make connections in suitable accessory boxes.
10. Fit the trunking cover securely.
11. Inspect the installation and carry out the required tests.

Applications

- Offices.
- Computer laboratories.
- Shops.
- Classrooms.
- Domestic buildings.
- Small commercial installations.
- Surface extensions to existing installations where permitted.

Advantages

1. Easy to install.
2. Provides a neat appearance.
3. Protects cables from minor mechanical damage.
4. Makes inspection and maintenance easier.
5. Allows access to cables by removing the cover.
6. Useful for adding wiring to an existing building without extensive wall cutting.

Disadvantages

1. Provides less mechanical protection than some heavy-duty conduit systems.
2. May be affected by excessive heat.
3. Can become discoloured with age or sunlight exposure.
4. May not be suitable for areas exposed to severe impact.
5. Can look untidy if poorly planned or installed.

2.5 Surface Wiring System

Definition

Surface wiring is a wiring arrangement in which cables or wiring enclosures are installed on the visible surface of walls, ceilings or other building structures.

The cables may be supported by clips, enclosed in trunking or installed in surface-mounted conduit.

Features

1. Wiring routes are visible.
2. Installation does not usually require cutting channels into walls.
3. Inspection and maintenance are relatively easy.
4. It is useful when modifying existing buildings.
5. Suitable protection must be provided against mechanical damage.

Applications

- Workshops.
- Stores.
- Temporary structures.
- Existing buildings undergoing renovation.
- Utility rooms.
- Certain domestic and commercial installations.

Advantages

1. Easy to inspect.
2. Easy to modify.
3. Reduces the amount of wall chasing.
4. Usually requires less building alteration.

5. Faults may be easier to locate.

Disadvantages

1. May affect the appearance of a room.
2. Cables may be exposed to physical damage if not protected.
3. May collect dust on exposed surfaces.
4. Requires neat routing and secure fixing.

2.6 Concealed Wiring System

Definition

Concealed wiring is a wiring system in which cables or conduits are installed inside walls, ceilings, floors or other building structures so that they are not normally visible.

Installation features

1. Wiring routes are planned before walls or ceilings are completed.
2. Cables are normally installed in suitable conduits or other approved wiring enclosures.
3. Accessory boxes are installed at the positions of switches and socket outlets.
4. The routes are selected to allow safe cable installation and future maintenance.
5. Suitable protection is required where cables pass through structural elements.

Applications

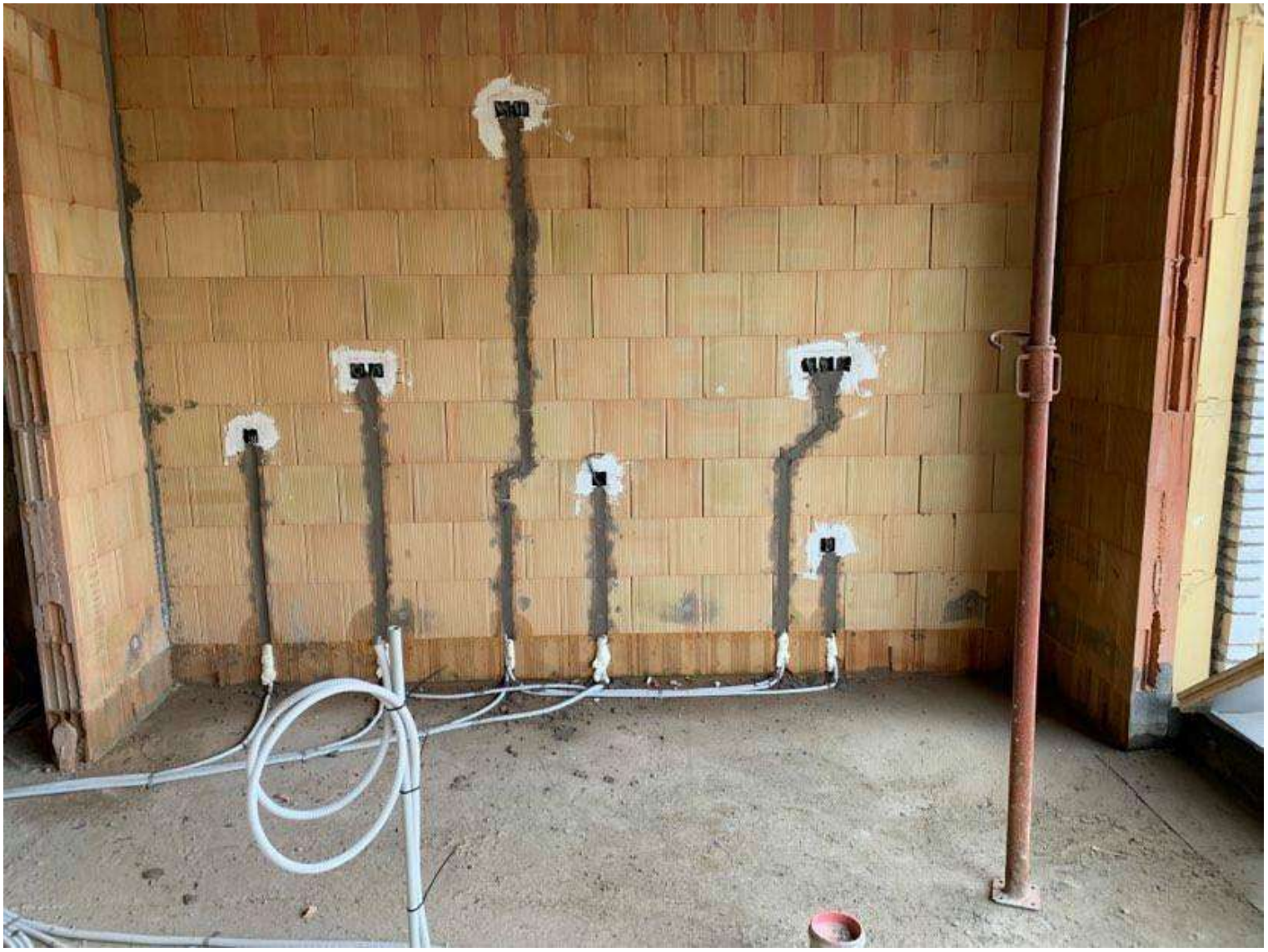
- Modern residential houses.
- Hotels.
- Hospitals.
- Offices.
- Schools.
- Commercial buildings.

Advantages

1. Provides an attractive appearance.
2. Protects cables from many forms of accidental contact.
3. Reduces visible wiring.
4. Provides an organised installation.
5. Can improve the durability of an installation when correctly designed.

Disadvantages

1. More difficult to inspect.
2. Fault-finding may require additional work.
3. Installation can be expensive.
4. Modifications may require wall or ceiling work.
5. Poor planning can make future maintenance difficult.



2.7 Cable Tray and Cable Ladder Systems

Definition

A cable tray is a support structure used to carry and organise electrical cables along walls, ceilings or other building structures.

A cable ladder is a support system consisting of two side rails connected by cross-members, resembling a ladder.

Types of cable support systems

1. Perforated cable trays.
2. Solid-bottom cable trays.
3. Wire-mesh cable trays.
4. Ladder cable trays.
5. Cable trunking systems.

Applications

- Factories.
- Large commercial buildings.
- Data centres.

- Industrial plants.
- Large electrical distribution installations.
- Power stations.

Advantages

1. Supports large numbers of cables.
2. Makes cable routing organised.
3. Provides easier inspection.
4. Facilitates future cable additions.
5. Can reduce the need for multiple separate conduits.

Disadvantages

1. Requires adequate structural support.
2. Some types provide limited mechanical protection.
3. May require earthing and bonding.
4. Can be expensive for small installations.
5. Requires proper separation and arrangement of different cable services.

2.8 Comparison of Wiring Systems

Wiring system	Main feature	Common application
PVC-sheathed wiring	Insulated conductors with outer PVC sheath	Domestic and general building wiring
PVC conduit	Cables enclosed in PVC tubes	Homes, schools and offices
Metal conduit	Cables enclosed in metal tubes	Industrial and workshop installations
Mini-trunking	Cables enclosed in small plastic channels	Offices and surface extensions
Surface wiring	Wiring installed on visible surfaces	Workshops and renovations
Concealed wiring	Wiring hidden in building structures	Modern houses and offices
Cable tray	Cables supported on trays	Commercial and industrial buildings
Cable ladder	Cables supported on ladder-like structures	Large industrial installations

Important: The suitability of a wiring system depends on the actual environmental conditions, cable characteristics, mechanical protection, fire requirements and applicable installation standards. A wiring system should not be selected on appearance or cost alone.

3.0 Factors Determining the Choice of a Wiring System

A suitable wiring system must be selected before an electrical installation begins. The selection should ensure safety, reliability, durability and economy.

3.1 Type and use of the building

Different buildings have different wiring requirements.

Examples:

- A residential house may use concealed PVC conduit wiring.
- A school computer laboratory may use surface trunking or conduit.
- A factory may require heavy-duty metal conduit or cable tray systems.
- A temporary site office may use an approved surface wiring arrangement.

3.2 Cost of installation

The cost includes:

1. Cost of cables.
2. Cost of conduits or trunking.
3. Cost of accessories.
4. Labour charges.
5. Cost of installation tools and equipment.
6. Maintenance costs.

A low initial cost should not compromise safety or durability.

3.3 Environmental conditions

The installation environment affects the choice of wiring system.

Consider:

- Moisture.
- Dust.
- High temperatures.
- Corrosive substances.
- Direct sunlight.
- Chemical exposure.
- Risk of flooding.
- Outdoor weather conditions.

For example, wiring in a damp location requires materials and equipment suitable for that environment.

3.4 Mechanical protection

Where cables may be struck, crushed, cut or damaged, a wiring system providing suitable mechanical protection should be selected.

Examples include:

- Metal conduit in certain workshops.
- Heavy-duty conduit in exposed locations.

- Properly supported cable trays in industrial installations.

3.5 Appearance

In buildings where appearance is important, concealed wiring or neatly installed mini-trunking may be preferred.

3.6 Future expansion

The system should allow future modifications where possible.

Examples:

- Offices may require additional data and power outlets.
- Schools may need extra classroom socket outlets.
- Commercial premises may need additional equipment circuits.

3.7 Type of electrical load

The wiring system must accommodate the current and operating conditions of the connected equipment.

Examples:

- Lighting circuits.
- Socket-outlet circuits.
- Water heaters.
- Electric cookers.
- Motors.
- Workshop machinery.

3.8 Ease of inspection and maintenance

Some systems make it easier to inspect and replace cables than others.

Surface conduit and trunking may provide easier access than concealed wiring, depending on the installation design.

3.9 Fire safety

Materials and wiring arrangements should be selected to reduce fire risks and comply with applicable fire and electrical installation requirements.

3.10 Skills and availability of materials

The availability of trained installers, suitable tools, approved materials and replacement accessories can influence the selection of a wiring system.

3.11 Summary of selection factors

1. Cost.
2. Safety.
3. Building type.
4. Environmental conditions.
5. Mechanical protection.
6. Appearance.

7. Load requirements.
8. Ease of maintenance.
9. Future expansion.
10. Availability of materials and skilled labour.
11. Fire safety.
12. Compliance with regulations.

4.0 Electrical Wiring Regulations and Standards in Kenya

4.1 Meaning of electrical wiring regulations

Electrical wiring regulations are legally recognised requirements and technical rules that guide the design, selection, installation, inspection, testing and maintenance of electrical installations.

They are intended to protect people, property and electrical equipment from dangers associated with electricity.

4.2 Importance of wiring regulations

Wiring regulations are important because they:

1. Protect people against electric shock.
2. Reduce the risk of electrical fires.
3. Ensure that electrical equipment is correctly selected.
4. Provide guidance on cable sizes and current ratings.
5. Ensure effective earthing and bonding.
6. Guide the selection of protective devices.
7. Promote uniformity in electrical installations.
8. Improve the reliability of electrical systems.
9. Provide requirements for inspection and testing.
10. Ensure installations are safe for use.

4.3 Main regulatory framework in Kenya

Electrical installation work in Kenya should comply with the applicable laws, Kenya Standards and recognised technical requirements.

Important references include:

1. Energy Act, 2019

The Energy Act provides the legal framework for the energy sector in Kenya. It includes requirements relating to electrical installation work and the authorisation of persons carrying out such work.

2. National Building Code, 2024

The National Building Code, 2024, includes requirements for electrical installations in buildings. Part XV addresses electrical installations and refers to applicable Kenyan standards and other recognised technical standards.

3. KS 662 – Electrical Installations

KS 662 is a Kenya Standard referenced in the National Building Code for electrical installations. It provides requirements for electrical installation work.

4. KS 1587 – National Electrical Safety Code

This standard is among the technical references identified for electrical installation safety in Kenya.

5. BS 7671 – IET Wiring Regulations

BS 7671 provides requirements for electrical installations. It is referenced in Kenya's National Building Code as one of the applicable technical standards.

6. IEC Standards

The International Electrotechnical Commission (IEC) develops international standards for electrical equipment and installations. Relevant IEC standards are adopted or referenced through applicable Kenyan standards.

7. EPRA licensing requirements

The Energy and Petroleum Regulatory Authority (EPRA) regulates the licensing of electrical workers and electrical contractors in Kenya. Electrical installation work must be undertaken by appropriately authorised persons.

Important textbook note

The National Building Code, 2024, identifies the Energy Act, KS 662, KS 1587 and relevant KS IEC standards, as well as BS 7671, among the references for building electrical installations. Always consult the current editions and applicable legal requirements before carrying out actual installation work. Do not assume that an older wiring code or colour convention automatically applies to a new installation.

4.4 General requirements of electrical wiring regulations

Electrical installations should meet the following requirements:

1. Electrical equipment must be suitable for the intended purpose.
2. Conductors must have appropriate current-carrying capacity.
3. Cables must have suitable insulation and protection.
4. Circuits must be protected against overcurrent.
5. Effective earthing and bonding must be provided where required.
6. Live parts must be adequately insulated or enclosed.
7. Switches and protective devices must be correctly rated.
8. Wiring routes must be selected to minimise damage.
9. Connections must be secure and made in suitable enclosures.
10. Installations must be inspected and tested before being put into service.
11. Electrical work must be carried out by appropriately authorised personnel.
12. Records and certificates must be provided where required.

4.5 Cable colour identification

Cable colours help identify the function of conductors. The harmonised colours commonly used in modern single-phase installations are:

Conductor	Colour	Function

Live (line)	Brown	Carries supply voltage to the load
Neutral	Blue	Provides the normal return path in the circuit
Protective earth	Green/yellow	Provides a protective path for fault current

For a modern three-phase system, the commonly used harmonised identification is:

Conductor	**Colour**
Line 1 (L1)	Brown
Line 2 (L2)	Black
Line 3 (L3)	Grey
Neutral	Blue
Protective earth	Green/yellow

Caution: Older installations may use different colour conventions. Never identify a conductor by colour alone. A competent person must verify conductors using appropriate testing procedures.

4.6 Earthing and bonding

Earthing is the connection of exposed conductive parts of electrical equipment to the earthing system to help reduce the risk of electric shock under fault conditions.

Bonding is the electrical connection of conductive parts to maintain them at substantially the same potential and reduce dangerous voltage differences.

Importance of earthing

1. Provides a path for fault current.
2. Helps protective devices operate during certain earth faults.
3. Reduces the risk of electric shock.
4. Protects equipment and installations.
5. Helps improve electrical safety.

Examples of equipment requiring appropriate earthing arrangements

- Metal distribution boards.
- Metal conduit systems where required.
- Metal enclosures of electrical equipment.
- Certain appliances with exposed conductive parts.

4.7 Overcurrent protection

Overcurrent is a current greater than the current a circuit or equipment is designed to carry.

It may occur due to:

- Overloading.
- Short circuits.
- Fault conditions.

Common protective devices include:

a) Fuse

A fuse is a protective device containing a conductor that melts when excessive current flows through it, thereby interrupting the circuit.

b) Miniature Circuit Breaker (MCB)

An MCB is a protective switching device that automatically disconnects a circuit when an overcurrent condition occurs.

c) Residual Current Device (RCD)

An RCD disconnects a circuit when it detects a residual current indicating an imbalance between outgoing and returning current.

d) Residual Current Circuit Breaker with Overcurrent Protection (RCBO)

An RCBO combines residual-current protection and overcurrent protection in one device.

4.8 Isolation of electrical circuits

Isolation is the disconnection of an electrical circuit or equipment from its source of electrical supply to allow safe work.

Before work begins, a competent person should:

1. Identify the correct circuit.
2. Disconnect the supply using a suitable isolating device.
3. Prevent accidental reconnection.
4. Verify that the circuit is dead using an approved voltage tester.
5. Follow the appropriate safe working procedure.

A switch being in the OFF position is not, by itself, proof that a circuit is safe to work on.

5.0 Electrical Wiring Layout Diagrams

5.1 Definition of a wiring layout diagram

A wiring layout diagram is a drawing showing the positions of electrical accessories, equipment and wiring routes in a building or installation.

It helps the electrician understand where electrical components should be installed and how the wiring should be arranged.

5.2 Importance of wiring layout diagrams

1. Guide the installation process.
2. Show the position of switches and socket outlets.
3. Indicate lighting points.
4. Show distribution board locations.

5. Help estimate cable and accessory requirements.
6. Reduce installation errors.
7. Assist in maintenance and fault-finding.
8. Improve communication between designers and installers.

5.3 Types of electrical diagrams

1. Layout diagram

Shows the physical positions of electrical accessories and equipment within a building.

2. Schematic diagram

Shows the electrical operation and relationship of components using standard symbols. It does not necessarily represent their physical positions.

3. Wiring diagram

Shows the actual electrical connections between components and conductors.

4. Single-line diagram

Represents a multi-conductor electrical system using a single line and standard symbols or annotations.

5.4 Common electrical symbols

Symbol description	**Meaning**
Circle with cross	Lighting point
S	One-way switch
S2	Two-way switching arrangement
Socket symbol	Socket outlet
DB	Distribution board
M	Electric motor
F	Fuse
MCB	Miniature circuit breaker
E	Earth connection
L	Live conductor
N	Neutral conductor

Symbols may vary according to the drawing standard being used. Always refer to the legend provided on a particular drawing.

5.5 Interpreting a wiring layout diagram

When interpreting a wiring layout diagram:

1. Read the drawing title.
2. Identify the building or room layout.
3. Study the symbol legend.
4. Identify the distribution board.
5. Locate lighting points.
6. Locate switches.
7. Identify socket outlets.
8. Trace the indicated wiring routes.
9. Identify the number and type of circuits.
10. Check dimensions and installation notes.
11. Identify special equipment such as water heaters or motors.
12. Observe any safety and installation instructions.

5.6 Example of interpreting a simple classroom layout

A classroom electrical layout may show:

- One distribution board near the entrance.
- Four lighting points distributed across the ceiling.
- Two one-way switches near the door.
- Four double socket outlets along the walls.
- A dedicated circuit for special equipment where required.

The layout assists the installer in estimating cable lengths, accessories and labour requirements.

6.0 Electrical Wiring Components and Their Functions

An electrical wiring system consists of several components that work together to distribute electricity safely.

6.1 Electrical cables

Function:

- Carry electric current.
- Connect the supply to electrical loads.
- Link switches, socket outlets and other accessories.

6.2 Conduits

Function:

- Enclose and protect cables.
- Provide organised cable routes.
- Assist with future cable replacement where the system permits.

6.3 Trunking

Function:

- Encloses groups of cables.
- Provides neat surface wiring routes.
- Allows access to cables for inspection and maintenance.

6.4 Switches

A switch is a device used to make or break an electrical circuit.

Functions:

- Controls lighting points.
- Controls electrical equipment.
- Allows users to disconnect certain circuits or loads.

6.5 Socket outlets

A socket outlet is an electrical accessory that provides a connection point for an appliance plug.

Functions:

- Supplies electrical power to appliances.
- Provides a safe and standardised connection.
- Allows appliances to be connected and disconnected.

6.6 Junction boxes

A junction box is an enclosure used to contain electrical connections and branching points.

Functions:

- Protects electrical connections.
- Prevents accidental contact with live parts.
- Provides an accessible point for inspection where required.

6.7 Distribution boards

Functions:

- Distribute electrical power to different circuits.
- House protective devices.
- Provide a means of controlling and isolating circuits.
- Help organise circuit identification.

6.8 Fuses and circuit breakers

Functions:

- Protect conductors and equipment against overcurrent.
- Disconnect faulty circuits.
- Help prevent damage caused by excessive current.

6.9 Earthing conductors

Functions:

- Connect exposed conductive parts to the earthing system.
- Provide a path for fault current.
- Support the operation of protective devices.

6.10 Cable clips and saddles

Functions:

- Hold cables or conduits in position.
- Prevent unnecessary movement.
- Maintain neat wiring routes.
- Reduce strain on cable connections.

6.11 Insulating bushes and grommets

Functions:

- Protect cables from sharp edges.
- Reduce the possibility of insulation damage.
- Provide a smoother entry into enclosures.

7.0 Planning an Electrical Wiring Installation

Proper planning is essential before installing any wiring system.

7.1 Steps involved in planning

Step 1: Study the building

Identify:

- Number of rooms.
- Building use.
- Construction materials.
- Environmental conditions.
- Areas requiring special protection.

Step 2: Identify electrical requirements

Determine:

- Number of lighting points.
- Number of socket outlets.
- Appliances to be connected.
- Special equipment requirements.
- Expected electrical load.

Step 3: Prepare the wiring layout

Show:

- Distribution board position.

- Lighting points.
- Switch positions.
- Socket outlet positions.
- Cable routes.
- Special equipment points.

Step 4: Select the wiring system

Consider:

- Cost.
- Safety.
- Building type.
- Environmental conditions.
- Mechanical protection.
- Maintenance requirements.

Step 5: Select cables and protective devices

The cable size and protective-device rating must be determined using the applicable design requirements and calculations. They should not be selected by guesswork.

Step 6: Prepare a materials list

The list may include:

1. Electrical cables.
2. Conduits.
3. Trunking.
4. Switches.
5. Socket outlets.
6. Junction boxes.
7. Distribution board.
8. Circuit breakers.
9. Earthing accessories.
10. Fixing screws and clips.

Step 7: Prepare a work schedule

Arrange the installation activities in a logical order to ensure efficient use of labour, materials and tools.

8.0 Tools and Equipment Used in Wiring Installation

The correct tools improve accuracy, efficiency and safety.

Tool or equipment	**Function**
Screwdriver	Tightening and loosening screws

Combination pliers	Holding, gripping and bending conductors
Side-cutting pliers	Cutting conductors and small wires
Wire stripper	Removing insulation without damaging the conductor
Measuring tape	Measuring cable and conduit routes
Spirit level	Checking alignment
Hacksaw	Cutting conduit and trunking
Conduit bender	Bending conduit
Electrician's knife	Removing cable sheath where appropriate
Fish tape or draw wire	Pulling cables through conduit
Voltage tester	Checking for the presence of voltage
Approved test instruments	Carrying out electrical installation tests
Drill and suitable bits	Making fixing holes
Hammer	Driving suitable fixings



8.1 Personal protective equipment (PPE)

PPE includes equipment worn to reduce exposure to workplace hazards.

Examples:

1. Safety boots.
2. Safety glasses.
3. Suitable protective gloves.
4. Overalls.
5. Hard hat where necessary.
6. Hearing protection when using noisy equipment.

PPE does not replace safe isolation, correct tools, competent supervision or proper working procedures.

9.0 Installation Techniques for Different Wiring Systems

9.1 General preparation before installation

1. Study the approved wiring diagram.
2. Confirm that the installation work is authorised and properly supervised.
3. Identify the supply source and circuits.
4. Isolate the supply before working on existing electrical circuits.
5. Verify that the circuit is dead using an appropriate tester.
6. Wear suitable PPE.
7. Prepare the required tools and materials.
8. Mark the wiring routes accurately.
9. Check that the materials are suitable and in good condition.
10. Keep the working area clean and organised.

9.2 Installing PVC-sheathed wiring

1. Study and mark the cable route.
2. Measure the required cable length.
3. Select the appropriate cable type and size.
4. Route the cable using the approved method.
5. Fix the cable using suitable supports.
6. Protect cables against sharp edges and mechanical damage.
7. Make connections in suitable accessories or enclosures.
8. Identify conductors correctly.
9. Inspect the completed work.
10. Carry out the required tests before energising.

9.3 Installing PVC conduit wiring

1. Mark the conduit route.

2. Measure and cut the conduit.
3. Remove burrs and rough edges.
4. Bend the conduit carefully.
5. Install the required boxes and fittings.
6. Fix the conduit using suitable saddles.
7. Check alignment and continuity of the route.
8. Draw the cables through the conduit.
9. Make connections in suitable enclosures.
10. Inspect and test the installation.

9.4 Installing mini-trunking

1. Mark the trunking route.
2. Measure and cut the trunking.
3. Separate the base and cover.
4. Fix the base securely.
5. Install bends, tees and couplers.
6. Place the cables neatly inside the base.
7. Avoid overcrowding and damage to insulation.
8. Make connections in appropriate boxes.
9. Fit the cover.
10. Inspect and test the installation.

9.5 Quality checks during installation

The installer should check that:

1. Wiring follows the approved layout.
2. Cables are correctly supported.
3. Conduits and trunking are firmly fixed.
4. Connections are secure.
5. Insulation is not damaged.
6. Correct accessories are used.
7. Protective conductors are properly connected.
8. Cables are not overcrowded.
9. Appropriate separation is maintained between different services.
10. All enclosures and covers are fitted correctly.

10.0 Inspection and Testing of Electrical Installations

10.1 Meaning of inspection

Inspection is the process of examining an electrical installation to determine whether the materials, components and workmanship meet the required safety and installation standards.

10.2 Meaning of testing

Testing is the use of approved instruments and procedures to establish whether an electrical installation is electrically safe and operates correctly.

10.3 Importance of inspection and testing

1. Identifies installation errors.
2. Detects damaged insulation.
3. Checks continuity of conductors.
4. Verifies the effectiveness of protective arrangements.
5. Helps identify faults before energising.
6. Confirms that the installation is suitable for use.
7. Provides information for maintenance records.

10.4 Common inspection checks

1. Correct selection of cables.
2. Proper cable support.
3. Correct identification of conductors.
4. Secure connections.
5. Suitable enclosures.
6. Correct selection of protective devices.
7. Effective earthing and bonding.
8. Suitable isolation arrangements.
9. Correct positioning of accessories.
10. Absence of visible damage.

10.5 Common electrical installation tests

The following tests are examples of tests used in electrical installation verification. They must be conducted by trained and authorised personnel using suitable instruments and the applicable procedures.

1. Continuity of protective conductors

Checks whether protective conductors provide a continuous electrical path.

2. Insulation resistance test

Checks the quality of insulation between conductors and between conductors and earth, as appropriate.

3. Polarity test

Confirms that line, neutral and protective conductors are correctly connected to the intended terminals.

4. Earth fault loop impedance test

Determines the impedance of the earth fault current path to help establish whether protective devices can operate effectively under fault conditions.

5. RCD test

Checks the operation and performance of a residual current device.

6. Functional test

Confirms that switches, controls and equipment operate as intended.

11.0 Electrical Safety During Wiring Installation

Electricity can cause electric shock, burns, fires and serious injury. Safety must therefore be observed at every stage of an installation.

11.1 General safety precautions

1. Electrical work should be carried out by appropriately trained and authorised persons.
2. Always isolate the supply before working on an existing circuit.
3. Verify that the circuit is dead using an approved voltage tester.
4. Never work with damaged electrical tools.
5. Use tools with suitable insulation and condition.
6. Keep the working area dry and clean.
7. Avoid handling electrical equipment with wet hands.
8. Use the correct cable size and protective devices.
9. Do not overload socket outlets.
10. Ensure proper earthing and bonding.
11. Keep exposed live conductors enclosed.
12. Replace damaged cables and accessories.
13. Use warning signs and barriers where necessary.
14. Keep unauthorised persons away from the work area.
15. Do not energise an installation before the required inspection and testing.

11.2 Common electrical hazards

Hazard	Possible consequence	Preventive measure
Exposed live conductors	Electric shock	Insulate and enclose live parts
Damaged cables	Shock or fire	Replace damaged cables
Overloading	Overheating and fire	Use correctly designed circuits
Poor connections	Heat generation and fire	Make secure approved connections
Wet working conditions	Electric shock	Keep equipment and work areas suitably

		dry
Incorrect earthing	Dangerous touch voltage	Provide effective earthing and bonding
Incorrect protective device	Failure to disconnect a fault	Select suitable protective devices
Poor cable support	Cable damage	Use suitable clips and supports

11.3 Safe working practices

- Follow isolation and lock-off procedures.
- Use a suitable proving method for voltage testers.
- Never rely on a circuit label alone to identify a safe circuit.
- Keep tools and materials organised.
- Avoid pulling cables with excessive force.
- Use suitable ladders and access equipment.
- Dispose of waste materials safely.
- Report defects immediately.

12.0 Maintenance of Electrical Wiring Systems

12.1 Definition of maintenance

Maintenance is the process of inspecting, servicing, repairing or replacing parts of an electrical installation to keep it safe and in good working condition.

12.2 Types of maintenance

1. Preventive maintenance

Maintenance carried out at planned intervals to reduce the likelihood of faults.

Examples:

- Routine inspection.
- Checking enclosures.
- Checking for visible cable damage.
- Reviewing circuit identification.

2. Corrective maintenance

Maintenance carried out after a defect or fault has been identified.

Examples:

- Replacing a damaged socket outlet.
- Repairing a defective accessory.
- Replacing a faulty protective device with a suitable one.

3. Predictive maintenance

Maintenance based on observations and measurements that help identify possible future failure.

Examples:

- Monitoring abnormal temperatures.
- Recording repeated equipment faults.
- Assessing trends in test results.

12.3 Maintenance activities

1. Inspect cable routes for physical damage.
2. Check conduit and trunking supports.
3. Replace cracked or damaged enclosures.
4. Check that accessories are firmly fixed.
5. Inspect distribution boards for visible defects.
6. Confirm that circuit labels are legible.
7. Arrange appropriate periodic testing.
8. Keep maintenance records.
9. Correct identified defects promptly.
10. Ensure that modifications are documented.

12.4 Importance of maintenance

1. Improves safety.
2. Reduces unexpected breakdowns.
3. Extends the service life of equipment.
4. Helps prevent electrical fires.
5. Maintains reliable power distribution.
6. Reduces repair costs.
7. Supports compliance with applicable requirements.

13.0 Practical Applications of Wiring Systems in Kenya

Electrical wiring systems are used in many sectors of the Kenyan economy.

13.1 Domestic buildings

Examples:

- Lighting circuits in houses.
- Socket outlets in bedrooms.
- Cooker circuits in kitchens.
- Water-heater circuits in bathrooms.

13.2 Schools and training institutions

Examples:

- Classroom lighting.

- Computer laboratory wiring.
- Workshop power circuits.
- Administration block installations.
- Science laboratory equipment circuits.

13.3 Hospitals and health centres

Examples:

- Lighting systems.
- Socket outlets for medical equipment.
- Emergency power circuits.
- Special installations for critical equipment.

Such installations require careful design and compliance with requirements for the relevant special locations and equipment.

13.4 Commercial buildings

Examples:

- Shops.
- Supermarkets.
- Banks.
- Hotels.
- Office blocks.

13.5 Agricultural installations

Examples:

- Water pumps.
- Irrigation systems.
- Poultry-house lighting.
- Milk-cooling equipment.
- Farm workshops.

Agricultural installations may be exposed to moisture, dust, chemicals and mechanical damage. Wiring systems must therefore be selected to suit the environment.

13.6 Industrial installations

Examples:

- Motor circuits.
- Production machinery.
- Control panels.
- Industrial lighting.
- Distribution systems.

14.0 Competency-Based Education (CBE) Integration

The learning of wiring systems and regulations should develop practical skills, problem-solving abilities and responsible behaviour.

14.1 Core competencies

Core competency	How it is developed
Communication and collaboration	Learners discuss wiring methods and work in installation groups
Critical thinking and problem-solving	Learners select suitable wiring systems for different buildings
Creativity and imagination	Learners design wiring layouts and installation models
Digital literacy	Learners research wiring systems and regulations using digital media
Learning to learn	Learners investigate new wiring materials and technologies
Self-efficacy	Learners plan and complete supervised practical tasks

14.2 Values

Responsibility: Learners handle tools and materials carefully.

Integrity: Learners follow safety rules and report defects honestly.

Respect: Learners respect the safety of colleagues and users.

Unity: Learners cooperate during group practical activities.

Patriotism: Learners appreciate the role of electrical technology in Kenya's development.

14.3 Pertinent and contemporary issues (PCIs)

1. **Safety and security:** Safe handling of electrical tools and equipment.
2. **Environmental conservation:** Responsible disposal and recycling of cable and plastic waste.
3. **Health education:** Prevention of electrical injuries.
4. **Financial literacy:** Cost estimation and economical use of materials.
5. **Disaster risk reduction:** Prevention of electrical fires and accidents.
6. **Occupational safety:** Safe working practices in electrical workshops.

15.0 Suggested Learning Experiences and Practical Activities

Activity 1: Identification of wiring systems

Objective: Identify different wiring systems and their components.

Materials:

- PVC-sheathed cables.
- PVC conduits.
- Metal conduits.

- Mini-trunking.
- Junction boxes.
- Cable clips.
- Sample switches and socket outlets.

Procedure:

1. Learners observe the different wiring materials.
2. Identify each material.
3. Describe its main features.
4. State its functions.
5. Identify possible applications.
6. Present findings to the class.

Expected outcome: Learners identify wiring systems and explain their applications.

Activity 2: Selecting a wiring system for a building

Objective: Select an appropriate wiring system for a given application.

Situation:

A school plans to install electricity in the following areas:

- Computer laboratory.
- Administration office.
- Workshop.
- Classroom block.

Procedure:

1. Learners work in groups.
2. Discuss the conditions in each area.
3. Identify the likely wiring requirements.
4. Select a suitable wiring arrangement.
5. Explain the reasons for their choices.
6. Present their findings.

Expected outcome: Learners make informed decisions when selecting wiring systems.

Activity 3: Drawing a wiring layout

Objective: Interpret and draw simple wiring layouts.

Procedure:

1. Draw a simple classroom plan.
2. Mark the lighting points.
3. Show the switch positions.
4. Indicate socket outlets.

5. Show the distribution board.
6. Prepare a symbol legend.
7. Present the layout for assessment.

Activity 4: Installing a mini-trunking sample

Objective: Install a sample mini-trunking system using appropriate techniques.

Materials:

- Mini-trunking.
- Screws.
- Measuring tape.
- Hacksaw.
- Screwdriver.
- Suitable sample cables.
- PPE.

Procedure:

1. Measure the required length.
2. Mark the cutting positions.
3. Cut the trunking neatly.
4. Fix the trunking base.
5. Install the cables without damaging them.
6. Fit the cover.
7. Inspect the finished sample.

Safety note: This is a supervised training exercise. Do not connect the sample to a live supply unless the complete installation has been properly designed, inspected and tested by an authorised person.

Activity 5: Research on wiring regulations

Objective: Identify regulations and standards governing electrical installations in Kenya.

Procedure:

1. Use print or digital sources.
2. Research the Energy Act, 2019.
3. Examine the National Building Code, 2024.
4. Identify relevant Kenya Standards.
5. Research EPRA licensing requirements.
6. Discuss the importance of following wiring regulations.
7. Present a summary to the class.

16.0 Key Points to Remember

1. An electrical wiring system distributes electrical energy safely within a building.

2. Common wiring systems include PVC-sheathed, PVC conduit, metal conduit, mini-trunking, surface and concealed wiring.
3. The selection of a wiring system depends on cost, safety, building type, environment and load requirements.
4. Wiring regulations promote safety and reliability.
5. Kenya's National Building Code, 2024, identifies important standards applicable to electrical installations.
6. Electrical wiring diagrams guide the installation process.
7. Electrical components must be correctly selected and installed.
8. Earthing and bonding are important protective measures.
9. Inspection and testing must be carried out before an installation is put into service.
10. Electrical installation work must be undertaken by appropriately authorised persons.
11. Maintenance helps keep wiring systems safe and reliable.
12. Correct installation techniques reduce faults and electrical accidents.

REVISION QUESTIONS

SECTION A: MULTIPLE-CHOICE QUESTIONS (30 MARKS)

1. What is an electrical wiring system?

A. An arrangement of water pipes in a building.

B. An arrangement of conductors, accessories and protective devices used to distribute electricity.

C. A system used to generate mechanical energy.

D. An arrangement used to store electrical energy.

2. Which of the following materials is commonly used to manufacture electrical cable insulation?

A. Copper

B. Aluminium

C. Polyvinyl chloride

D. Brass

3. Which wiring system uses small rectangular plastic channels to enclose electrical cables?

A. Metal conduit wiring

B. Mini-trunking wiring

C. Cable ladder wiring

D. Open wiring

4. What is the main function of an electrical conduit?

A. To generate electricity.

B. To increase the current in a circuit.

C. To protect and route electrical cables.

D. To store electrical energy.

5. Which wiring system is commonly used where strong mechanical protection of cables is required?

A. Metal conduit wiring

B. Open wiring

C. Unprotected surface wiring

D. Temporary wiring

6. Which of the following is an advantage of concealed wiring?

A. It is always cheaper to install.

B. It provides an attractive appearance.

C. It makes all cables visible.

D. It requires no planning.

7. Which wiring system is particularly useful when adding wiring to an existing office without extensive wall cutting?

A. Underground wiring only

B. Mini-trunking wiring

C. Open bare-conductor wiring

D. Overhead transmission wiring

8. Which of the following components is used to join two lengths of conduit?

A. Socket outlet

B. Switch

C. Coupler

D. Fuse

9. Which of the following factors should be considered when selecting an electrical wiring system?

A. Colour of the building only

B. Environmental conditions

C. Number of windows only

D. Type of furniture

10. Which of the following wiring systems is suitable for carrying large groups of cables in an industrial building?

A. Cable tray system

B. Miniature lamp holder

C. Domestic plug system

D. Ceiling rose system

11. What is the main function of a junction box in an electrical installation?

A. To generate electrical power.

B. To contain and protect electrical connections.

C. To increase the voltage of a circuit.

D. To measure electrical resistance.

12. Which organisation regulates the licensing of electrical workers and contractors in Kenya?

A. KNEC B. KICD

C. EPRA D. NEMA

13. Which of the following laws provides the main legal framework for the energy sector in Kenya?

A. Employment Act, 2007

B. Energy Act, 2019

C. Traffic Act

D. Public Health Act

14. Which of the following documents contains building requirements for electrical installations in Kenya?

A. National Building Code, 2024

B. Kenya Traffic Code

C. School Assessment Code

D. Agricultural Policy

15. What is the main purpose of electrical wiring regulations?

A. To increase the cost of installations.

B. To make buildings look attractive only.

C. To promote safety and reliability of electrical installations.

D. To reduce the number of electrical appliances.

16. Which colour is commonly used to identify the live conductor in a modern harmonised single-phase electrical installation?

A. Green/yellow

B. Blue

C. Brown

D. Green

17. Which colour identifies the neutral conductor in a modern harmonised electrical installation?

A. Brown

B. Blue

C. Green/yellow

D. Red

18. What is the function of the green/yellow conductor in an electrical installation?

A. Live connection.

B. Neutral connection.

C. Protective earthing.

D. Switching the lamp.

19. What is the main function of a Miniature Circuit Breaker (MCB)?

A. To increase the supply voltage.

B. To protect a circuit against overcurrent.

C. To store electrical energy.

D. To measure electrical power.

20. Which electrical device provides protection by detecting residual current imbalance?

A. Ceiling rose

B. Residual Current Device (RCD)

C. Lamp holder

D. Junction box

21. What is the main purpose of earthing in an electrical installation?

A. To increase the current in an appliance.

B. To provide a protective path for fault current.

C. To reduce the length of cables.

D. To increase the supply frequency.

22. Which type of diagram shows the physical positions of electrical accessories within a building?

A. Graphical chart

B. Wiring layout diagram

C. Bar graph

D. Flow chart

23. What does a schematic diagram mainly show?

A. The colour of the building walls.

B. The electrical relationship and operation of components.

C. The size of furniture.

D. The cost of electrical materials.

24. Which of the following tools is commonly used to measure the length of a wiring route?

A. Hammer

B. Measuring tape

C. Soldering iron

D. Chisel

25. Which tool is used to remove insulation from an electrical conductor?

A. Hacksaw

B. Wire stripper

C. Spirit level

D. Hammer

26. What is the purpose of a conduit saddle in electrical installation?

A. To join electrical conductors.

B. To secure conduit to a surface.

C. To control lighting circuits.

D. To measure voltage.

27. Which electrical test is carried out to check the quality of insulation between conductors?

A. Polarity test

B. Insulation resistance test

C. Functional test

D. Visual inspection only

28. What should be done before working on an existing electrical circuit?

A. Increase the supply voltage.

B. Isolate the supply and verify that the circuit is dead.

C. Remove all circuit labels.

D. Connect additional appliances.

29. Which type of maintenance is carried out at planned intervals to reduce the possibility of electrical faults?

A. Corrective maintenance

B. Emergency maintenance

C. Preventive maintenance

D. Accidental maintenance

30. Which of the following is an important advantage of cable tray systems?

A. They generate electrical energy.

B. They support and organise large groups of cables.

C. They eliminate the need for protective devices.

D. They increase electrical resistance.

Section B: Structured Questions (50 Marks)

Instructions: Answer all the questions. Show your work clearly where necessary.

Question 1: Electrical Wiring Systems (8 Marks)

a) Define an electrical wiring system. (2 marks)

b) State four types of electrical wiring systems used in buildings. (4 marks)

c) State two purposes of installing electrical wiring systems in buildings. (2 marks)

Question 2: Selection of Wiring Systems (8 Marks)

a) State four factors that should be considered when selecting a wiring system for a building. (4 marks)

b) A school intends to install additional electrical wiring in its computer laboratory without carrying out extensive wall cutting.

i. Identify one suitable wiring system for the laboratory. (1 mark)

ii. Give three reasons why the selected wiring system is appropriate. (3 marks)

Question 3: Components of Wiring Systems (8 Marks)

a) State the functions of the following components:

i. Conduit. (1 mark)

ii. Junction box. (1 mark)

iii. Distribution board. (1 mark)

iv. Cable clips. (1 mark)

b) Explain two advantages of PVC conduit wiring. (2 marks)

c) State two disadvantages of metal conduit wiring. (2 marks)

Question 4: Wiring Regulations and Safety (8 Marks)

a) State four reasons why electrical wiring regulations are important. (4 marks)

b) Identify the correct conductor colours used in modern harmonised single-phase wiring for:

i. Live conductor. (1 mark)

ii. Neutral conductor. (1 mark)

iii. Protective earth conductor. (1 mark)

c) State one function of an MCB in an electrical installation. (1 mark)

Question 5: Wiring Diagrams and Installation (9 Marks)

a) Differentiate between a wiring layout diagram and a schematic diagram. (2 marks)

b) State three pieces of information that can be obtained from an electrical wiring layout diagram. (3 marks)

c) Outline four steps followed when installing PVC conduit wiring. (4 marks)

Question 6: Inspection, Testing and Maintenance (9 Marks)

a) Define electrical installation inspection. (2 marks)

b) State three tests carried out during electrical installation verification. (3 marks)

c) Explain two reasons why regular maintenance of electrical wiring systems is important. (2 marks)

d) State two safety precautions that should be observed before working on an existing electrical circuit. (2 marks)

18.0 Suggested Assessment and Project Work

Project: Design and install a model wiring system for a two-room school administration block.

The model should show:

1. A suitable wiring system.
2. A distribution board.
3. Lighting points.
4. Switches.
5. Socket outlets.
6. Cable routes.
7. Suitable protective devices.
8. A wiring layout diagram.
9. Correct identification of conductors.
10. Safety precautions.

Assessment criteria:

Assessment area	Suggested marks
Identification of materials and tools	10
Selection of an appropriate wiring system	10
Preparation of wiring layout	10
Installation workmanship	20
Safety and correct handling of tools	10

Inspection and presentation	10
Total	70

STRAND 3.0: ELECTRICAL INSTALLATION

SUB-STRAND 3.2: EARTHING AND EXCESS CURRENT PROTECTION

1.0 Introduction to Earthing and Excess Current Protection

Electrical energy is useful in homes, schools, hospitals, offices, industries and other buildings. However, electricity can cause serious accidents when electrical installations are poorly designed, incorrectly connected or inadequately protected.

Common electrical hazards include:

- Electric shock.
- Electrical burns.
- Electrical fires.
- Damage to electrical appliances.

- Overheating of cables.
- Short circuits.
- Equipment failure.
- Damage caused by lightning and electrical surges.

To reduce these dangers, electrical installations are provided with protective arrangements. Two important safety measures are **earthing** and **excess current protection**.

Earthing provides a protective connection between exposed conductive parts of electrical equipment and the earthing system. Excess current protection disconnects a circuit when current exceeds the safe value for the circuit or its equipment.

In a typical Kenyan domestic installation, protective arrangements may include an earth electrode, protective conductors, main earthing terminal, fuses, miniature circuit breakers (MCBs), residual current devices (RCDs) and residual current circuit breakers with overcurrent protection (RCBOs).

1.1 Definition of earthing

Earthing is the intentional electrical connection of an installation or equipment to the general mass of the earth through an appropriate earthing arrangement.

In electrical installations, earthing helps to reduce dangerous touch voltages and provides a path for fault current so that protective devices can disconnect the faulty circuit.

1.2 Definition of excess current protection

Excess current protection is the use of protective devices to automatically disconnect an electrical circuit when the current flowing through it exceeds the safe operating limit.

Examples of excess current protection devices include:

1. Fuses.
2. Miniature circuit breakers (MCBs).
3. Circuit breakers with overcurrent protection.
4. Thermal overload relays for motor circuits.

1.3 Definition of electrical fault

An **electrical fault** is an abnormal condition in an electrical circuit that causes the current, voltage or operation of the circuit to differ from its intended safe condition.

Examples include:

- Short-circuit faults.
- Earth faults.
- Overloads.
- Insulation failure.
- Open-circuit faults.

1.4 Learning outcomes

By the end of this sub-strand, the learner should be able to:

a) Explain how earthing and excess current protection ensure safety in electrical installations.

b) Describe the operation of different types of protective devices used in domestic installations.

c) Identify types of earthing systems used in domestic installations.

d) Install protective devices in domestic installations under appropriate supervision.

e) Appreciate the importance of protective devices in domestic installations.

2.0 Understanding Electrical Hazards

An electrical hazard is a dangerous condition associated with electricity that may cause injury, death, fire or damage to property.

Electrical hazards can occur in domestic installations due to poor workmanship, damaged equipment, incorrect wiring, lack of maintenance and failure to use suitable protective devices.

2.1 Electric shock

Electric shock occurs when electric current passes through a person's body.

It may happen when a person:

- Touches a bare live conductor.
- Touches a faulty electrical appliance with an energised metal casing.
- Uses an electrical appliance with damaged insulation.
- Touches electrical equipment while standing on a wet floor.
- Handles electrical equipment with wet hands.
- Comes into contact with exposed live parts.

Effects of electric shock include:

1. Pain and muscle contraction.
2. Burns.
3. Difficulty in breathing.
4. Disturbance of the heart's normal rhythm.
5. Unconsciousness.
6. Death in severe cases.

The seriousness of electric shock depends on factors such as current magnitude, duration of contact, path through the body, frequency and body conditions.

2.2 Electrical fire

An electrical fire is a fire caused by an electrical fault or overheating of electrical equipment or wiring.

Causes of electrical fires:

1. Overloaded socket outlets.
2. Loose electrical connections.
3. Damaged cable insulation.
4. Incorrectly rated protective devices.
5. Short circuits.
6. Poor-quality electrical accessories.

7. Excessive heating of conductors.
8. Faulty appliances.
9. Poor installation practices.

Prevention of electrical fires:

- Use correctly sized cables.
- Install suitable fuses and circuit breakers.
- Avoid overloading circuits.
- Ensure secure electrical connections.
- Replace damaged cables.
- Carry out regular inspection and testing.
- Use suitable electrical accessories.
- Ensure effective earthing and bonding.

2.3 Short-circuit fault

A short circuit occurs when two conductors at different electrical potentials come into direct or unintended contact through a low-impedance path.

For example, a short circuit may occur when the live and neutral conductors touch due to damaged insulation.

Effects of a short circuit:

1. Very high current may flow.
2. Conductors may overheat.
3. Insulation may be damaged.
4. Electrical equipment may be destroyed.
5. Arcing may occur.
6. Fire may result.

Protection: Fuses and MCBs are commonly used to disconnect circuits under short-circuit conditions when correctly selected and installed.

2.4 Overload

An overload occurs when the current flowing through a circuit exceeds its intended rated current under normal circuit conditions.

Example:

A socket circuit may become overloaded when several high-power appliances are operated simultaneously beyond the circuit's designed capacity.

Effects of overload:

- Excessive heating of conductors.
- Deterioration of insulation.
- Damage to electrical appliances.
- Increased fire risk.

- Unwanted operation of protective devices.

Protection: Correctly rated fuses and MCBs protect circuits against overload current.

2.5 Earth fault

An earth fault occurs when a live conductor makes unintended electrical contact with earth or an earthed conductive part.

For example, if insulation inside an electric kettle becomes damaged, the live conductor may touch its metallic casing.

If the casing is properly earthed, a fault current can flow through the protective conductor. This helps the protective device disconnect the supply.

2.6 Lightning-related electrical hazards

Lightning is a natural electrical discharge that can produce very high voltages and currents.

It may cause:

1. Damage to electrical equipment.
2. Fire in buildings.
3. Failure of electronic devices.
4. Dangerous voltage surges.
5. Damage to overhead electrical lines.

Protection may involve properly designed lightning protection systems, earthing arrangements and surge protective devices (SPDs).

Important distinction: A lightning protection system and an electrical installation's protective earthing system are related but serve different purposes. Their design and bonding must be coordinated.

3.0 Earthing in Electrical Installations

3.1 Meaning and purpose of earthing

Earthing is an important protective measure in electrical installations. It helps to prevent exposed metal parts of electrical equipment from remaining at dangerous voltages during certain fault conditions.

Under normal operating conditions, the protective earthing conductor does not normally carry load current.

During an earth fault, it provides a path for fault current, allowing suitable protective devices to operate.

3.2 Why electrical appliances are earthed

Electrical appliances are earthed for the following reasons:

1. **Prevention of electric shock:** Earthing helps prevent exposed metal parts from remaining dangerously energised during an insulation fault.

2. **Provision of a fault-current path:** It provides a low-impedance path for fault current where the earthing arrangement is designed to achieve this.

3. **Operation of protective devices:** It assists the operation of fuses, MCBs and other protective devices during earth faults.

4. **Protection of property:** It helps reduce the risk of electrical fires and equipment damage associated with faults.

5. **Reduction of touch voltage:** It helps control dangerous voltage differences between exposed conductive parts and other accessible conductive parts.

6. **Improvement of installation safety:** It forms part of the overall electrical safety system.

7. **Protection of users:** It reduces the risk of electric shock when a fault occurs.

8. **Compliance with regulations:** Proper earthing is a requirement of safe electrical installation practice.

3.3 How earthing works

Consider an electric iron with a metallic casing.

Under normal conditions:

- The live conductor supplies electrical energy to the heating element.
- The neutral conductor provides the normal return path.
- The protective earth conductor connects the metal casing to the installation's protective earthing system.
- The protective earth conductor does not normally carry load current.

When insulation fails and the live conductor touches the metal casing:

1. The casing may become live.
2. The protective earthing conductor provides a fault-current path.
3. Fault current flows through the protective arrangement.
4. A suitable protective device operates.
5. The faulty circuit is disconnected from the supply.
6. The danger of electric shock is reduced.

3.4 Components of an earthing system

An earthing system consists of different components that work together to provide electrical protection.

1. Earth electrode

An earth electrode is a conductive component installed in contact with the general mass of the earth to provide an electrical connection to earth.

Common types include:

- Earth rods.
- Earth plates.
- Earth strips.
- Earth wires or tapes buried in suitable arrangements.
- Foundation or structural electrodes designed for earthing purposes.

Functions:

1. Establishes an electrical connection with the earth.
2. Forms part of the earthing arrangement.

3. Provides a connection point for the earthing conductor.
4. Helps achieve the required earthing performance.

2. Earthing conductor

An earthing conductor connects the main earthing terminal of an installation to the earth electrode or other earthing arrangement, as applicable.

Functions:

- Connects the installation's earthing terminal to the earth electrode.
- Provides a conductive path within the earthing arrangement.
- Helps maintain the continuity of the earthing system.

3. Protective conductor

A protective conductor connects exposed conductive parts of electrical equipment to the protective earthing system.

It is commonly identified by green-and-yellow insulation.

Functions:

1. Provides a fault-current path.
2. Connects metal enclosures to the earthing system.
3. Helps protective devices operate during earth faults.
4. Reduces the risk of electric shock.

4. Main earthing terminal (MET)

The main earthing terminal is the terminal or bar where protective conductors and the main earthing conductor are connected.

Functions:

- Provides a common earthing connection point.
- Connects the earthing conductor to protective conductors.
- Provides a connection point for main protective bonding conductors where required.

5. Main protective bonding conductor

This conductor connects relevant extraneous-conductive-parts to the main earthing terminal.

Examples of extraneous-conductive-parts may include:

- Certain incoming metallic water service pipes.
- Certain structural metalwork.
- Other conductive services that can introduce an external potential.

Bonding is carried out according to the applicable installation requirements. Not every metal pipe or metal object automatically requires bonding.

6. Earth clamp

An earth clamp is a suitable mechanical and electrical connector used to connect an earthing conductor to an earth electrode or another approved conductive component.

Functions:

- Holds the conductor firmly.
- Provides electrical continuity.
- Helps prevent loose connections.

7. Earth inspection chamber

An earth inspection chamber is an enclosure that provides access to an earth electrode connection for inspection and testing.

Functions:

1. Protects the connection from accidental damage.
2. Allows inspection.
3. Allows testing where appropriate.
4. Makes maintenance easier.

3.5 Difference between earthing and bonding

These two terms are related but do not mean the same thing.

Earthing	Bonding
Connects an installation or equipment to the earthing arrangement.	Connects conductive parts together to reduce dangerous potential differences.
Provides part of the fault-current path.	Helps maintain equipotential conditions.
Uses earthing conductors and electrodes as applicable.	Uses bonding conductors.
Helps protective devices operate during certain faults.	Helps reduce dangerous voltage differences between conductive parts.

4.0 Types of Earthing Systems Used in Domestic Installations

Earthing systems are classified according to how the supply source and exposed conductive parts of the installation are connected to earth.

The common systems include:

1. TT system.
2. TN-S system.
3. TN-C-S system.

These systems are identified using letters.

4.1 Meaning of the letters used in earthing systems

Letter	Meaning
T	One point of the supply is directly connected to earth.

N	Exposed conductive parts are connected to the earthed point of the supply.
S	Neutral and protective earth functions are provided by separate conductors.
C	Neutral and protective earth functions are combined in one conductor.

4.2 TT Earthing System

Definition

A TT earthing system is an arrangement in which the supply source has an earthed point, while the exposed conductive parts of the consumer's installation are connected to a local earth electrode that is electrically independent of the supply neutral earthing arrangement.

In a typical TT system, an RCD is an important protective device because the earth fault current may be too small to operate an ordinary overcurrent device quickly.

Main components

1. Supply transformer.
2. Supply neutral.
3. Local earth electrode.
4. Earthing conductor.
5. Main earthing terminal.
6. Protective conductors.
7. RCD.
8. MCBs or fuses.

Operation of the TT system

1. The supply transformer has an earthed neutral point.
2. The consumer installs an earth electrode.
3. The earth electrode is connected to the main earthing terminal.
4. Protective conductors connect exposed conductive parts to the earthing terminal.
5. During an earth fault, current flows through the protective conductor and earth path.
6. The RCD detects the residual current imbalance.
7. The RCD disconnects the faulty circuit when its operating conditions are met.

Advantages

1. Can be used where a supply earth terminal is not provided.
2. The consumer has a local earthing electrode.
3. RCD protection provides sensitive earth-leakage protection.
4. It can be useful in rural and other installations where the supply earthing arrangement is unsuitable for direct use by the consumer.

Disadvantages

1. Requires a suitable local earth electrode.

2. Earth electrode resistance must be assessed and maintained.
3. RCD protection is generally essential for effective fault protection.
4. Earth electrode connections require inspection and testing.
5. The installation may require additional protection against voltage surges and lightning according to the site conditions.

4.3 TN-S Earthing System

Definition

A TN-S earthing system is an arrangement in which the supply neutral is earthed at the source and the neutral conductor and protective earth conductor are separate throughout the installation.

The letter S indicates that the neutral and protective earth functions are separated.

Main components

1. Supply transformer.
2. Earthed transformer neutral.
3. Separate neutral conductor.
4. Separate protective earth conductor.
5. Main earthing terminal.
6. Protective devices.
7. Electrical appliances.

Operation

1. The supply transformer neutral is connected to earth.
2. A separate protective earth conductor is provided from the source.
3. The neutral conductor carries normal load return current.
4. The protective conductor connects exposed conductive parts to the protective earthing arrangement.
5. During an earth fault, current flows through the protective conductor towards the source.
6. A suitable fuse or circuit breaker disconnects the faulty circuit.

Advantages

1. Neutral and protective earth functions remain separate.
2. The protective conductor does not normally carry neutral load current.
3. Fault-current paths can be designed to provide effective operation of protective devices.
4. It can provide a reliable protective arrangement where correctly installed and maintained.

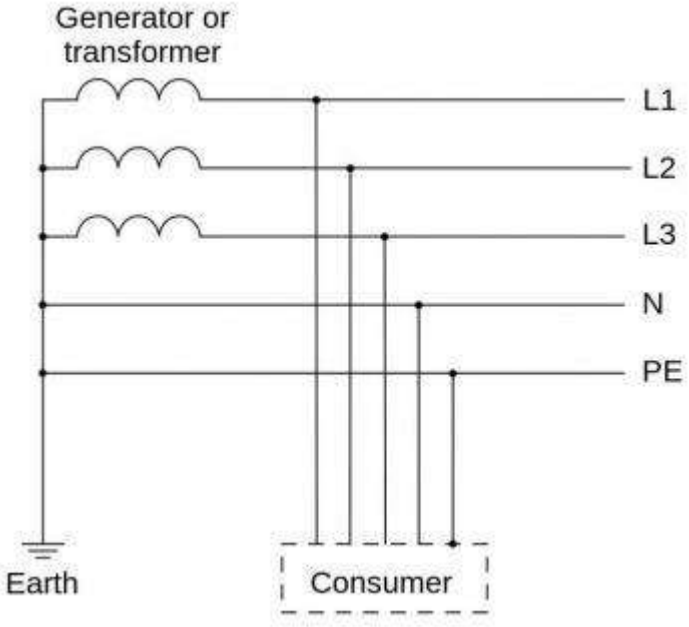
Disadvantages

1. Requires separate neutral and protective conductors.
2. May be more expensive than some other arrangements.
3. The effectiveness depends on the continuity and impedance of the protective conductor.

4. Damage to the supply protective conductor can compromise safety.

TN-S Networks

Separate protective earth (PE) and neutral (N) conductors from transformer to consuming device, which are not connected together at any point after the building distribution point.



4.4 TN-C-S Earthing System

Definition

A TN-C-S earthing system is an arrangement in which the neutral and protective earth functions are combined in part of the supply system and separated in the consumer's installation.

The combined conductor is called the PEN conductor.

Main components

1. Supply transformer.
2. Earthed transformer neutral.
3. Combined protective earth and neutral conductor (PEN).
4. Main earthing terminal.
5. Separate neutral conductor after the point of separation.
6. Separate protective earth conductor after the point of separation.
7. Protective devices.
8. Electrical appliances.

Operation

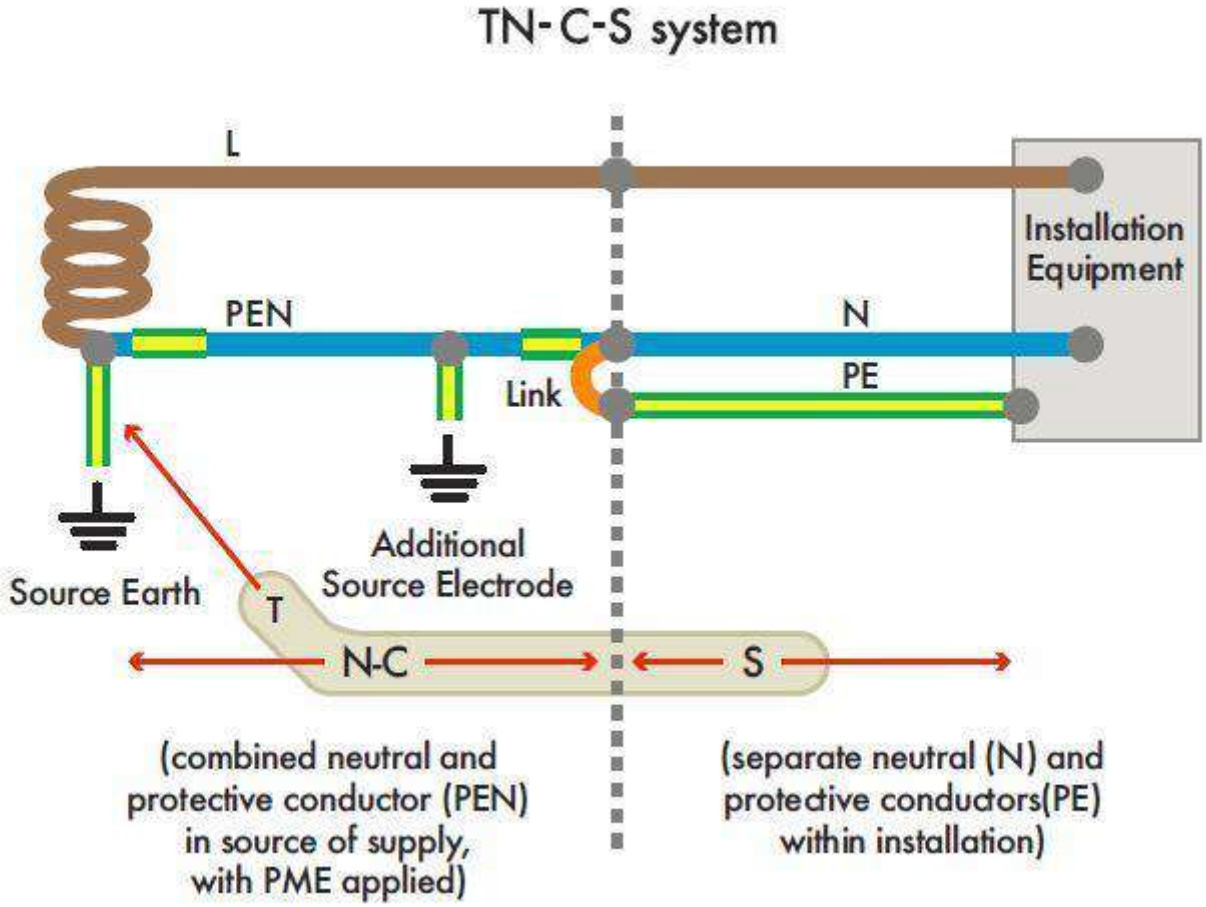
1. The supply transformer neutral is connected to earth.
2. The supply network uses a combined PEN conductor for neutral and protective functions.
3. At the designated point of separation, the PEN conductor is divided into separate neutral and protective earth conductors.
4. The neutral conductor carries normal load current.
5. The protective earth conductor connects exposed conductive parts to the protective system.
6. During an earth fault, the protective arrangement provides a fault-current path.
7. A suitable protective device disconnects the faulty circuit.

Advantages

1. Reduces the need for separate neutral and protective conductors throughout the supply network.
2. Can provide an effective protective arrangement when correctly designed.
3. Allows separate neutral and protective conductors within the consumer's installation.
4. Is widely recognised in electrical distribution practice.

Disadvantages

1. A break in the PEN conductor can create dangerous conditions.
2. Requires correct installation and bonding arrangements.
3. The separation of neutral and protective conductors must be carried out at the correct point.
4. Neutral and protective conductors must not be reconnected together downstream of the designated separation point.



4.5 Comparison of TT, TN-S and TN-C-S Earthing Systems

Feature	TT system	TN-S system	TN-C-S system
Consumer earth electrode	Normally provided	Depends on supply arrangement	Depends on supply arrangement
Neutral and earth	Separate at consumer installation	Separate throughout	Combined in part, then separated

Supply protective earth	Not supplied as the consumer's main earth path	Supplied separately	Provided through PEN before separation
Common protective device	RCD	Fuse, MCB and RCD as required	Fuse, MCB and RCD as required
Main consideration	Earth electrode and RCD performance	Continuity of separate PE conductor	PEN conductor integrity and correct separation

Important: The earthing arrangement available to a consumer depends on the electricity supply network and the applicable requirements. An installer must not assume that a particular earthing system is available without verifying the supply arrangement.

5.0 Excess Current and Its Causes

5.1 Definition of excess current

Excess current is a current that exceeds the current-carrying capacity or rated current of a circuit or equipment.

It can result from overloading, short circuits and certain fault conditions.

5.2 Types of excess current

The main types are:

1. Overload current.
2. Short-circuit current.

5.3 Overload current

Overload current is an excessive current flowing in a circuit that is electrically sound but carrying more load than it is designed to supply.

Example:

A domestic socket circuit supplies several appliances whose combined current exceeds the circuit's designed capacity.

Causes of overload:

- Connecting too many appliances to one circuit.
- Using high-power appliances simultaneously.
- Incorrect circuit design.
- Selecting cables that are too small for the intended load.
- Adding extra loads without assessing the circuit capacity.

5.4 Short-circuit current

Short-circuit current is the excessive current that flows when conductors at different potentials become connected through a low-impedance path.

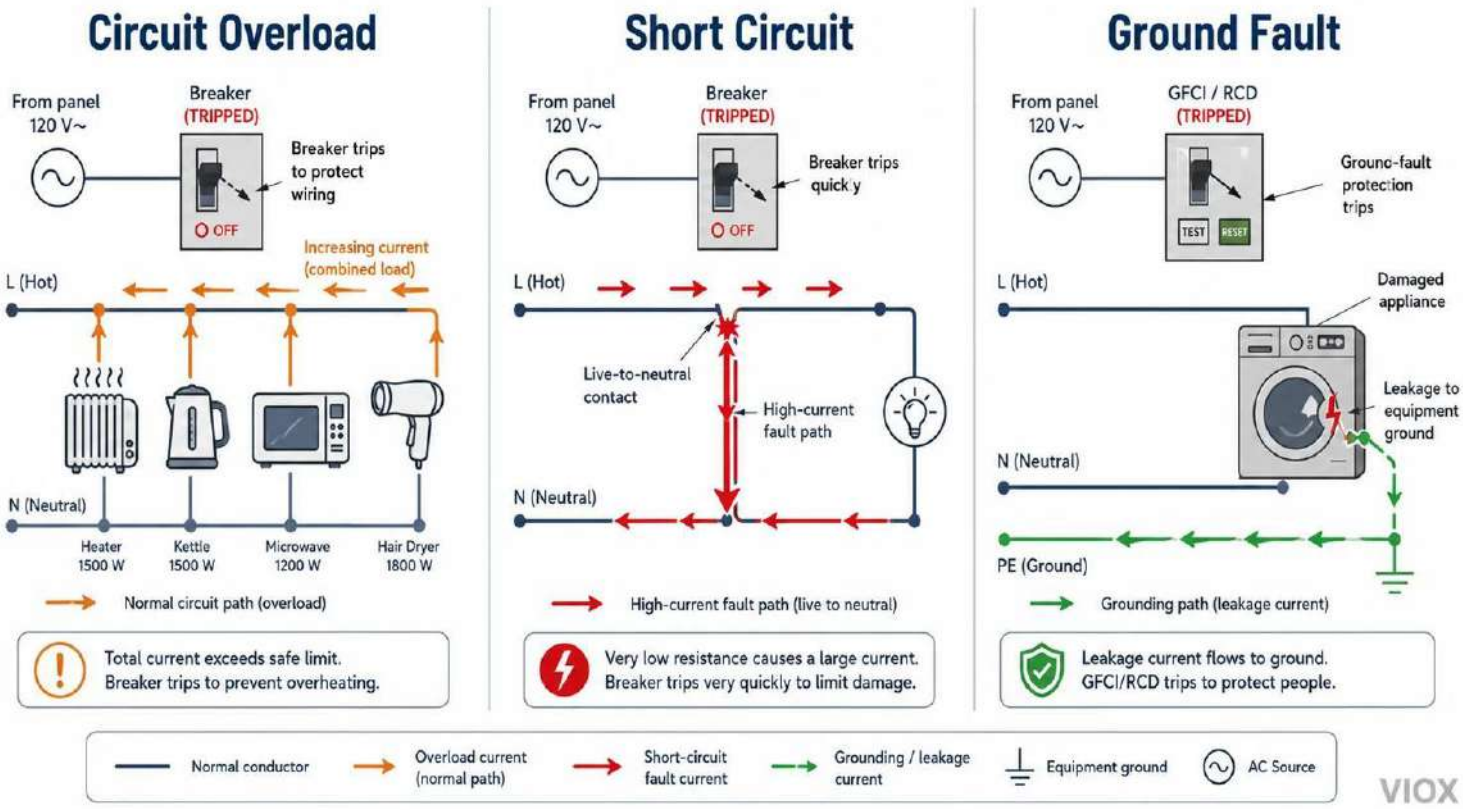
Causes:

1. Damaged cable insulation.
2. Loose or incorrectly made connections.

3. Faulty electrical appliances.
4. Water entering electrical accessories.
5. Incorrect wiring.
6. Damaged electrical equipment.

5.5 Differences between overload and short circuit

Overload	Short circuit
Occurs when a circuit carries more load current than intended.	Occurs when conductors at different potentials make unintended contact through a low-impedance path.
Current may rise gradually or remain moderately above the rated value.	Current can rise to a very high value rapidly.
Often results from connecting too many loads.	Often results from insulation failure or incorrect connections.
Causes excessive heating over time.	May cause severe heating and arcing very quickly.
Protected by correctly selected fuses and circuit breakers.	Protected by suitable devices with adequate breaking capacity.



5.6 Effects of excess current

1. Overheating of conductors.
2. Damage to insulation.

3. Damage to electrical appliances.
4. Melting of cable insulation.
5. Electrical fires.
6. Arcing and sparking.
7. Damage to switches and socket outlets.
8. Unwanted interruption of electrical supply.

6.0 Protective Devices Used in Domestic Installations

Protective devices are electrical components designed to detect abnormal electrical conditions and disconnect or limit the supply to reduce danger.

The main protective devices include:

1. Fuses.
2. Miniature circuit breakers (MCBs).
3. Residual current devices (RCDs).
4. Residual current circuit breakers with overcurrent protection (RCBOs).
5. Surge protective devices (SPDs).
6. Thermal overload relays for appropriate equipment circuits.

6.1 Fuse

Definition

A fuse is an electrical protective device containing a fusible element that melts when excessive current flows through it, thereby interrupting the circuit.

Main parts of a fuse

1. Fuse element.
2. Fuse body or cartridge.
3. Terminals.
4. Insulating casing.
5. Fuse holder, where applicable.

Working principle of a fuse

A fuse operates according to the heating effect of electric current.

When current passes through the fuse element, heat is produced. If the current exceeds the safe operating limit for a sufficient period, the element becomes hot enough to melt.

The circuit is then interrupted.

Operation of a fuse

1. Current flows through the fuse element.
2. Under normal conditions, the element carries the current safely.
3. Excessive current produces excessive heat.
4. The fuse element melts.

5. The circuit becomes open.
6. Current stops flowing through the protected circuit.

Types of fuses

1. Rewirable fuse

A rewirable fuse contains a replaceable fuse wire mounted in a fuse carrier.

Features:

- Simple construction.
- Fuse wire can be replaced after operation.
- Requires the correct fuse-wire rating.
- Can be incorrectly rewired if unsuitable wire is used.

2. Cartridge fuse

A cartridge fuse has a fusible element enclosed in a protective insulating cartridge.

Features:

- Enclosed construction.
- Available in different current ratings.
- Commonly used in electrical equipment and certain distribution arrangements.
- Must be replaced with the correct type and rating.

3. HRC fuse

HRC means High Rupturing Capacity.

An HRC fuse is designed to interrupt high fault currents safely within its rated breaking capacity.

Features:

- Enclosed fuse element.
- High fault-interrupting capacity.
- Suitable for certain demanding applications.
- Must be selected according to the system's fault level and design.

Advantages of fuses

1. Simple construction.
2. Relatively inexpensive.
3. Reliable when correctly selected.
4. Can interrupt high fault currents when suitably rated.
5. Require little maintenance.

Disadvantages of fuses

1. Must be replaced after operation.
2. Incorrect replacement can compromise safety.
3. Cannot normally be reset.

4. Fault indication may be limited.
5. Repeated replacement can increase maintenance time.

Applications of fuses

- Domestic distribution equipment.
- Electrical appliances.
- Control circuits.
- Motor circuits when suitably selected.
- Certain industrial installations.

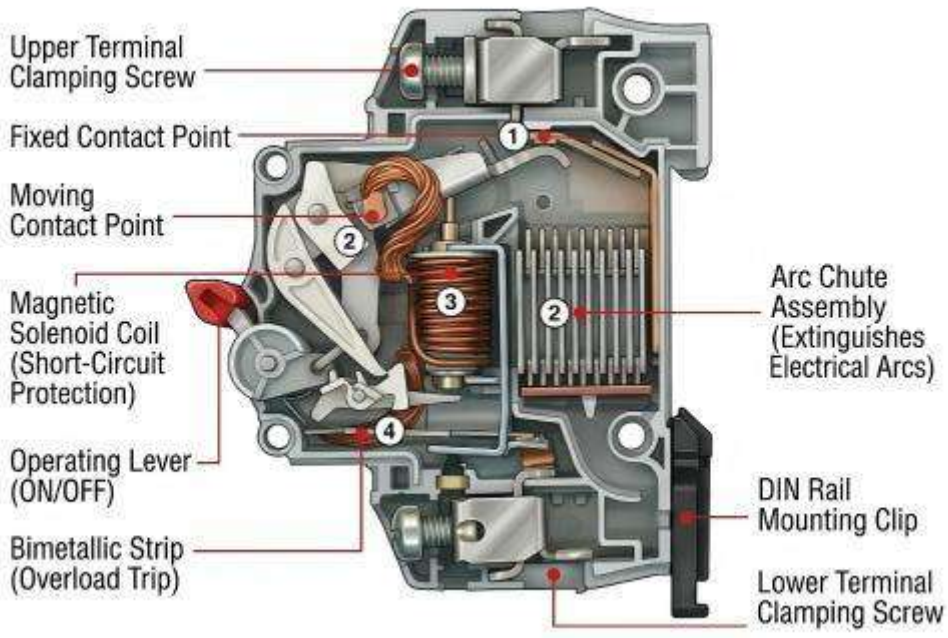
6.2 Miniature Circuit Breaker (MCB)

Definition

A Miniature Circuit Breaker is an automatic protective switching device that disconnects an electrical circuit when excessive current flows due to an overload or short-circuit fault.

Main parts of an MCB

1. Operating handle.
2. Fixed contact.
3. Moving contact.
4. Thermal trip mechanism.
5. Magnetic trip mechanism.
6. Arc chute.
7. Terminals.
8. Insulating casing.



Working principle of an MCB

An MCB normally uses two mechanisms:

1. Thermal operation

The thermal mechanism protects against overload current.

- Current flows through a bimetallic strip.
- Excess current produces heat.
- The bimetallic strip bends.
- The movement releases the trip mechanism.
- The contacts open.
- The circuit is disconnected.

2. Magnetic operation

The magnetic mechanism protects against high short-circuit current.

- A high fault current flows through a coil.
- The coil produces a strong magnetic field.
- The magnetic force operates the trip mechanism.
- The contacts open rapidly.
- The faulty circuit is disconnected.

Advantages of MCBs

1. Can be reset after a fault has been cleared.
2. Provides overload protection.
3. Provides short-circuit protection.
4. Provides clear ON and OFF positions.
5. Offers convenient operation.
6. Reduces the need to replace fuse elements.
7. Provides reliable protection when correctly selected.

Disadvantages of MCBs

1. More expensive than simple fuses in some applications.
2. Must be selected according to the circuit characteristics.
3. Can fail if damaged or poorly maintained.
4. Must have adequate breaking capacity for the prospective fault current.

Applications of MCBs

- Domestic lighting circuits.
- Socket-outlet circuits.
- Cooker circuits.
- Water-heater circuits.

- Small commercial installations.
- Certain control circuits.

MCB current ratings

MCBs are manufactured in different rated currents to suit different circuits.

Examples include:

- 6 A.
- 10 A.
- 16 A.
- 20 A.
- 32 A.
- 40 A.
- 50 A.
- 63 A.

Note: These are examples of available ratings, not instructions for selecting a device for a particular circuit. Selection must consider cable size, installation method, load, fault level and applicable regulations.

6.3 Residual Current Device (RCD)

Definition

A Residual Current Device is a protective device that detects an imbalance between the current flowing through the line conductor and the current returning through the neutral conductor, and disconnects the circuit when the residual current reaches its operating conditions.

Purpose of an RCD

An RCD is mainly used to provide additional protection against electric shock and certain earth-leakage faults.

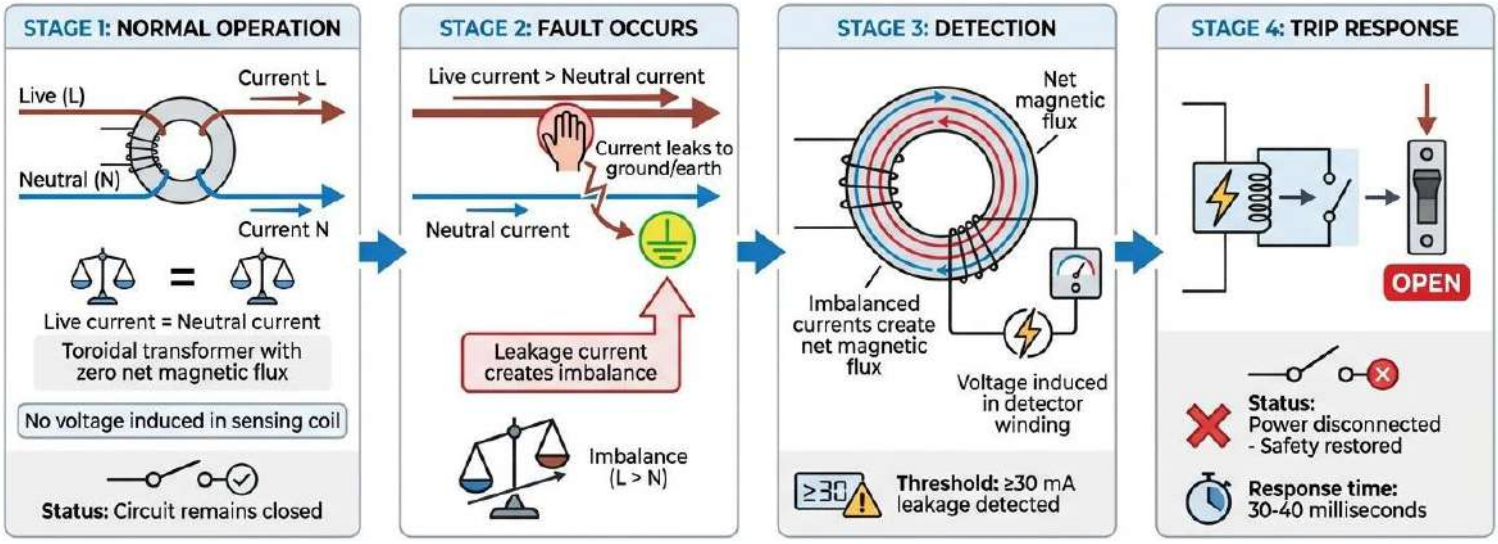
Working principle of an RCD

Under normal conditions:

1. Current flows through the line conductor to the load.
2. The same current returns through the neutral conductor.
3. The currents are balanced.
4. The RCD does not trip due to residual current.

During an earth-leakage fault:

1. Some current flows through an unintended path to earth.
2. The line and neutral currents become unequal.
3. The RCD detects the imbalance.
4. The tripping mechanism operates.
5. The RCD disconnects the circuit.



Common RCD types

1. RCCB

A Residual Current Circuit Breaker provides residual-current protection but does not normally provide integral overload and short-circuit protection.

It must therefore be coordinated with suitable overcurrent protection.

2. RCBO

A Residual Current Circuit Breaker with Overcurrent Protection combines residual-current protection with overload and short-circuit protection.

Common sensitivity ratings

RCDs are available with different rated residual operating currents.

Examples include:

- 30 mA.
- 100 mA.
- 300 mA.

A 30 mA RCD is commonly used for additional protection against electric shock in many domestic applications, subject to applicable requirements.

Other ratings may be used for different protective purposes and must be selected according to the installation design.

Advantages of RCDs

1. Detects residual current.
2. Provides additional protection against electric shock.
3. Helps reduce the risk of certain electrical fires caused by earth leakage.
4. Disconnects faulty circuits quickly within its specified operating conditions.
5. Can provide protection to several circuits when appropriately designed.

Disadvantages of RCDs

1. May trip due to cumulative leakage current.

2. Does not normally provide overload protection unless combined with an overcurrent device.
3. Requires regular testing according to the manufacturer's instructions.
4. Incorrect selection or wiring can cause unreliable operation.
5. It does not protect against every form of electric shock.

Important: An RCD does not replace earthing, bonding, insulation or overcurrent protection.

6.4 Surge Protective Device (SPD)

Definition

A Surge Protective Device is a protective device designed to limit transient overvoltages and divert surge currents to earth or another suitable path.

Transient overvoltages may result from lightning or switching operations in electrical systems.

Functions of an SPD

1. Helps protect sensitive electrical equipment.
2. Limits the effects of transient overvoltages.
3. Diverts surge current through an appropriate protective path.
4. Helps reduce damage to electronic equipment.
5. Supports the overall surge protection arrangement.

Types of SPDs

Type 1 SPD

Designed for protection against partial lightning currents where the installation is exposed to direct lightning-current effects and the system design requires it.

Type 2 SPD

Commonly installed in distribution boards to protect against transient overvoltages.

Type 3 SPD

Used close to sensitive equipment as part of a coordinated surge protection arrangement.

6.5 Thermal overload relay

Definition

A thermal overload relay is a protective device that detects excessive current in an electrical motor circuit over a period of time and causes the control circuit to disconnect the motor.

Operation

1. Motor current passes through the relay's sensing elements.
2. Excessive current produces heat.
3. The thermal elements operate.
4. The relay changes the state of its contacts.
5. The contactor coil is de-energised.
6. The motor is disconnected.

Applications

- Water pumps.
- Workshop motors.
- Industrial machinery.
- Ventilation systems.
- Certain domestic motor-driven equipment.

Important: A thermal overload relay does not normally provide short-circuit protection by itself. It must be coordinated with suitable short-circuit protective equipment.

6.6 Comparison of protective devices

Protective device	Main protection provided	Can it be reset?
Fuse	Overcurrent	No; fuse element is replaced
MCB	Overload and short circuit	Yes, after fault clearance
RCD/RCCB	Residual-current protection	Yes, after fault clearance
RCBO	Residual current, overload and short circuit	Yes, after fault clearance
SPD	Transient overvoltage protection	Depends on device type and condition
Thermal overload relay	Motor overload	Usually resettable, according to design

7.0 How Protective Devices Are Connected in Electrical Installations

Protective devices must be connected correctly to ensure that electrical faults are detected and disconnected safely.

The arrangement depends on the type of device, the earthing system, the circuit design and the applicable installation requirements.

7.1 General arrangement of a domestic electrical installation

A typical domestic electrical installation receives electricity from the supply network through the service connection and metering equipment. The supply then passes through the main switching and protective equipment before being distributed to individual circuits.

Simplified domestic installation arrangement

Domestic electrical distribution arrangement

Electricity supply network

Supply transformer and service cable

Energy meter

Measures electrical energy consumed

Main isolator

Allows the installation to be disconnected

RCD / RCBO protection

Residual-current protection as designed

Distribution board

Contains circuit protective devices

Lighting MCB

Lighting circuit

Socket MCB

Socket circuit

Appliance MCB

Dedicated circuit

The protective earth arrangement is connected to the main earthing terminal and protective conductors; it is not routed through ordinary circuit MCBs as a load conductor.

7.2 Connection of a fuse

A fuse is connected in series with the live conductor of the circuit it protects.

Reasons for connecting the fuse in the live conductor:

1. It disconnects the supply to the faulty equipment when it operates.
2. It prevents the appliance from remaining connected to the live supply through the circuit.
3. It helps isolate the faulty circuit from the source.

A fuse should not be installed only in the neutral conductor because the appliance may remain connected to the live supply even after the fuse operates.

7.3 Connection of an MCB

An MCB is connected in the circuit conductor or conductors as required by the installation design and device type.

In a typical single-phase domestic distribution board:

- The line conductor passes through the relevant MCB.
- The neutral conductor connects to the appropriate neutral terminal or neutral bar, depending on the circuit and protective arrangement.
- The protective conductor connects to the earth bar or main earthing terminal.

The MCB must have a suitable current rating and breaking capacity.

7.4 Connection of an RCD

An RCD is installed so that all live conductors supplying the protected circuit pass through its sensing arrangement.

In a typical single-phase arrangement:

1. The incoming line conductor passes through the RCD.
2. The incoming neutral conductor also passes through the RCD.
3. The outgoing line and neutral conductors supply the protected circuit.
4. The protective earth conductor does not pass through the RCD sensing path.
5. The protective conductor remains connected to the earthing system.

Important: The neutral conductors of circuits protected by different RCDs must be correctly separated. Incorrect neutral connections can cause unwanted tripping or compromise protection.

7.5 Connection of an RCBO

An RCBO combines residual-current protection and overcurrent protection.

It is normally connected to protect an individual circuit.

Functions:

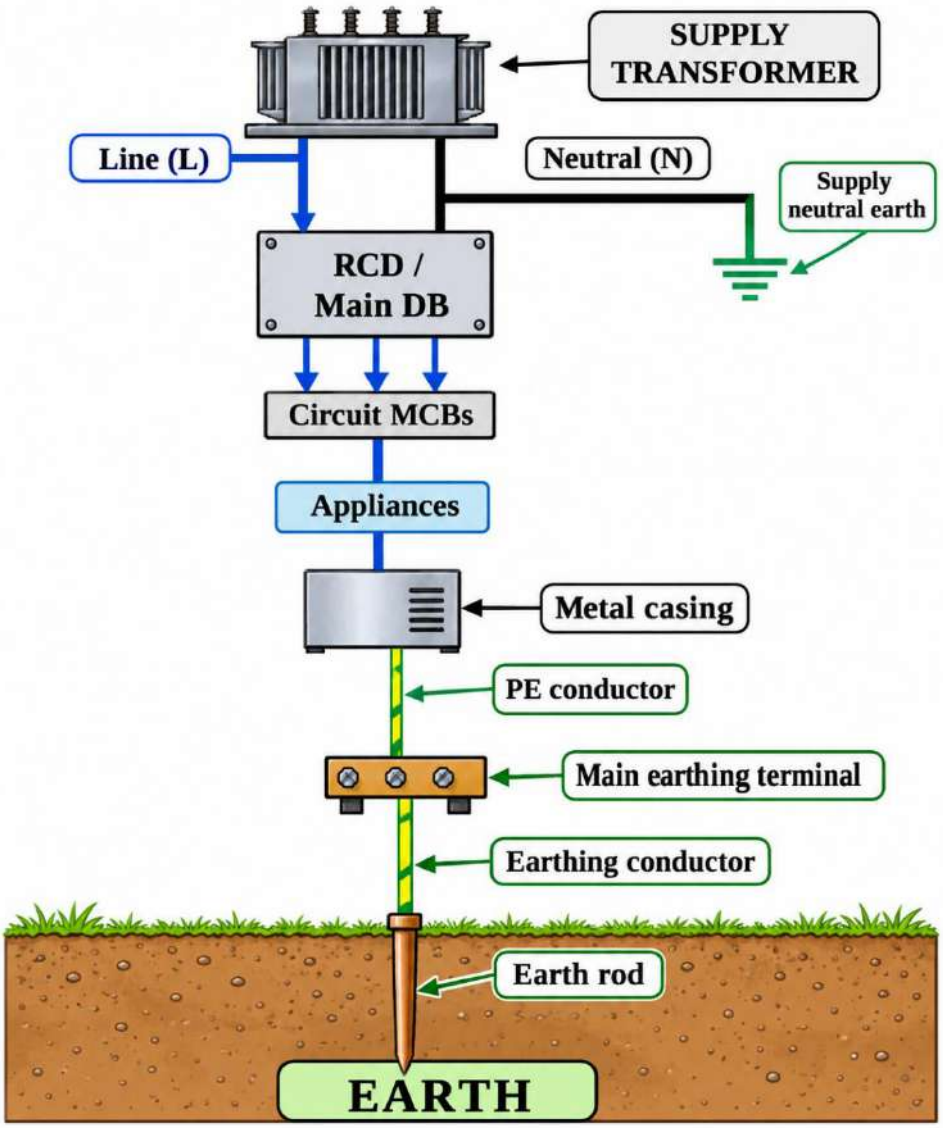
- Detects residual current.
- Detects overload current.
- Detects short-circuit current.
- Disconnects the protected circuit when the relevant fault condition occurs.

7.6 Connection of an earth electrode

In a TT earthing arrangement, the earth electrode is connected to the main earthing terminal through the earthing conductor.

The main earthing terminal is then connected to the protective conductors serving the installation.

Simplified TT earthing arrangement:



This is a simplified teaching diagram. Actual arrangements must be designed to meet the relevant installation requirements.

7.7 Relationship between earthing and protective devices

Earthing and protective devices work together.

For example, when an earth fault occurs on an earthed metal appliance:

1. The metal casing may become energised.
2. The protective conductor provides a fault-current path.
3. The fault creates an abnormal electrical condition.
4. A suitable fuse, MCB or RCD detects the fault condition, depending on the earthing system and protection arrangement.
5. The protective device disconnects the supply.
6. The danger to the user is reduced.

Key point: Earthing alone does not guarantee safety. It must be combined with suitable protective devices, insulation, bonding and correct installation practices.

8.0 Installation of Earthing and Protective Devices

Installation of earthing and protective devices requires proper planning, suitable materials, correct tools and compliance with electrical regulations.

Practical work on a real domestic installation must be carried out by an appropriately authorised electrician. Learners should undertake supervised training using safe demonstration boards and isolated practice equipment.

8.1 Materials used in earthing installation

1. Copper-bonded earth rod.
2. Earthing conductor.
3. Protective conductor.
4. Earth clamp.
5. Main earthing terminal.
6. Earth inspection chamber.
7. Bonding conductor.
8. Suitable earth bar.
9. Approved connectors and accessories.

8.2 Tools used in earthing installation

Tool	Function
Earth rod driving tool	Helps install an earth electrode
Hammer or suitable driving equipment	Drives the electrode into the ground
Spanner	Tightens suitable connections
Screwdriver	Tightens terminal screws
Measuring tape	Measures conductor and installation distances
Wire stripper	Removes insulation where appropriate
Cable cutter	Cuts conductors
Earth resistance tester	Measures earth electrode resistance
Multifunction installation tester	Performs relevant installation tests

8.3 General procedure for installing an earth electrode

The following is a learning overview rather than a substitute for a site-specific installation design.

1. Study the installation design and determine the required earthing arrangement.
2. Select an appropriate earth electrode and suitable location.

3. Check for buried services and underground hazards before excavation or driving an electrode.
4. Prepare the location according to the design.
5. Install the earth electrode using the approved method.
6. Make the connection using a suitable approved earth clamp or connector.
7. Connect the earthing conductor to the main earthing terminal.
8. Protect the conductor and connection from mechanical damage and corrosion.
9. Provide an accessible inspection arrangement where required.
10. Carry out the prescribed inspection and tests.
11. Record the results.
12. Rectify any defects before the installation is put into service.

8.4 Installing protective devices in a distribution board

The main stages include:

1. Study the electrical installation design.
2. Identify the circuits requiring protection.
3. Determine the appropriate protective-device types.
4. Check current ratings and breaking capacities.
5. Confirm compatibility with the distribution board.
6. Mount the devices in their designated positions.
7. Connect the conductors according to the manufacturer's instructions.
8. Ensure correct neutral and protective conductor arrangements.
9. Label the circuits clearly.
10. Inspect and test the installation.
11. Complete the required records before energising.

Safety warning: Learners should not connect, disconnect or test live distribution boards. Practical installation and testing must be supervised by competent and authorised personnel using suitable procedures.

9.0 Lightning Protection and Surge Protection

9.1 Meaning of lightning protection

Lightning protection is the arrangement of components designed to protect a building and its occupants against the damaging effects of lightning strikes.

Lightning can cause fire, structural damage, electric shock and damage to electrical equipment.

9.2 Components of an external lightning protection system

1. Air termination system

This consists of rods, conductors or other approved components positioned to intercept lightning strikes.

2. Down conductors

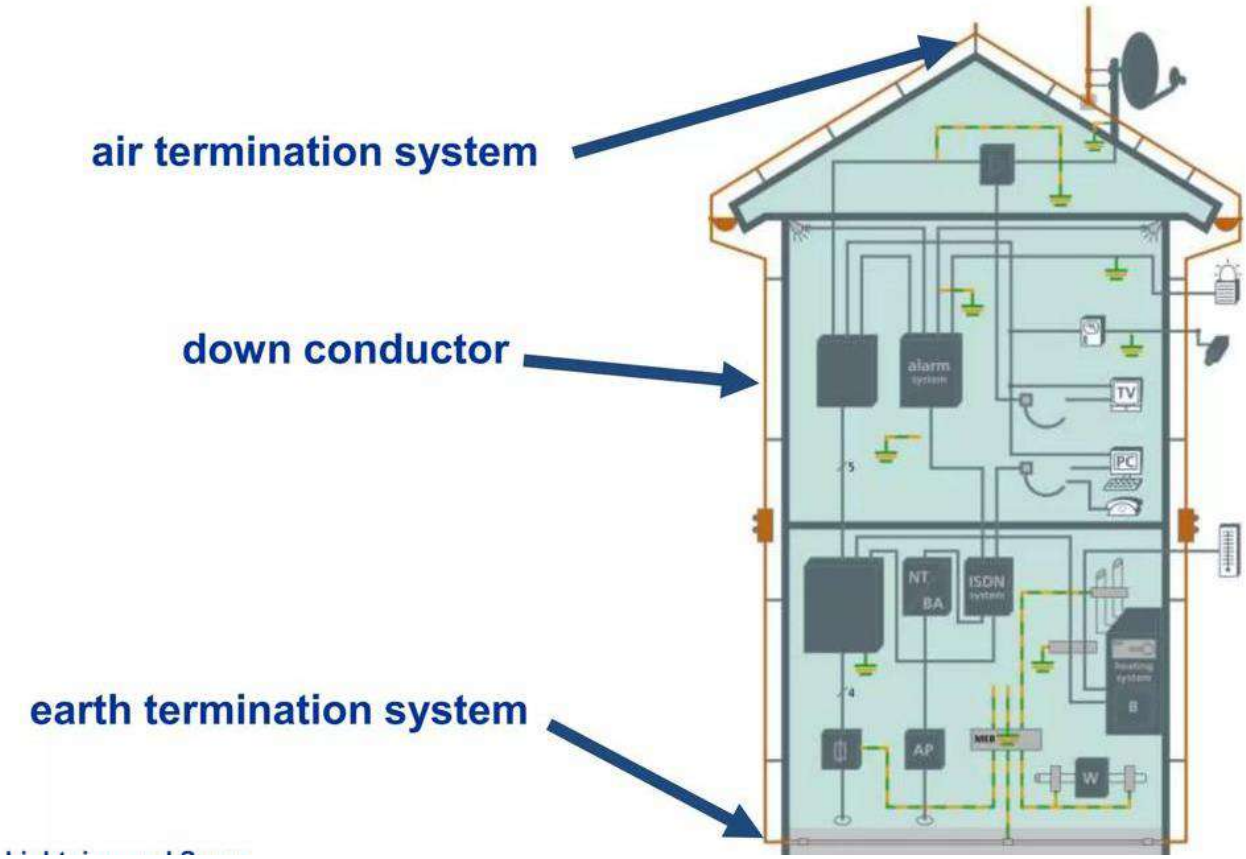
These provide a path for lightning current from the air termination system to the earth termination system.

3. Earth termination system

This provides a suitable connection to the ground for the lightning protection system.

4. Bonding arrangements

These reduce dangerous potential differences between relevant conductive parts.



9.3 Functions of a lightning protection system

1. Intercepts lightning strikes using an appropriately designed air termination system.
2. Provides a controlled path for lightning current.
3. Reduces the likelihood of structural damage.
4. Helps protect occupants and property.
5. Reduces dangerous potential differences when correctly bonded and designed.

9.4 Difference between lightning protection and electrical earthing

Lightning protection	**Electrical earthing**
Primarily deals with lightning current and its effects.	Primarily provides protective earthing for electrical installations and equipment.
Uses air terminals, down conductors and earth termination arrangements.	Uses protective conductors, earthing conductors and electrodes as required.
Protects buildings and systems against lightning	Helps reduce electric shock risk and supports fault

hazards.	protection.
Requires a coordinated lightning protection design.	Requires a suitable electrical installation earthing design.

9.5 Surge protective devices and lightning protection

A lightning strike or switching operation may cause a transient overvoltage in an electrical installation.

An SPD helps limit the effects of such transient overvoltages.

Examples of equipment that may need surge protection:

- Computers.
- Televisions.
- Routers.
- Communication equipment.
- Electronic control systems.
- Sensitive medical and laboratory equipment.

An SPD should be selected and installed as part of a coordinated protection design. It does not replace external lightning protection where that system is required.

10.0 Selection of Protective Devices

Protective devices must be selected carefully to ensure that they operate effectively under the expected conditions.

10.1 Factors to consider when selecting a fuse

1. Rated current.
2. Rated voltage.
3. Breaking capacity.
4. Type of load.
5. Prospective short-circuit current.
6. Cable current-carrying capacity.
7. Time-current characteristics.
8. Environmental conditions.

10.2 Factors to consider when selecting an MCB

1. Rated current.
2. Rated voltage.
3. Number of poles.
4. Breaking capacity.
5. Tripping characteristics.
6. Cable size.
7. Load characteristics.

8. Prospective fault current.
9. Type of circuit.
10. Manufacturer's recommendations.

10.3 Factors to consider when selecting an RCD

1. Rated current.
2. Rated residual operating current.
3. Type of RCD.
4. Number of poles.
5. Supply voltage.
6. Nature of connected equipment.
7. Expected leakage current.
8. Coordination with other protective devices.
9. Manufacturer's recommendations.

10.4 Factors to consider when selecting an earth electrode

1. Soil type.
2. Soil resistivity.
3. Moisture content.
4. Corrosion conditions.
5. Mechanical strength.
6. Electrode material.
7. Required electrical performance.
8. Availability of suitable installation space.
9. Presence of underground services.
10. Applicable earthing requirements.

11.0 Electrical Protection Calculations and Examples

Calculations help learners understand current, resistance and the operation of protective devices.

CALCULATIONS INVOLVING SINGLE-PHASE ELECTRICAL LOADS

11.1 Calculating Electrical Current

The electrical current drawn by a single-phase load can be calculated using the formula:

$$I = \frac{P}{V}$$

Where:

- I = current in amperes (A).
- P = power in watts (W).
- V = voltage in volts (V).

Worked Example 1

An electric kettle rated at 2,000 W is connected to a 230 V supply. Calculate the current drawn by the kettle.

Solution

Given:

- Power, $P = 2000\,W$
- Voltage, $V = 230\,V$

Formula:

$$I = \frac{P}{V}$$

Substituting:

$$I = \frac{2000}{230}$$

$$I = 8.70\,A$$

Answer: The current drawn by the electric kettle is approximately **8.70 A**.

11.2 Calculating Total Current for Several Appliances

When several appliances are connected to a single-phase supply, the total power is obtained by adding the power ratings of all the appliances.

The total current can then be calculated using:

$$I = \frac{P_T}{V}$$

Where:

- I = total current in amperes (A).
- P_T = total power in watts (W).
- V = supply voltage in volts (V).

Worked Example 2

A domestic electrical circuit supplies the following appliances:

- Television: 150 W.
- Refrigerator: 250 W.
- Computer: 200 W.
- Lighting: 100 W.

If the supply voltage is 230 V, calculate the total current drawn, assuming the stated power ratings represent the total real power and the combined power factor is approximately unity.

Solution

Step 1: Calculate the total power.

$$P_T = 150 + 250 + 200 + 100$$

$$P_T = 700\,W$$

Step 2: Calculate the total current.

Formula:

$$I = \frac{P_T}{V}$$

Substituting:

$$I = \frac{700}{230}$$

$$I = 3.04\,A$$

Answer: The approximate total current drawn by the appliances is **3.04 A**.

11.3 Calculating Electrical Power Using Voltage and Current

The electrical power of a resistive load can be calculated using the formula:

$$P = VI$$

Where:

- P = electrical power in watts (W).
- V = voltage in volts (V).
- I = current in amperes (A).

Worked Example 3

An electric heater operates at 230 V and draws a current of 10 A. Calculate its electrical power.

Solution

Given:

- Voltage, $V = 230\,V$.
- Current, $I = 10\,A$.

Formula:

$$P = VI$$

Substituting:

$$P = 230 \times 10$$

$$P = 2300\,W$$

Converting into kilowatts:

$$P = \frac{2300}{1000}$$

$$P = 2.3\,kW$$

Answer: The electrical power of the heater is **2,300 W or 2.3 kW**.

11.4 Calculating Resistance Using Ohm's Law

Ohm's law states that the current flowing through a conductor is directly proportional to the voltage across it, provided the physical conditions, such as temperature, remain constant.

The mathematical expression is:

$$V = IR$$

Making resistance R the subject:

$$R = \frac{V}{I}$$

Where:

- R = resistance in ohms (Ω).
- V = voltage in volts (V).
- I = current in amperes (A).

Worked Example 4

A resistive electrical circuit has a voltage of 230 V and draws a current of 5 A. Calculate its resistance.

Solution

Given:

- Voltage, $V = 230\,V$.
- Current, $I = 5\,A$.

Formula:

$$R = \frac{V}{I}$$

Substituting:

$$R = \frac{230}{5}$$

$$R = 46\,\Omega$$

Answer: The resistance of the circuit is **46 ohms**.

11.5 Earth Electrode Resistance

The resistance of an earth electrode is important because it influences the effectiveness of an electrical earthing arrangement.

In a TT earthing system, a commonly used design relationship for residual current device (RCD) protection is:

$$R_A \times I_{\Delta n} \leq U_L$$

Where:

- R_A = resistance of the earth electrode and protective conductor arrangement in ohms (Ω).
- $I_{\Delta n}$ = rated residual operating current of the RCD in amperes (A).
- U_L = applicable conventional touch-voltage limit in volts (V).

For many ordinary locations, a conventional touch-voltage limit of 50 V is used. Special locations may require lower limits.

Worked Example 5

A TT electrical installation has an earth electrode resistance of 100 Ω and uses an RCD with a rated residual operating current of 30 mA. Determine whether the relationship above is satisfied using a touch-voltage limit of 50 V.

Solution

Step 1: Identify the given values.

- Earth electrode resistance, $R_A = 100\,\Omega$.
- RCD rated residual current, $I_{\Delta n} = 30\,mA$.
- Touch-voltage limit, $U_L = 50\,V$.

Step 2: Convert milliamperes into amperes.

Since:

$$1000\,mA = 1\,A$$

Therefore:

$$I_{\Delta n} = \frac{30}{1000}$$

$$I_{\Delta n} = 0.03\,A$$

Step 3: State the formula.

$$R_A \times I_{\Delta n} \leq U_L$$

Step 4: Substitute the values.

$$100 \times 0.03 \leq 50$$

$$3\,V \leq 50\,V$$

Answer: The stated relationship is satisfied because the calculated value of 3 V is less than the specified touch-voltage limit of 50 V.

Conclusion: The earth electrode resistance satisfies the stated RCD relationship. However, this calculation alone does not establish that the entire earthing installation is safe; the protective devices, earthing continuity and installation requirements must also be verified.

Important: Satisfying this relationship alone does not prove that an installation is safe. The complete installation must meet all applicable requirements, including RCD performance, protective conductor continuity, disconnection times and inspection and testing.

12.0 Inspection, Testing and Maintenance of Earthing Systems

Earthing systems and protective devices must be inspected, tested and maintained to ensure that they remain effective throughout the service life of an installation.

12.1 Inspection of an earthing system

Inspection involves examining the physical condition and arrangement of earthing components to identify defects.

Items to inspect

1. Condition of the earth electrode.
2. Tightness of earth connections.
3. Condition of the earthing conductor.
4. Condition of protective conductors.
5. Signs of corrosion.
6. Condition of the earth inspection chamber.
7. Continuity of protective conductors.

8. Condition of the main earthing terminal.
9. Correct identification of conductors.
10. Evidence of unauthorised alterations.

12.2 Testing of earthing systems

The following tests are commonly associated with electrical installation verification.

1. Earth electrode resistance test

This test determines the resistance of an earth electrode to the general mass of the earth.

It helps establish whether the electrode arrangement meets the required design performance.

An earth resistance tester may be used, depending on the earthing arrangement and testing method.

2. Protective conductor continuity test

This test checks whether protective conductors provide a continuous electrical path between exposed conductive parts and the main earthing terminal.

3. Earth fault loop impedance test

This test determines the impedance of the earth fault current path.

It helps establish whether sufficient fault current can flow to operate the protective device within the required time.

4. RCD operating test

This test checks whether an RCD operates according to its rated characteristics and the applicable testing requirements.

5. Insulation resistance test

This test checks the insulation condition between conductors and between conductors and earth, as appropriate.

12.3 Maintenance of earthing systems

Maintenance activities include:

1. Inspecting earth electrode connections.
2. Checking for corrosion.
3. Replacing damaged earthing conductors.
4. Checking protective conductor continuity.
5. Inspecting the main earthing terminal.
6. Checking bonding arrangements.
7. Maintaining accessibility of inspection chambers.
8. Carrying out required electrical tests.
9. Correcting loose connections.
10. Recording inspection and test results.

12.4 Maintenance of protective devices

Protective devices should be maintained according to the manufacturer's instructions and applicable regulations.

Maintenance may involve:

- Visual inspection of protective devices.
- Checking for signs of overheating.
- Checking for physical damage.
- Confirming that device ratings are appropriate.
- Testing RCD operation using suitable instruments.
- Replacing defective devices with compatible approved devices.
- Checking circuit identification and labelling.

Important: Protective devices must never be bypassed, modified or replaced with devices of higher ratings merely to prevent nuisance tripping. The underlying fault must first be investigated.

13.0 Common Faults in Earthing and Protection Systems

Fault	Possible cause	Possible effect	Corrective action
Broken earth conductor	Mechanical damage	Loss of protective continuity	Repair or replace correctly
Loose earth connection	Poor workmanship	Increased resistance and unreliable protection	Correct and secure connection
Corroded earth electrode connection	Moisture or unsuitable materials	Poor electrical connection	Replace or repair using suitable materials
RCD trips repeatedly	Earth leakage or incorrect wiring	Loss of supply	Investigate and correct the fault
MCB trips frequently	Overload or short circuit	Circuit interruption	Identify and rectify the cause
Fuse repeatedly melts	Excess current or incorrect circuit design	Repeated supply interruption	Investigate the fault and correct the design
Damaged insulation	Ageing or mechanical damage	Shock or short-circuit risk	Replace damaged cable
Incorrect neutral arrangement	Wiring error	Unwanted RCD tripping or unsafe operation	Correct the wiring arrangement
Defective protective device	Wear or internal damage	Failure to disconnect a fault	Replace with a suitable device

13.1 Causes of frequent RCD tripping

1. Damaged appliance insulation.
2. Moisture entering electrical accessories.
3. Faulty heating elements.
4. Damaged cables.
5. Incorrect neutral-to-earth connections downstream of the RCD.
6. Cumulative leakage current from several appliances.
7. Defective RCD.
8. Incorrect circuit connections.

The correct response is to investigate and identify the fault rather than repeatedly resetting the device.

14.0 Practical Applications of Earthing and Excess Current Protection in Kenya

Earthing and protective devices are important in different sectors of the Kenyan economy.

14.1 Domestic buildings

Examples:

- Earthing metallic casings of appliances.
- Protecting socket-outlet circuits using suitable MCBs and RCDs.
- Providing earthing arrangements for water heaters.
- Protecting domestic lighting circuits.
- Providing surge protection for sensitive electronics where required.

14.2 Schools and training institutions

Examples:

- Earthing electrical equipment in workshops.
- Protecting computer laboratories.
- Providing suitable protection for science laboratory equipment.
- Protecting electrical installations in classrooms.
- Providing suitable protection for water pumps.

14.3 Hospitals and health centres

Examples:

- Earthing appropriate medical equipment.
- Providing suitable protection for essential electrical circuits.
- Coordinating protective devices in critical areas.
- Protecting sensitive electronic equipment.

Special medical locations have additional requirements and must be designed by competent professionals.

14.4 Agricultural installations

Examples:

- Earthing water pumps.
- Protecting milking equipment.
- Protecting poultry-house electrical installations.
- Protecting irrigation control systems.
- Protecting equipment in farm workshops.

Agricultural environments may contain moisture, dust, chemicals and conductive structures, making appropriate protection particularly important.

14.5 Commercial and industrial buildings

Examples:

- Earthing machinery.
- Protecting motor circuits.
- Protecting distribution boards.
- Providing lightning and surge protection.
- Protecting electrical control equipment.

16.0 Suggested Learning Experiences and Practical Activities

Activity 1: Identification of earthing components



Objective: Identify the main components of an earthing system.

Materials:

- Earth rod.
- Earth clamp.
- Earthing conductor.

- Protective conductor.
- Earth bar.
- Main earthing terminal.
- Inspection chamber.

Procedure:

1. Learners observe the different earthing components.
2. Identify each component.
3. Describe its construction.
4. State its function.
5. Explain where it is used.
6. Present findings to the class.

Expected learning outcome: Learners identify earthing components and explain their functions.

Activity 2: Identifying protective devices

Objective: Identify different protective devices used in domestic installations.

Materials:

- Sample fuse.
- MCB.
- RCD.
- RCBO.
- SPD.

Procedure:

1. Learners observe the devices.
2. Identify the name of each device.
3. Read the markings and ratings.
4. Explain the operation of each device.
5. State the faults each device protects against.
6. Compare their advantages and limitations.

Activity 3: Drawing earthing systems

Objective: Draw and compare TT, TN-S and TN-C-S earthing arrangements.

Procedure:

1. Divide learners into groups.
2. Assign each group an earthing system.
3. Draw the supply transformer.
4. Show the neutral and protective conductors.
5. Identify the earth electrode where applicable.

6. Label the main earthing terminal.
7. Present the diagrams.
8. Compare the systems.

Expected learning outcome: Learners distinguish different earthing systems and explain their operation.

Activity 4: Demonstration of protective devices

Objective: Explain the operation of protective devices.

Materials:

- Demonstration distribution board.
- MCB.
- RCD.
- Fuse.
- Safe fault-simulation equipment.

Procedure:

1. Observe the demonstration board.
2. Identify the protective devices.
3. Discuss the function of each device.
4. Observe a teacher-controlled simulation of a fault.
5. Explain why the protective device operates.
6. Record the observations.

Safety note: Fault simulation must use purpose-designed training equipment. Learners must never create faults on a live domestic installation.

Activity 5: Visit to a domestic electrical installation site

Objective: Observe the arrangement of earthing and protective devices.

Procedure:

1. Visit an authorised domestic installation site with a qualified electrician.
2. Observe the distribution board.
3. Identify the MCBs and RCDs.
4. Observe the earthing conductor and main earthing terminal where accessible.
5. Identify the earth electrode arrangement where accessible.
6. Discuss the purpose of each component.
7. Record observations.
8. Present findings in class.

Expected learning outcome: Learners relate classroom knowledge to actual domestic electrical installations.

REVISION QUESTIONS

SUBJECT: ELECTRICITY TECHNOLOGY

SECTION A: MULTIPLE-CHOICE QUESTIONS (30 MARKS)

Instructions: Answer all questions. Choose the correct answer from the alternatives A, B, C and D. Each question carries one mark.

1. What is the meaning of earthing in an electrical installation?

A. Connecting the live conductor to the neutral conductor.

B. Connecting an installation or equipment to the earthing arrangement.

C. Connecting all appliances in series.

D. Increasing the voltage supplied to an appliance.

2. Which of the following is the main purpose of earthing electrical appliances?

A. To increase their power consumption.

B. To prevent them from using electricity.

C. To reduce the risk of electric shock during an earth fault.

D. To increase the resistance of the circuit.

3. Which component is installed in contact with the general mass of the earth?

A. MCB

B. Earth electrode

C. Fuse

D. Socket outlet

4. Which conductor connects exposed conductive parts of electrical equipment to the protective earthing system?

A. Live conductor

B. Neutral conductor

C. Protective conductor

D. Switching conductor

5. Which colour is commonly used to identify a protective earth conductor in modern harmonised wiring?

A. Brown

B. Blue

C. Green/yellow

D. Black

6. Which of the following is an earthing system in which the consumer has a local earth electrode?

A. TT

B. TN-S

C. TN-C-S

D. IT only

7. In a TN-S earthing system, the neutral and protective earth conductors are:

A. Combined throughout the installation.

B. Separate throughout the system.

C. Connected only to the live conductor.

D. Not required.

8. What does the letter C represent in a TN-C-S earthing system?

A. Current

B. Circuit

C. Combined neutral and protective earth functions

D. Conductor resistance

9. Which of the following devices detects residual current imbalance?

A. Fuse

B. RCD

C. Switch

D. Socket outlet

10. Which protective device operates by melting a fusible element?

A. MCB

B. RCD

C. Fuse

D. SPD

11. What is the main function of an MCB?

A. To measure electrical energy.

B. To protect against overload and short-circuit current.

C. To increase the supply voltage.

D. To store electrical energy.

12. Which mechanism in an MCB commonly provides overload protection?

A. Thermal mechanism

B. Magnetic mechanism only

C. Manual mechanism

D. Mechanical locking mechanism only

13. Which mechanism in an MCB responds to very high short-circuit current?

A. Thermal mechanism only

B. Magnetic mechanism

C. Insulation mechanism

D. Earthing mechanism

14. Which device combines residual-current protection and overcurrent protection?

A. Fuse

B. RCCB

C. RCBO

D. Earth electrode

15. What is the main purpose of an SPD?

A. To increase the current in a circuit.

B. To limit transient overvoltages.

C. To replace the main switch.

D. To measure resistance.

16. Which of the following describes an overload?

A. A circuit carrying more current than it is designed to carry.

B. A circuit with no electrical supply.

C. A conductor with no insulation.

D. A circuit operating at zero voltage.

17. A short circuit occurs when:

A. A switch is turned off.

B. Conductors at different potentials make unintended contact through a low-impedance path.

C. An appliance uses its normal rated current.

D. A circuit is correctly earthed.

18. Which of the following is a common cause of an electrical earth fault?

A. Correct insulation.

B. Proper bonding.

C. Damaged cable insulation.

D. Correctly rated circuit breakers.

19. In a typical TT installation, which device is particularly important for earth-fault protection?

A. Lamp holder

B. RCD

C. Ceiling rose

D. Socket faceplate

20. What is the main function of the main earthing terminal?

A. To increase the voltage.

B. To provide a common connection point for protective earthing conductors.

C. To measure energy consumption.

D. To disconnect the live supply.

21. Which of the following is the correct function of a bonding conductor?

A. To increase the current in a circuit.

B. To connect relevant conductive parts and reduce dangerous potential differences.

C. To replace the neutral conductor.

D. To supply power to lighting points.

22. Which of the following is a possible effect of excessive current in an electrical cable?

A. Reduced temperature in all cases.

B. Improved insulation.

C. Overheating and possible fire.

D. Increased cable life.

23. Which device normally needs replacement after its fusible element operates?

A. MCB

B. Fuse

C. RCD

D. Main switch

24. Which instrument is commonly used to measure earth electrode resistance?

A. Ammeter

B. Earth resistance tester

C. Wattmeter

D. Tachometer

25. Which test checks the continuity of protective conductors?

A. Polarity test

B. Protective conductor continuity test

C. Functional test

D. Voltage measurement only

26. Which of the following is a function of a lightning protection system?

A. To increase the voltage of the supply.

B. To provide a controlled path for lightning current.

C. To replace the distribution board.

D. To prevent normal load current from flowing.

27. What should be done before working on an existing electrical circuit?

A. Remove all protective devices.

B. Isolate the supply and verify that the circuit is dead.

C. Connect an additional load.

D. Increase the fuse rating.

28. Which of the following is a possible cause of frequent RCD tripping?

A. Correct insulation.

B. Damaged appliance insulation.

C. Correctly connected protective conductors.

D. Properly maintained wiring.

29. Which type of maintenance is carried out at planned intervals to reduce the likelihood of faults?

A. Corrective maintenance

B. Preventive maintenance

C. Emergency maintenance

D. Accidental maintenance

30. Why should protective devices not be bypassed?

A. To increase electricity consumption.

B. To prevent them from operating during faults.

C. Because doing so removes an important safety measure.

D. To make the installation more expensive.

SECTION B: STRUCTURED QUESTIONS (50 MARKS)

Instructions: Answer all questions. Show working where necessary.

QUESTION 1: Earthing in Electrical Installations (8 Marks)

a) Define earthing as used in electrical installations. (2 marks)

b) State four reasons why electrical appliances should be properly earthed. (4 marks)

c) Name two components of an earthing system. (2 marks)

QUESTION 2: Types of Earthing Systems (8 Marks)

a) Name the three common types of earthing systems used in domestic installations. (3 marks)

b) Differentiate between TN-S and TN-C-S earthing systems. (2 marks)

c) State three advantages of providing an effective earthing arrangement in a domestic installation. (3 marks)

QUESTION 3: Excess Current and Protective Devices (8 Marks)

a) Define excess current. (2 marks)

b) Differentiate between overload and short-circuit faults. (2 marks)

c) Explain how a fuse operates when excessive current flows through it. (2 marks)

d) State two functions of an MCB. (2 marks)

QUESTION 4: Residual Current Protection (8 Marks)

a) Define a Residual Current Device (RCD). (2 marks)

b) Explain how an RCD operates when an earth-leakage fault occurs. (3 marks)

c) State three differences between an RCD and an MCB. (3 marks)

QUESTION 5: Electrical Protection Calculations and Installation (9 Marks)

a) An electric heater rated at 2,300 W is connected to a 230 V domestic supply.

Calculate the current drawn by the heater. (3 marks)

b) State three factors considered when selecting a protective device for a domestic circuit. (3 marks)

c) State three safety precautions that should be observed when installing protective devices in a distribution board. (3 marks)

QUESTION 6: Lightning Protection, Inspection and Maintenance (9 Marks)

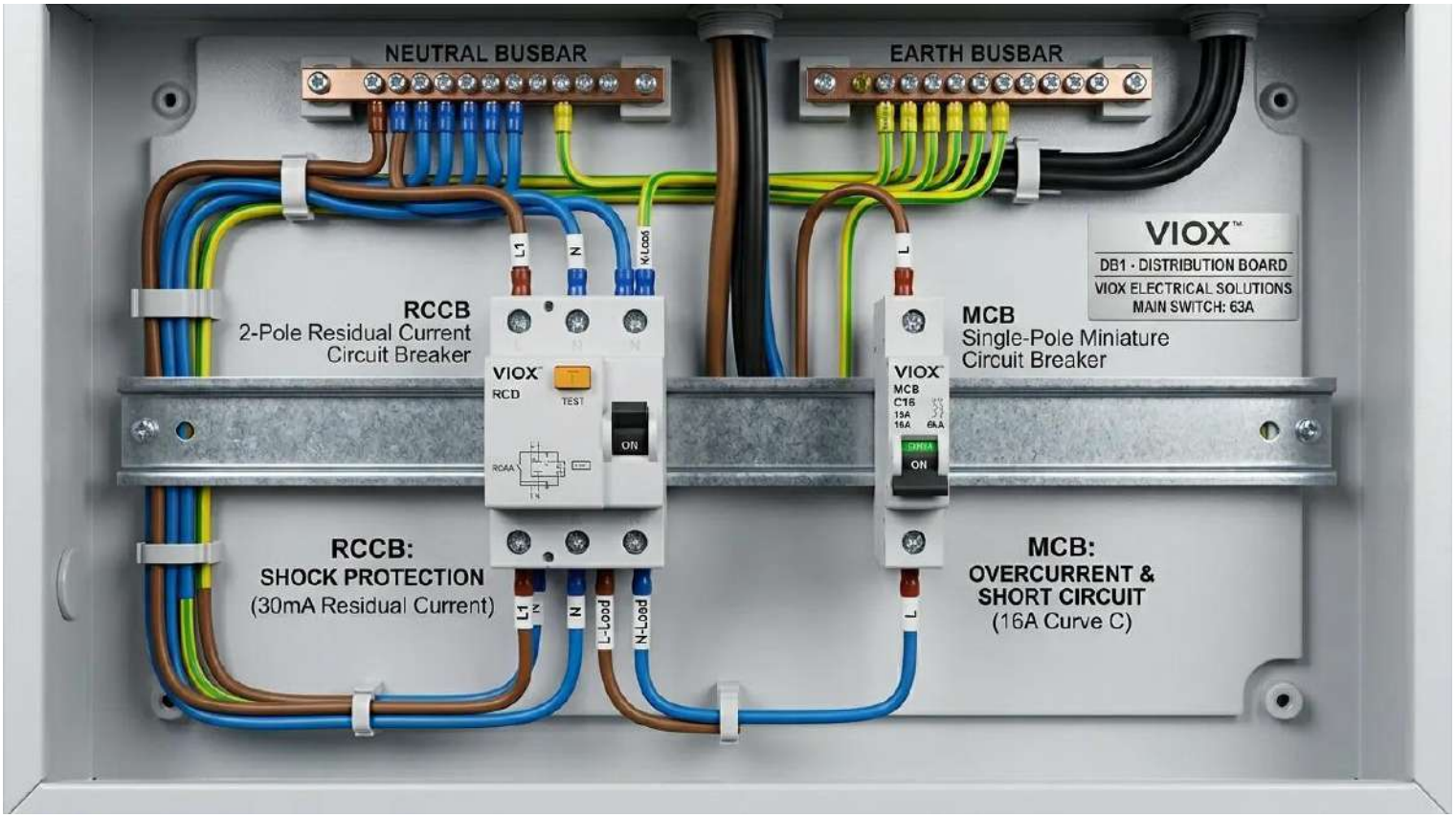
a) State three components of an external lightning protection system. (3 marks)

b) State three tests carried out during the verification of an electrical installation. (3 marks)

c) Explain three reasons why regular inspection and maintenance of earthing systems are important. (3 marks)

19.0 Suggested CBE Assessment Project

Project: Design a Domestic Earthing and Protection Demonstration Board



Project task: Design and assemble a non-energised demonstration model showing how earthing and protective devices are arranged in a typical domestic electrical installation.

Required components

1. Model electricity supply connection.
2. Energy meter representation.
3. Main isolator representation.
4. Distribution board.
5. MCBs.
6. RCD or RCBO.
7. Earth bar.
8. Main earthing terminal.
9. Protective conductors.
10. Earth electrode representation.
11. Lighting circuit representation.
12. Socket-outlet circuit representation.

Suggested project procedure

1. Research domestic earthing arrangements.
2. Identify the protective devices required.
3. Draw a simple circuit diagram.
4. Select suitable demonstration components.
5. Arrange the components on a mounting board.

6. Label all components clearly.
7. Explain the operation of the protective devices.
8. Present the completed model.
9. Evaluate the safety and accuracy of the model.

Suggested assessment rubric

Assessment area	Marks
Identification of components	10
Understanding of earthing systems	10
Correct arrangement of protective devices	15
Quality of demonstration model	10
Safety awareness and handling of materials	10
Explanation and presentation	5
Total	60

20.0 Summary of Important Terms

Term	Meaning
Earthing	Connection of an installation or equipment to the earthing arrangement
Earth electrode	Conductive component in contact with the general mass of the earth
Earthing conductor	Conductor connecting the earthing arrangement to the main earthing terminal
Protective conductor	Conductor connecting exposed conductive parts to the protective earthing system
Bonding	Electrical connection of relevant conductive parts to reduce potential differences
Overload	Current exceeding the intended circuit or equipment rating
Short circuit	Unintended low-impedance connection between conductors at different potentials
Fuse	Device that interrupts current by melting a fusible element

MCB	Automatic device providing overload and short-circuit protection
RCD	Device that detects residual current imbalance
RCBO	Device combining residual-current and overcurrent protection
SPD	Device limiting transient overvoltages
TT system	Earthing system with a local consumer earth electrode
TN-S system	System with separate neutral and protective earth conductors
TN-C-S system	System with combined PEN conductor in part of the supply and separate conductors after separation
Lightning protection	System designed to protect structures against lightning effects

STRAND 3.0: ELECTRICAL INSTALLATION

SUB-STRAND 3.3: INSPECTION AND TESTING



1.0 Introduction to Inspection and Testing of Electrical Installations

1.1 Meaning of electrical installation

An **electrical installation** refers to an arrangement of electrical equipment, wiring, accessories and protective devices connected together to distribute and utilise electrical energy safely within a building or other premises.

A domestic electrical installation is an electrical system designed to supply electricity to a residential building such as a house, apartment or bungalow.

Examples of components found in a domestic electrical installation include:

1. Consumer unit or distribution board.
2. Main switch.
3. Energy meter.
4. Circuit breakers.
5. Residual current devices (RCDs).
6. Electrical cables.
7. Lighting switches.
8. Socket outlets.
9. Lighting points.
10. Earthing conductors.
11. Earth electrodes, where applicable.
12. Junction boxes.
13. Conduit and trunking systems.
14. Electrical accessories.

1.2 Meaning of electrical inspection

Electrical inspection is the systematic visual examination of an electrical installation to establish whether its components, wiring arrangements and protective devices have been correctly installed and are in a safe operating condition.

Inspection involves examining the physical condition and arrangement of electrical equipment without necessarily carrying out electrical measurements.

Examples of items examined during inspection:

- Condition of electrical cables.
- Correct installation of switches and sockets.
- Proper mounting of distribution boards.
- Presence of protective devices.
- Correct identification of conductors.
- Condition of cable insulation.
- Proper enclosure of live electrical parts.
- Suitable earthing arrangements.
- Correct cable support and mechanical protection.

1.3 Meaning of electrical testing

Electrical testing is the process of using suitable electrical measuring instruments and approved procedures to determine whether an electrical installation meets specified electrical safety and performance requirements.

Testing involves taking measurements and checking the electrical characteristics of an installation.

Examples include:

1. Continuity testing.
2. Insulation resistance testing.
3. Earth electrode resistance testing.
4. Protective conductor continuity testing.
5. Polarity testing.
6. Earth fault loop impedance testing.
7. RCD operation testing.
8. Functional testing.
9. Verification of supply voltage.

1.4 Difference between inspection and testing

Although inspection and testing are closely related, they involve different procedures.

Electrical inspection	Electrical testing
Involves visual examination.	Involves electrical measurements.

Checks physical installation conditions.	Checks electrical characteristics and performance.
May identify damaged cables and loose accessories.	Identifies faults such as poor continuity and insulation breakdown.
Uses visual observation and suitable inspection tools.	Uses instruments such as insulation resistance testers and earth loop testers.
Does not necessarily require electrical energisation.	Some tests are performed with the installation isolated, while specified verification tests may require controlled energisation.
Checks whether components are installed correctly.	Checks whether electrical circuits operate and provide the required protection.

Important: Inspection and testing complement each other. Both are necessary before an electrical installation is commissioned.

2.0 Importance of Inspection and Testing of Electrical Installations

Electrical inspection and testing are important because electrical faults may cause electric shocks, fires, equipment damage and loss of life.

2.1 Reasons for inspecting and testing domestic electrical installations

1. Prevention of electric shocks

- Testing helps identify defective insulation.
- Inspection identifies exposed live conductors.
- Earthing tests help verify protective conductor arrangements.
- Protective devices help disconnect dangerous fault currents.

2. Prevention of electrical fires

- Identifies loose electrical connections.
- Detects damaged cables.
- Identifies inappropriate circuit protection.
- Helps prevent overheating caused by electrical faults.

3. Verification of correct installation

- Confirms that electrical accessories are correctly installed.
- Checks that cables are properly routed and supported.
- Verifies that distribution boards are correctly arranged.
- Ensures protective devices are properly selected.

4. Compliance with electrical regulations

- Helps establish whether an installation meets applicable Kenyan electrical safety requirements.
- Supports compliance with relevant Kenya Standards and applicable wiring standards.

- Helps ensure that work is carried out by appropriately qualified and authorised electrical personnel.

5. Protection of electrical equipment

- Identifies faults that could damage appliances.
- Helps ensure that voltage and circuit protection arrangements are suitable.
- Reduces the possibility of equipment failure.

6. Prevention of electrical accidents

- Identifies unsafe installation conditions.
- Helps eliminate potential electrical hazards.
- Protects occupants, electricians and maintenance personnel.

7. Improved reliability

- Ensures that electrical circuits operate correctly.
- Reduces unexpected power interruptions.
- Helps identify defects before they cause system failure.

8. Verification of protective devices

- Confirms that protective conductors are continuous.
- Checks that circuit breakers and RCDs are suitable.
- Verifies the effectiveness of protective arrangements.

9. Provision of installation records

- Provides evidence of the condition of the installation.
- Records test results.
- Supports future maintenance.
- Helps identify changes made to the installation.

10. Protection of property

- Reduces the risk of electrical fires.
- Helps prevent damage to buildings.
- Protects domestic appliances and electronic equipment.

2.2 Consequences of failing to inspect and test electrical installations

1. Increased risk of electric shock.
2. Electrical fires.
3. Damage to household appliances.
4. Frequent circuit breaker tripping.
5. Failure of protective devices.
6. Poor electrical performance.
7. Increased maintenance costs.

8. Danger to electricians and building occupants.
9. Failure to meet applicable safety requirements.
10. Premature deterioration of electrical equipment.

3.0 Types of Inspection of Domestic Electrical Installations

Inspection is conducted at different stages of electrical installation work.

3.1 Initial inspection

Initial inspection is the visual examination of a new electrical installation or an addition to an existing installation before it is placed into service.

Items checked during initial inspection

1. Correct selection of cables.
2. Correct cable routing.
3. Proper installation of conduits and trunking.
4. Secure mounting of switches and socket outlets.
5. Correct positioning of distribution boards.
6. Appropriate circuit identification.
7. Suitable protective devices.
8. Correct connection of conductors.
9. Proper earthing and bonding arrangements.
10. Protection against mechanical damage.
11. Proper enclosure of live parts.
12. Accessibility of electrical equipment for maintenance.

Example: Before a newly constructed house in Nakuru is connected to the electrical supply, its electrical installation is visually examined to identify any defects.

3.2 Periodic inspection

Periodic inspection is the examination and testing of an existing electrical installation at suitable intervals to establish whether it remains safe for continued use.

Reasons for periodic inspection

- Ageing of electrical cables.
- Deterioration of insulation.
- Wear of electrical accessories.
- Changes in building usage.
- Addition of new electrical appliances.
- Frequent circuit failures.
- Environmental conditions such as moisture and dust.

Example: Inspecting the electrical installation of an older residential building to establish whether the wiring and protective devices remain safe.

3.3 Visual inspection

Visual inspection involves observing the physical condition and arrangement of electrical installation components.

Items to observe

- Damaged cable insulation.
- Broken switches.
- Cracked socket outlets.
- Exposed conductors.
- Loose distribution board covers.
- Signs of overheating.
- Water entry into electrical equipment.
- Poorly supported cables.
- Missing protective covers.
- Incorrect circuit labelling.

3.4 Inspection during installation

This is inspection conducted while electrical installation work is in progress.

It helps identify mistakes before they become difficult or expensive to correct.

Examples

1. Checking conduit installation before plastering.
2. Inspecting concealed wiring before covering walls.
3. Checking cable sizes before connecting circuits.
4. Confirming correct cable identification.
5. Inspecting earthing conductors before final enclosure.

4.0 Types of Electrical Tests Performed on Domestic Installations

Electrical tests are carried out using suitable instruments and approved procedures.

The main tests include:

1. Continuity test.
2. Insulation resistance test.
3. Earthing test.
4. Polarity test.
5. Earth fault loop impedance test.
6. RCD operation test.
7. Functional test.
8. Voltage test.

4.1 Continuity test

Meaning of continuity

Continuity refers to the existence of an unbroken electrical conducting path between two points in an electrical circuit.

A continuity test is an electrical test performed to establish whether a conductor or electrical circuit provides a complete and sufficiently low-resistance conducting path.



Purpose of a continuity test

1. To confirm that conductors are not broken.
2. To identify open circuits.
3. To verify the continuity of protective conductors.
4. To check the continuity of circuit conductors.
5. To verify connections between electrical accessories.
6. To identify loose connections.
7. To establish that protective bonding conductors are continuous.

Instruments used

- Continuity tester.
- Digital multimeter with resistance function.
- Low-resistance ohmmeter.
- Approved multifunction installation tester.

Procedure for performing a continuity test

De-energised test

Continuity testing must be performed on an isolated circuit.

1. Identify the circuit to be tested.
2. Switch off and isolate the relevant supply.
3. Secure the isolation against accidental reconnection.
4. Prove the voltage tester on a known source or proving unit.
5. Confirm that the circuit is dead using an appropriate voltage tester.
6. Prove the voltage tester again.
7. Disconnect sensitive equipment where necessary.
8. Select the appropriate low-resistance or continuity function.
9. Connect the test leads to the relevant conductor ends.
10. Take the measurement.
11. Record the resistance reading.
12. Compare the result with the applicable requirements.

Interpretation of continuity test results

- A very low resistance reading indicates a good conducting path.
- An infinite or extremely high resistance reading may indicate a broken conductor or open circuit.
- An unstable reading may indicate loose connections or poor contact.
- The acceptable resistance depends on conductor length, cross-sectional area and the circuit requirements.

Example

A protective conductor is tested using a suitable low-resistance tester. The measured resistance is 0.18 Ω.

This indicates a low-resistance path, but the result must be evaluated against the expected resistance of the conductor and the installation requirements.

Causes of continuity failure

1. Broken conductors.
2. Loose terminals.
3. Corroded connections.
4. Poorly made joints.
5. Damaged cables.
6. Incorrect wiring connections.

4.2 Insulation resistance test

Meaning of insulation resistance

Insulation resistance is the resistance offered by insulating materials to the flow of unwanted electric current between conductors or between conductors and earth.

An insulation resistance test is performed to determine the effectiveness of electrical insulation in preventing unwanted current leakage.



Purpose of insulation resistance testing

1. To identify damaged insulation.
2. To detect moisture in electrical equipment.
3. To identify leakage paths between conductors.
4. To prevent electric shock.
5. To reduce the risk of electrical fires.
6. To verify the condition of newly installed cables.
7. To determine whether electrical circuits are suitable for service.

Instrument used

An insulation resistance tester, commonly called a megger, is used to measure insulation resistance.

The instrument applies a specified DC test voltage and measures the resulting resistance.

Insulation resistance is normally measured in:

- Ohms (Ω).
- Kilohms (kΩ).
- Megohms (MΩ).

Construction and features of a megger

A typical digital insulation resistance tester contains:

1. Display screen.
2. Test voltage selection control.
3. Test button.
4. Positive test terminal.
5. Negative test terminal.
6. Resistance measurement circuit.
7. Internal power source.
8. Test leads.

Common insulation resistance test voltages

The appropriate test voltage depends on the rated voltage of the circuit and the applicable standard.

Circuit category	Common DC test voltage
Extra-low-voltage circuits	250 V
Circuits up to and including 500 V	500 V
Circuits above 500 V	1,000 V

These are common reference values from IEC-based installation testing practice. The applicable standard and equipment manufacturer's instructions must be checked before selecting a test voltage.

Procedure for performing an insulation resistance test

De-energised test

1. Identify the circuit to be tested.
2. Switch off and isolate the circuit.
3. Lock off or otherwise secure the isolation.
4. Confirm that the circuit is dead using an approved voltage tester.
5. Disconnect or protect sensitive electronic equipment, surge protection devices and other components that may be damaged by the test voltage.
6. Ensure that all relevant switches are in the correct test position.
7. Select the correct insulation test voltage.
8. Connect the test leads to the appropriate conductors.
9. Operate the tester according to the manufacturer's instructions.
10. Record the insulation resistance reading.
11. Allow the tester to discharge the circuit after testing.
12. Compare the results with the applicable minimum requirements.

Common insulation resistance test arrangements

A. Live conductor to neutral

- Checks insulation between the live and neutral conductors.
- Helps identify insulation deterioration between the two conductors.

B. Live conductor to earth

- Checks insulation between the live conductor and protective earth.
- Helps identify leakage paths that may cause electric shock.

C. Neutral conductor to earth

- Checks insulation between neutral and protective earth where the test arrangement permits.
- Helps identify unwanted connections or insulation faults.

For appropriate circuit configurations, the live and neutral conductors may be connected together and tested against the protective conductor to reduce the risk of damaging connected equipment.

Interpretation of insulation resistance results

Under commonly used IEC 60364-6 reference requirements:

- A 500 V DC test for circuits up to and including 500 V generally requires a minimum insulation resistance of 1 MΩ.
- A 250 V DC test for certain SELV and PELV circuits generally requires at least 0.5 MΩ.

The exact requirement must be checked against the applicable standard, circuit type and equipment.

A higher insulation resistance generally indicates better insulation condition.

Causes of low insulation resistance

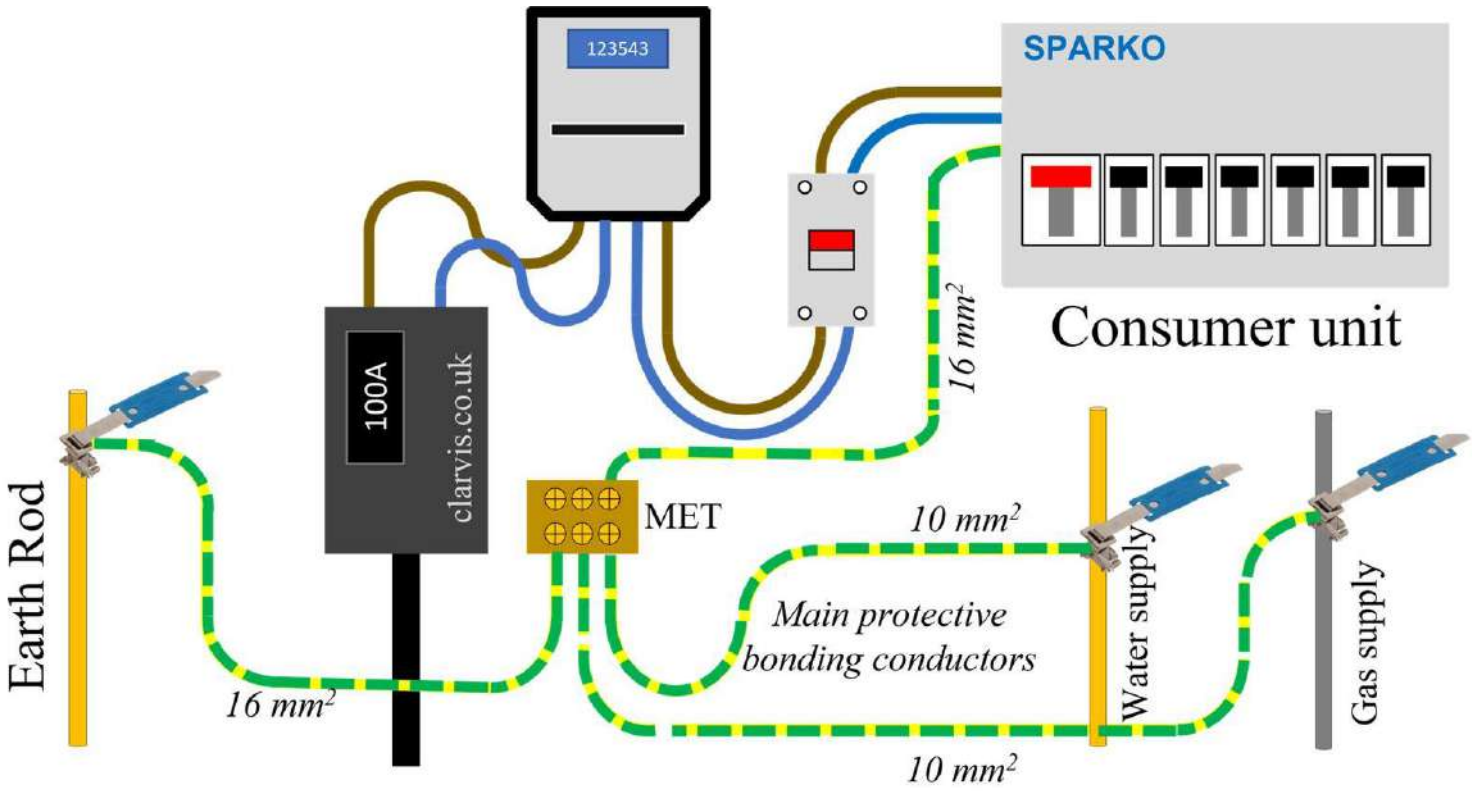
1. Damaged cable insulation.
2. Moisture entering electrical equipment.
3. Ageing of insulating materials.
4. Excessive heat.
5. Chemical contamination.
6. Poor installation workmanship.
7. Rodent damage.
8. Incorrect connections.

4.3 Earthing tests

Meaning of earthing

Earthing is the connection of exposed conductive parts of electrical equipment to the general mass of the earth through a suitable protective earthing arrangement.

The purpose is to reduce the risk of electric shock by providing an appropriate fault-current path and supporting the operation of protective devices.



Importance of earthing

1. Protects people against electric shock.
2. Provides a path for fault current.
3. Helps protective devices disconnect faulty circuits.
4. Reduces the risk of electrical fires.
5. Protects electrical equipment.
6. Supports equipotential bonding.
7. Improves electrical installation safety.

Types of earthing tests

1. Protective conductor continuity test

This test determines whether the protective conductor provides a continuous low-resistance path between exposed conductive parts and the main earthing terminal.

2. Earth electrode resistance test

This test measures the resistance between an earth electrode and the general mass of earth.

3. Earth fault loop impedance test

This test measures the impedance of the complete earth fault current path, allowing the effectiveness of automatic disconnection to be assessed.

Instruments used for earthing tests

- Low-resistance ohmmeter.
- Earth resistance tester.
- Earth loop impedance tester.
- Approved multifunction installation tester.

A. Protective conductor continuity testing

Procedure

1. Identify the protective conductor to be tested.
2. Isolate the electrical supply.
3. Confirm that the circuit is dead.
4. Select a suitable low-resistance tester.
5. Connect the instrument to the main earthing terminal and the relevant protective conductor point using an appropriate test arrangement.
6. Measure the resistance.
7. Record the reading.
8. Compare the reading with the expected conductor resistance and applicable requirements.

Interpretation

- Low resistance indicates a good protective conductor path.
- High resistance indicates a possible poor connection or damaged conductor.
- Infinite resistance indicates an open protective conductor.

B. Earth electrode resistance testing

Earth electrode resistance testing establishes the resistance of an earth electrode to the general mass of earth.

Instrument: Earth resistance tester.

Common method: Three-point or fall-of-potential method.

Procedure

1. Identify the earth electrode.
2. Follow the approved safe isolation procedure.
3. Disconnect the electrode only where safe and permitted by the testing procedure.
4. Position the auxiliary current and potential probes at suitable distances.
5. Connect the test leads according to the instrument instructions.
6. Operate the earth resistance tester.
7. Record the resistance reading.
8. Repeat measurements at suitable positions to verify stability.
9. Reconnect the electrode and verify the protective arrangement.

Factors affecting earth electrode resistance

- Soil moisture.
- Soil composition.
- Soil temperature.
- Electrode length.

- Electrode diameter.
- Depth of installation.
- Contact between electrode and soil.
- Corrosion of the electrode.

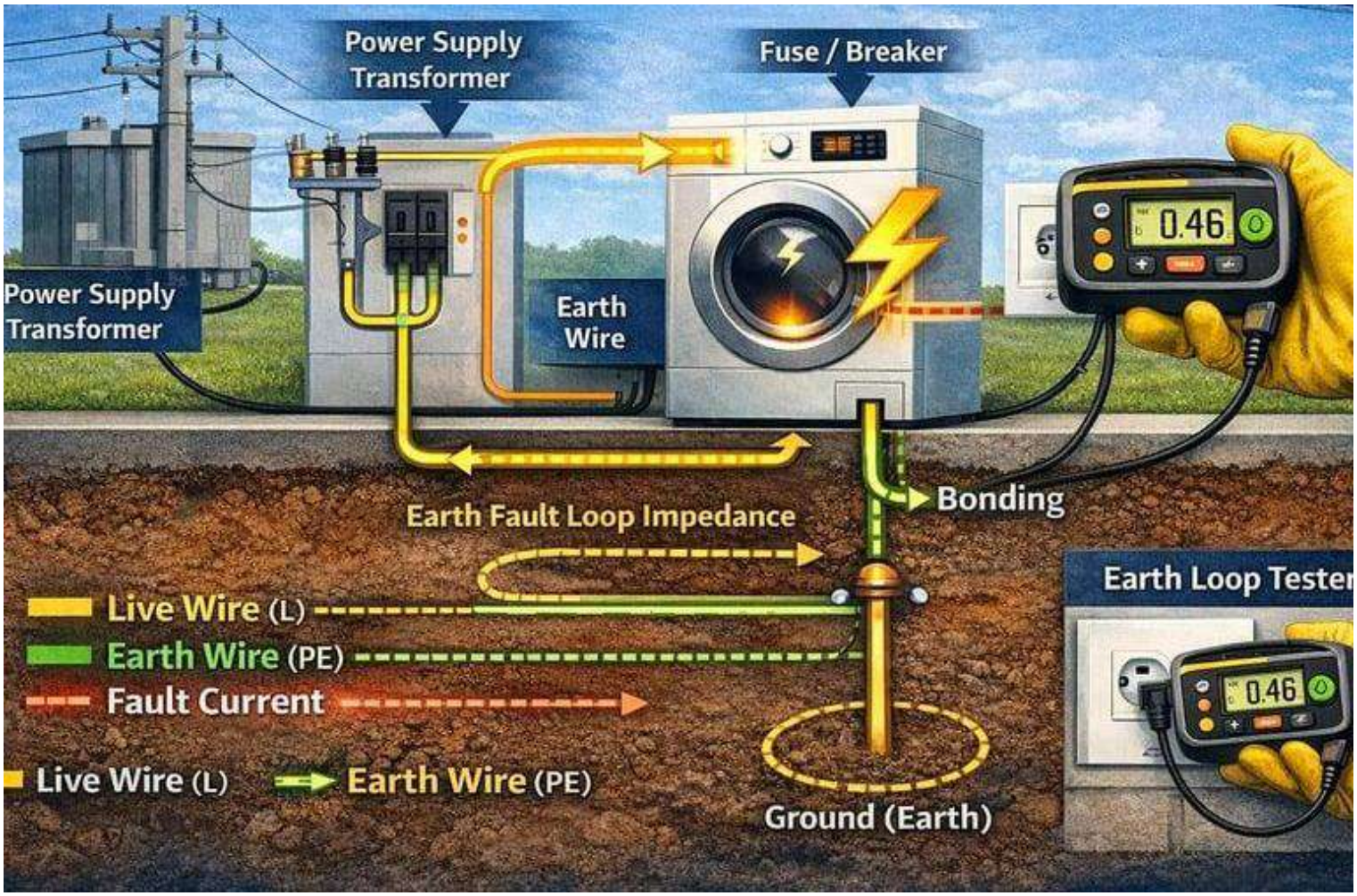
Methods of reducing earth electrode resistance

1. Installing suitable longer electrodes.
2. Using additional interconnected electrodes where designed.
3. Improving electrode placement.
4. Using suitable earthing arrangements.
5. Maintaining good connections.
6. Selecting an appropriate electrode system for the soil conditions.

Important: There is no single universal acceptable earth electrode resistance for every domestic installation. The required value depends on the earthing system, protective devices and applicable regulations.

C. Earth fault loop impedance test

Earth fault loop impedance is the total impedance of the path followed by fault current when a live conductor comes into contact with an earthed conductive part.



Instrument: Earth fault loop impedance tester.

Purpose

1. Determines the impedance of the earth fault loop.
2. Helps establish whether sufficient fault current will flow.
3. Verifies whether protective devices can disconnect the faulty circuit within the required time.
4. Helps assess the effectiveness of the earthing arrangement.

Basic procedure

This is a controlled live test and must only be performed by an appropriately qualified and authorised person using a suitable instrument and safe working procedure.

1. Verify that initial inspection and dead tests have been satisfactorily completed.
2. Confirm that the installation can safely be energised.
3. Select the correct test mode.
4. Connect the tester to the specified test point.
5. Carry out the measurement using the manufacturer's procedure.
6. Record the measured loop impedance.
7. Compare the result with the required maximum value for the protective device and disconnection time.
8. Investigate any unsatisfactory result before commissioning.

Interpretation

- Lower loop impedance generally allows a higher fault current.
- Higher loop impedance may prevent a protective device from disconnecting quickly enough.
- The measured result must be assessed against the protective device characteristics and applicable requirements.

4.4 Polarity test

Meaning of polarity

Polarity refers to the correct connection of live, neutral and protective conductors to their intended terminals in an electrical installation.

A polarity test is carried out to establish that single-pole switches, fuses and other devices are correctly connected in the live conductor and that accessories are wired according to their intended terminal arrangements.

Purpose of polarity testing

1. To ensure that switches control the live conductor.
2. To ensure that fuses are connected in the live conductor.
3. To verify correct wiring of socket outlets.
4. To prevent dangerous exposure of supposedly isolated equipment.
5. To identify reversed live and neutral connections.
6. To verify correct connection of electrical accessories.

Instruments used

- Continuity tester.

- Low-resistance ohmmeter.
- Digital multimeter.
- Approved multifunction installation tester.

Procedure for polarity testing

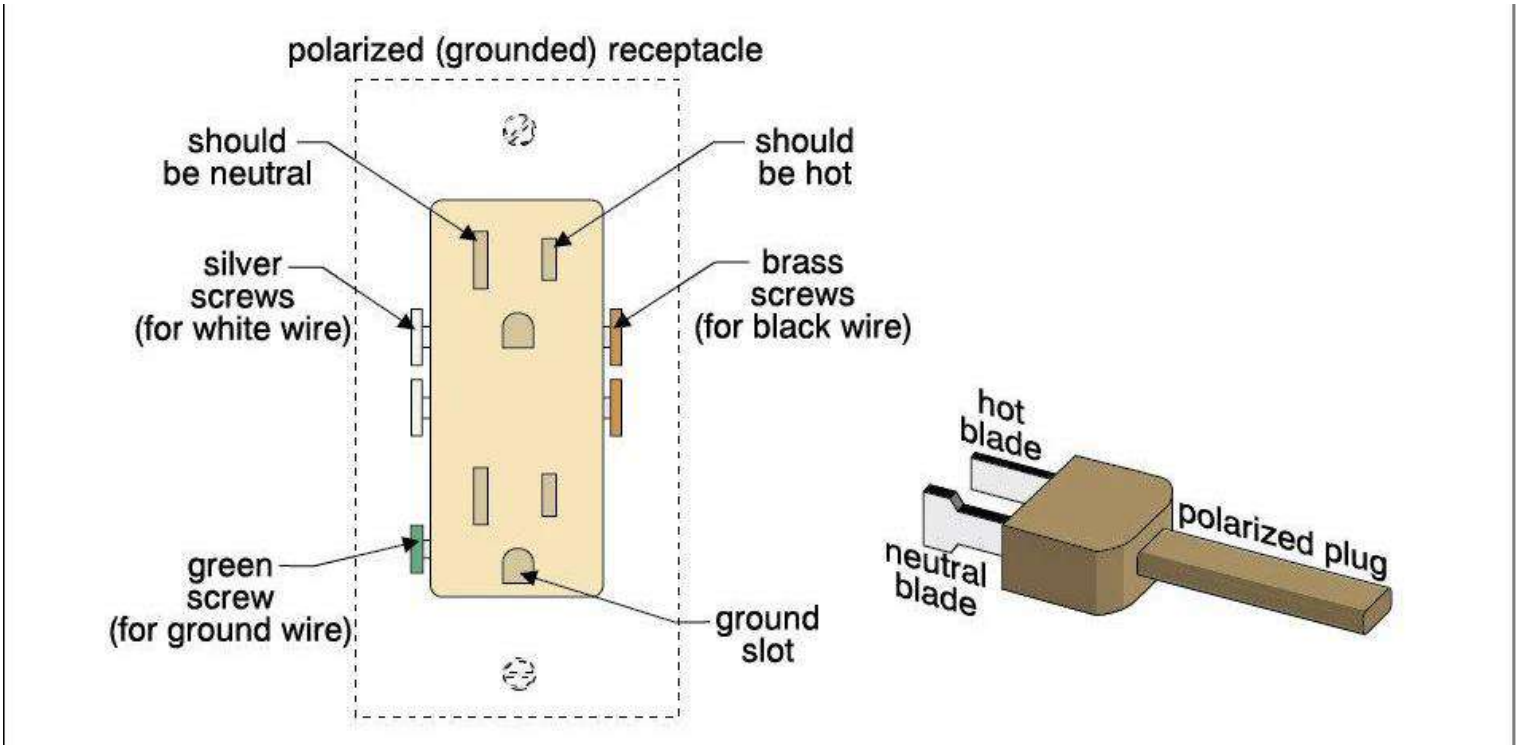
Dead testing method

1. Isolate the supply.
2. Secure the isolation.
3. Confirm that the circuit is dead.
4. Use a suitable continuity testing arrangement.
5. Trace the live conductor through the appropriate switch or protective device.
6. Confirm that the switching device interrupts the live conductor.
7. Verify correct conductor connections at the relevant accessories.
8. Record the result.

Live verification

Live polarity verification may be required as part of final testing. It must be performed by a qualified person using an approved procedure and suitable equipment.

Correct and incorrect polarity



Correct polarity

- Live conductor is connected to the designated live terminal.
- Neutral conductor is connected to the designated neutral terminal.
- Protective earth conductor is connected to the earth terminal.
- Single-pole switches interrupt the live conductor.

Incorrect polarity

- Live and neutral conductors are interchanged.
- A switch may interrupt the neutral instead of the live conductor.
- A fuse may be incorrectly connected in the neutral conductor.

Effects of incorrect polarity

1. Increased risk of electric shock.
2. Equipment may remain live even when switched off.
3. Incorrect operation of electrical accessories.
4. Failure to achieve the intended isolation.
5. Increased danger during maintenance.

4.5 Earth leakage and RCD operation test

Meaning of earth leakage

Earth leakage is the unintended flow of electrical current from a live part of an electrical circuit to earth or an earthed conductive part.

It may occur due to damaged insulation, moisture, defective appliances or faulty wiring.

Meaning of a residual current device (RCD)

An RCD is a protective device that detects an imbalance between the current flowing through the live conductor and the current returning through the neutral conductor.

When the imbalance reaches the device's operating threshold, it disconnects the circuit.

Functions of an RCD

1. Provides additional protection against certain electric shock hazards.
2. Detects earth leakage current.
3. Disconnects a circuit when the specified residual current condition is detected.
4. Helps reduce the risk of electrical fires caused by some earth leakage faults.
5. Improves electrical installation safety.

RCD operation testing

Instrument: RCD tester or suitable multifunction installation tester.

Procedure

This is a live test and must be performed by a qualified person.

1. Inspect the RCD for correct installation and rating.
2. Confirm that the installation is safe to energise.
3. Select the appropriate test current and test settings.
4. Connect the tester according to the manufacturer's instructions.
5. Conduct the test.
6. Observe whether the RCD disconnects the supply.
7. Record the measured operating time.

8. Compare the result with the applicable product standard and manufacturer's specifications.
9. Reset the RCD where appropriate.

Important: The test button on an RCD provides a basic functional check but does not replace instrument-based testing during installation verification.

4.6 Functional testing

Meaning of functional testing

Functional testing is the process of checking whether electrical equipment, accessories and protective devices operate correctly according to their intended functions.

Purpose of functional testing

1. To confirm correct operation of electrical switches.
2. To verify the operation of lighting circuits.
3. To check socket outlet operation.
4. To verify the operation of circuit breakers.
5. To check RCD operation.
6. To verify the correct operation of control equipment.
7. To confirm that the installation operates as intended.

Examples of functional tests

Equipment	Functional test
Lighting switch	Check that it controls the intended light
Socket outlet	Verify correct operation and polarity
Circuit breaker	Check its switching and protective operation
RCD	Verify operation using an appropriate tester
Distribution board	Check correct operation and circuit identification
Exhaust fan	Confirm that it starts and operates correctly
Doorbell	Confirm that the bell operates when activated

Procedure

1. Confirm that the initial inspection has been completed.
2. Ensure that all necessary electrical tests have satisfactory results.
3. Energise the installation under controlled conditions.
4. Operate the relevant switches and accessories.
5. Observe the operation of each circuit.

6. Record any abnormal operation.
7. Correct identified faults.
8. Repeat the necessary tests.

4.7 Voltage testing

Meaning of voltage testing

Voltage testing is the measurement of the potential difference between two points in an electrical circuit.

It helps establish whether the correct voltage is available at the supply terminals and electrical accessories.



Instrument used

- Digital multimeter.
- AC voltmeter.
- Approved voltage tester.

Applications

1. Checking supply voltage.
2. Verifying voltage at socket outlets.

3. Checking voltage between live and neutral.
4. Identifying abnormal voltage conditions.
5. Confirming the availability of electrical supply.

Procedure

Voltage testing is a live measurement and must be undertaken only by an appropriately trained and authorised person.

1. Inspect the test instrument and leads.
2. Select the correct AC voltage range.
3. Use suitable probes and protective equipment.
4. Carry out the measurement at the designated test point.
5. Observe the displayed voltage.
6. Record the reading.
7. Compare it with the required supply specifications.
8. Remove the test leads safely.

5.0 Electrical Measuring Instruments Used During Inspection and Testing

Different electrical measuring instruments are used to perform specific tests on domestic installations.

5.1 Digital multimeter



A digital multimeter is an electrical measuring instrument used to measure different electrical quantities.

Quantities measured

1. Voltage.
2. Current.

3. Resistance.
4. Continuity, where the instrument has this function.
5. Diode characteristics, where supported.

Main parts

- Display screen.
- Function selector.
- Positive input terminal.
- Common input terminal.
- Test probes.
- Internal fuse.
- Battery.

Precautions

- Select the correct measurement function.
- Use the correct input terminals.
- Never measure resistance on an energised circuit.
- Use properly rated instruments and leads.
- Inspect test leads before use.

5.2 Ohmmeter



An ohmmeter is an electrical measuring instrument used to measure resistance in an electrical component or circuit.

Functions

1. Measures electrical resistance.
2. Helps check continuity.
3. Identifies open circuits.
4. Helps detect unwanted resistance in connections.
5. Assists in electrical fault diagnosis.

Unit of measurement: Ohm (Ω).

Important: An ordinary ohmmeter must only be connected to a properly isolated, de-energised circuit.

5.3 Insulation resistance tester (Megger)



An insulation resistance tester is an instrument used to measure the resistance of electrical insulation.

Functions

- Tests cable insulation.
- Checks insulation between conductors.
- Identifies insulation deterioration.
- Helps detect leakage paths.

Unit: Megohm (MΩ).

5.4 Earth resistance tester



An earth resistance tester is an instrument used to determine the resistance of an earth electrode to the general mass of earth.

Functions

1. Measures earth electrode resistance.
2. Helps assess earthing system performance.
3. Identifies poor earth electrode conditions.
4. Supports verification of earthing arrangements.

5.5 Earth fault loop impedance tester



An earth fault loop impedance tester measures the impedance of the earth fault current path.

Functions

- Measures earth fault loop impedance.
- Helps determine whether sufficient fault current can flow.
- Helps verify automatic disconnection requirements.
- Supports assessment of circuit protection.

5.6 Test lamp



A test lamp is a device used to indicate the presence of an electrical voltage by means of a lamp or indicator.

Functions

1. Indicates the presence of voltage within its rated range.
2. Helps identify whether a supply is available.
3. Can be used in suitable controlled testing arrangements.
4. Assists in basic electrical fault diagnosis.

Limitations

- A simple test lamp does not provide an accurate voltage measurement.
- It may not detect all electrical hazards.
- It must be appropriately rated for the circuit.
- It should not replace an approved two-pole voltage detector for proving dead.

5.7 Comparison of electrical testing instruments

Instrument	Main application
Ohmmeter	Resistance measurement
Continuity tester	Checking conducting paths
Megger	Insulation resistance testing
Earth resistance tester	Earth electrode resistance testing

Earth loop tester	Earth fault loop impedance testing
RCD tester	RCD operating performance
Digital multimeter	Voltage, current and resistance measurements
Test lamp	Indication of voltage presence

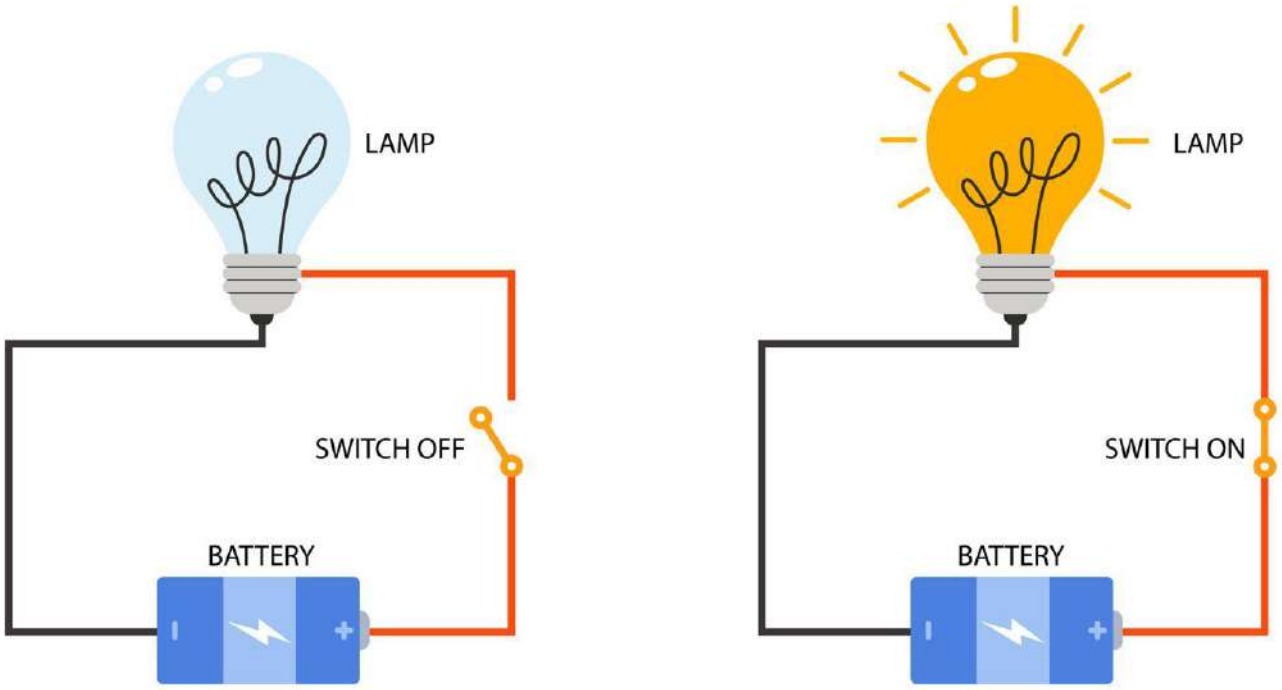
6.0 Electrical Faults Identified During Inspection and Testing

Electrical testing helps identify different faults that may affect the safety and performance of domestic installations.

6.1 Open-circuit fault

Meaning

An open-circuit fault occurs when an electrical conducting path is broken or interrupted, preventing current from flowing through the intended circuit.



Causes

1. Broken electrical conductors.
2. Loose terminal connections.
3. Damaged switches.
4. Burnt-out fuse elements.
5. Poorly made joints.
6. Broken internal appliance connections.

Effects

- Electrical appliances fail to operate.

- Lighting circuits fail.
- Current flow stops in the affected path.
- Equipment may operate intermittently if the connection is unstable.

Detection methods

1. Continuity testing.
2. Visual inspection.
3. Voltage testing.
4. Circuit tracing.

Corrective measures

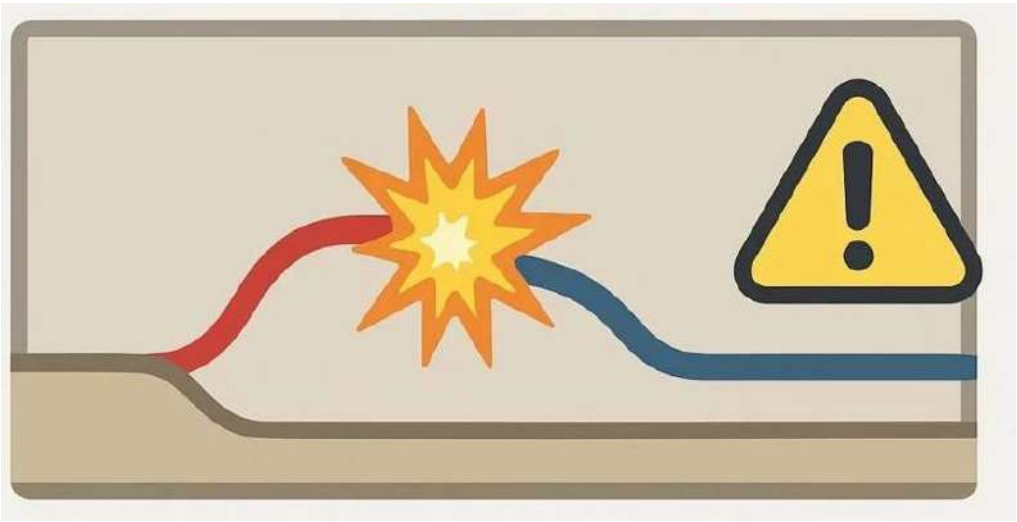
1. Identify the location of the break.
2. Isolate the circuit.
3. Repair or replace the damaged conductor.
4. Tighten or remake defective connections.
5. Repeat continuity and other required tests.

6.2 Short-circuit fault

Meaning

A short-circuit fault occurs when two conductors at different electrical potentials become connected through an unintended low-impedance path.

For example, a live conductor may come into direct contact with a neutral conductor.



Causes

1. Damaged cable insulation.
2. Incorrect wiring connections.
3. Loose conductors touching.
4. Moisture entering electrical accessories.
5. Faulty electrical appliances.
6. Damaged switches and socket outlets.

Effects

1. Excessive fault current.
2. Operation of circuit breakers or fuses.
3. Overheating of conductors.
4. Damage to electrical appliances.
5. Electrical fires.
6. Possible electric shock and injury.

Detection methods

- Visual inspection.
- Continuity and resistance tests under appropriate isolated conditions.
- Insulation resistance testing.
- Suitable protective-device and fault-loop verification.

Corrective measures

1. Isolate the affected circuit.
2. Identify the fault location.
3. Replace damaged cables or accessories.
4. Correct defective connections.
5. Repeat the necessary tests.
6. Restore the supply only when the installation is confirmed safe.

6.3 Earth fault

Meaning

An earth fault occurs when a live conductor makes unintended contact with earth or an earthed conductive part.

Causes

- Damaged insulation.
- Water penetration.
- Faulty electrical appliances.
- Damaged cable connections.
- Mechanical damage to wiring.

Effects

- Electric shock.
- Operation of protective devices.
- Electrical fires.
- Damage to equipment.

Detection

- Insulation resistance testing.
- Earth fault loop impedance testing.
- Protective conductor continuity testing.
- RCD testing.

6.4 Leakage current fault

Leakage current is an unintended current flowing through an alternative path, often through damaged insulation or moisture.

Causes

1. Deteriorated insulation.
2. Moisture.
3. Dust and contamination.
4. Defective appliances.
5. Damaged cable insulation.

Effects

- RCD tripping.
- Electric shock.
- Equipment malfunction.
- Fire risk.

6.5 Loose connection fault

A loose connection occurs when electrical conductors are not securely connected to their terminals.

Causes

- Poor workmanship.
- Vibration.
- Incorrect terminal tightening.
- Thermal expansion and contraction.
- Corrosion.

Effects

- Excessive resistance.
- Heating.
- Voltage drop.
- Sparking or arcing.
- Equipment failure.

6.6 Comparison of common electrical faults

Fault	Main characteristic	Common test
Open circuit	Broken conducting path	Continuity test
Short circuit	Unintended low-impedance connection	Insulation and fault investigation tests
Earth fault	Live conductor contacts earth	Insulation and loop impedance tests
Leakage current	Unwanted current flow	Insulation and RCD tests
Loose connection	Poor electrical contact	Inspection and continuity testing

7.0 Procedure for Inspection and Testing of a Domestic Electrical Installation

Inspection and testing must follow an organised sequence to ensure that all relevant aspects of an installation are examined.

7.1 Preparation before inspection and testing

The electrician or testing personnel should:

1. Obtain the installation drawings where available.
2. Identify the electrical supply arrangement.
3. Identify the circuits to be tested.
4. Gather suitable testing instruments.
5. Check that instruments are calibrated or verified as required.
6. Inspect test leads and accessories.
7. Wear suitable personal protective equipment.
8. Establish safe working procedures.
9. Inform relevant persons about the testing activity.
10. Identify possible hazards.

7.2 Safe isolation procedure

Critical safety procedure

Before carrying out dead tests, the circuit must be safely isolated.

The following procedure should be followed by trained personnel:

1. Identify the correct circuit and supply source.
2. Switch off the appropriate isolating device.
3. Secure the isolation against accidental reconnection.
4. Display an appropriate warning notice.
5. Use an approved voltage detector to verify that the circuit is dead.

6. Prove the voltage detector on a proving unit or known source before testing.
7. Verify the absence of voltage.
8. Prove the voltage detector again after testing.

This is commonly described as the prove-test-prove procedure.



Never assume that a circuit is dead simply because a switch has been turned off.

7.3 Sequence of inspection and testing

The general verification process consists of:

Stage 1: Visual inspection

Examine:

- Wiring arrangements.
- Cable insulation.
- Electrical accessories.
- Distribution boards.
- Protective devices.
- Earthing and bonding.
- Circuit identification.
- Mechanical protection.

Stage 2: Dead testing

Carry out appropriate tests with the installation safely isolated.

These include:

1. Protective conductor continuity.
2. Ring final circuit continuity, where applicable.
3. Insulation resistance.
4. Polarity verification by dead testing.

Stage 3: Live testing

After satisfactory inspection and dead testing, specified tests are carried out under controlled energised conditions by qualified personnel.

These may include:

1. Supply voltage verification.
2. Earth fault loop impedance.
3. RCD operation.
4. Live polarity verification.
5. Functional testing.

Stage 4: Recording results

Record:

- Inspection findings.
- Test instruments used.
- Measured values.
- Applicable acceptance requirements.
- Identified defects.
- Corrective recommendations.

Stage 5: Final evaluation

Determine whether the installation:

- Meets the applicable requirements.
- Has defects requiring correction.
- Is safe for commissioning.
- Requires further inspection or testing.

8.0 Preparation of an Inspection and Testing Report

8.1 Meaning of an inspection and testing report

An electrical inspection and testing report is a formal document that records the condition of an electrical installation, the inspection observations, tests performed, measurements obtained, defects identified and recommendations made.

It provides evidence that an electrical installation has been examined and tested.

8.2 Importance of an inspection and testing report

1. Provides a record of the installation condition.
2. Documents the results of electrical tests.
3. Identifies unsafe conditions.
4. Helps electricians plan corrective maintenance.
5. Supports verification of compliance.
6. Provides information to property owners.
7. Helps monitor changes in the installation.
8. Provides evidence for future inspections.
9. Supports decisions on whether an installation is suitable for commissioning.
10. Promotes accountability among electrical personnel.

8.3 Main sections of an inspection and testing report

A complete report should contain the following information.

A. General installation information

This section identifies the installation.

It includes:

- Name of client or property owner.
- Location of the installation.
- Building type.
- Installation reference.
- Date of inspection.
- Name of inspecting electrician.
- Relevant qualification or authorisation details.

B. Overview of the installation

This section describes the electrical installation being examined.

It may include:

1. Type of building.
2. Number of distribution boards.
3. Number of electrical circuits.
4. Type of electrical supply.
5. Earthing arrangement.
6. General condition of the installation.

C. Inspection observations

This section records the physical observations made during inspection.

Examples:

- Damaged cables.
- Loose socket outlets.
- Missing distribution board covers.
- Incorrect cable identification.
- Missing circuit labels.
- Poor earthing connections.
- Signs of overheating.

D. Test results

This section records the tests conducted and the corresponding measurements.

Test	Measured result	Requirement	Outcome
Continuity	0.18 Ω	Suitable low resistance	Pass, subject to assessment
Insulation resistance	5 MΩ	Applicable minimum	Pass
Earth electrode resistance	18 Ω	According to earthing design	Requires evaluation
Polarity	Correct	Correct connections	Pass
Earth loop impedance	0.65 Ω	Protective-device limit	Requires comparison
RCD operation	Recorded trip time	Manufacturer and standard requirement	Requires comparison

Illustrative results only. Actual acceptance must be based on the installation design, protective-device characteristics and applicable standards.

E. Fault analysis

This section describes the defects discovered and their possible causes.

Example:

Fault: Socket outlet fails continuity testing.

Possible cause: Loose protective conductor connection.

Effect: The socket may not provide the required protective earth path.

Recommendation: Isolate the circuit, repair the connection and repeat the protective conductor continuity test.

F. Recommendations

This section gives corrective actions.

Examples:

1. Replace damaged cables.

2. Repair defective socket outlets.
3. Tighten loose connections to the manufacturer's requirements.
4. Correct polarity errors.
5. Improve protective conductor connections.
6. Replace defective protective devices.
7. Repeat failed tests.
8. Arrange further inspection where necessary.

G. Final assessment

The report should state whether the installation is:

- Satisfactory.
- Unsatisfactory.
- Requires corrective work and retesting.
- Not yet ready for commissioning.

The report must not declare an installation safe where serious defects remain unresolved.

H. Signatures

The report should provide spaces for:

- Inspecting electrician.
- Responsible supervisor, where applicable.
- Client or property representative.
- Date of report.

8.4 Sample electrical inspection and testing report

The following is an educational prototype for learners to practise completing an inspection report.

ELECTRICAL INSTALLATION

INSPECTION & TESTING REPORT

DOMESTIC ELECTRICAL INSTALLATION

1. GENERAL INFORMATION

Item	Details
Property owner	_____
Location	_____
Building type	Residential
Date	_____

Electrician	_____
Report number	_____

2. INSTALLATION OVERVIEW

- Supply type: Single-phase AC.
- Nominal voltage: 230 V.
- Nominal frequency: 50 Hz.
- Distribution board condition: To be inspected.
- Earthing arrangement: To be verified.

3. INSPECTION OBSERVATIONS

Item	**Observation**
Cables	No visible damage observed in the sample
Socket outlets	To be inspected
Distribution board	To be inspected
Earthing	To be tested
Circuit labels	To be verified

4. TEST RESULTS

Test	**Result**
Continuity	_____
Insulation resistance	_____
Earthing	_____
Polarity	_____
Earth loop impedance	_____
RCD operation	_____

5. FAULT ANALYSIS

Fault identified: _____

Possible cause: _____

Risk associated: _____

6. RECOMMENDATIONS

1.

2.

3.

7. FINAL ASSESSMENT

Overall assessment: _____

Further action required: _____

8. AUTHORISATION

Inspecting electrician: _____

Signature: _____

Date: _____

Prototype for educational exercises. It is not a substitute for an approved electrical installation certificate or formal inspection report.

9.0 National Electrical Regulations and Safety Requirements in Kenya

Electrical installation work in Kenya must comply with applicable laws, standards and safety requirements.

9.1 Importance of electrical regulations

Electrical regulations establish minimum safety requirements for the design, installation, inspection, testing and maintenance of electrical systems.

They help to:

1. Protect human life.
2. Prevent electrical fires.
3. Ensure appropriate installation practices.
4. Promote standardisation.
5. Ensure the proper use of electrical equipment.
6. Improve reliability.
7. Protect property.
8. Promote professional accountability.

9.2 Relevant Kenyan regulatory framework

Learners should become familiar with:

- The Energy Act, 2019.
- Applicable Energy and Petroleum Regulatory Authority (EPRA) requirements.
- Applicable Kenya Standards developed through the Kenya Bureau of Standards (KEBS).

- Applicable electrical installation wiring standards, including relevant IEC 60364 requirements where adopted or referenced.
- Occupational Safety and Health Act, 2007.
- Electricity supply and connection requirements applicable to the premises.

The exact edition of the applicable standard and the current licensing requirements should be verified before undertaking professional electrical installation work.

9.3 Role of EPRA

The Energy and Petroleum Regulatory Authority (EPRA) is responsible for regulating the energy sector in Kenya under the relevant legal framework.

In electrical installation work, its functions include:

1. Regulating relevant electrical energy activities.
2. Administering applicable licensing requirements.
3. Promoting compliance with electrical safety requirements.
4. Supporting safe electricity use.
5. Regulating relevant electrical contractors and workers within its mandate.

9.4 Safety requirements during inspection and testing

1. Testing must be carried out by suitably trained and authorised personnel.
2. Use appropriate, correctly rated testing instruments.
3. Isolate circuits before dead testing.
4. Verify the absence of voltage before touching conductors.
5. Use appropriate personal protective equipment.
6. Keep testing areas dry and orderly.
7. Do not touch exposed live conductors.
8. Use insulated tools where required.
9. Keep unauthorised persons away from the work area.
10. Record test results accurately.
11. Do not energise an installation with unresolved dangerous defects.
12. Ensure that protective devices are correctly selected and installed.

10.0 Commissioning of a Domestic Electrical Installation

10.1 Meaning of commissioning

Commissioning is the process of verifying that an electrical installation has been correctly installed, inspected, tested and is suitable for operation according to its design and applicable requirements.

10.2 Activities carried out before commissioning

1. Complete the installation.
2. Conduct visual inspection.
3. Carry out continuity tests.

4. Conduct insulation resistance tests.
5. Verify polarity.
6. Verify earthing arrangements.
7. Conduct appropriate earth fault loop impedance tests.
8. Test RCD operation.
9. Conduct functional tests.
10. Record the results.
11. Correct all identified defects.
12. Prepare the relevant certification and inspection documentation.

10.3 Importance of commissioning

- Confirms the installation is ready for use.
- Verifies the operation of protective devices.
- Helps prevent electrical accidents.
- Confirms compliance with design requirements.
- Establishes a baseline for future maintenance.
- Provides evidence of inspection and testing.

10.4 Why must electrical installations be inspected and tested before commissioning?

An installation must be inspected and tested before commissioning to establish that:

1. Wiring is correctly installed.
2. Protective conductors are continuous.
3. Insulation is satisfactory.
4. Polarity is correct.
5. Protective devices are suitable.
6. Electrical accessories are correctly connected.
7. The installation is free from dangerous defects.
8. The system is suitable for safe operation.

11.0 Practical Activities in Inspection and Testing

Practical activities enable learners to develop the skills required to inspect, test and document domestic electrical installations.

All practical electrical work must be supervised by a competent instructor. Learners should practise on isolated training boards and approved low-voltage training equipment. Live testing should only be demonstrated by appropriately qualified personnel under controlled conditions.

11.1 Practical Activity 1: Visual inspection of a domestic electrical installation

Learning objective: To identify the main components of a domestic electrical installation and inspect their physical condition.

Requirements

- Domestic electrical installation training board.
- Inspection checklist.
- Torch.
- Appropriate PPE.
- Writing materials.

Procedure

1. Observe the general arrangement of the electrical installation.
2. Identify the distribution board.
3. Identify circuit breakers and RCDs.
4. Examine the condition of socket outlets.
5. Examine lighting switches.
6. Observe the cable routing and support.
7. Check visible earthing conductors.
8. Identify any damaged or missing accessories.
9. Record the observations.
10. Present the findings to the class.

Expected learning outcomes

The learner should be able to:

- Identify installation components.
- Recognise visible electrical defects.
- Explain the importance of visual inspection.
- Prepare an inspection checklist.

11.2 Practical Activity 2: Continuity testing

Learning objective: To demonstrate continuity testing using an ohmmeter.

Requirements

- Isolated training circuit.
- Digital multimeter.
- Connecting wires.
- Inspection record sheet.

Procedure

1. Identify the conductor to be tested.
2. Isolate the training circuit.

3. Verify that the circuit is dead.
4. Set the multimeter to the appropriate resistance or continuity range.
5. Connect the test leads across the conductor under examination.
6. Observe the instrument reading.
7. Record the result.
8. Repeat the procedure for other conductors.
9. Discuss the results.

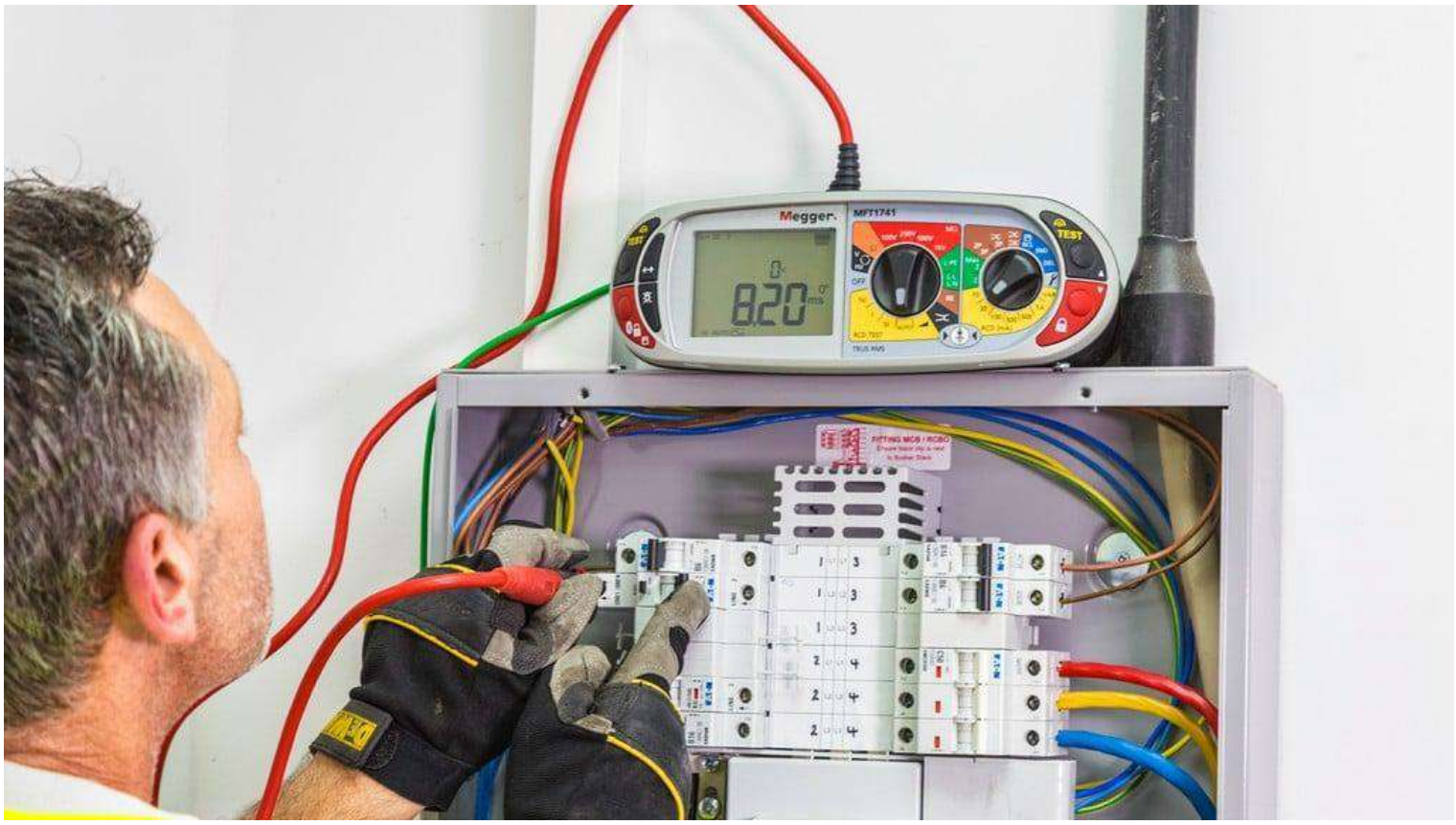
Observation table

Conductor	Resistance reading	Observation
Conductor A	0.3 Ω	Low resistance
Conductor B	OL	Open circuit
Conductor C	0.5 Ω	Low resistance

Illustrative training readings.

Conclusion: Continuity testing helps establish whether an electrical conductor has a complete conducting path.

11.3 Practical Activity 3: Insulation resistance testing



Learning objective: To demonstrate how insulation resistance is measured using an insulation resistance tester.

Requirements

- Insulation resistance tester.
- Isolated training circuit.
- Test leads.
- PPE.
- Recording sheet.

Procedure

1. Identify the circuit to be tested.
2. Isolate the circuit.
3. Verify that the circuit is dead.
4. Disconnect or protect sensitive equipment.
5. Select the correct test voltage.
6. Connect the instrument according to the test arrangement.
7. Carry out the test.
8. Record the insulation resistance.
9. Allow the instrument to discharge the circuit.
10. Compare the result with the specified requirement.

Sample observation table

Test arrangement	Reading
Live to neutral	25 MΩ
Live to earth	30 MΩ
Neutral to earth	28 MΩ

Illustrative results for learning purposes.

Conclusion: Insulation resistance testing establishes whether insulating materials can prevent unwanted current leakage.

11.4 Practical Activity 4: Earthing continuity testing

Learning objective: To establish the continuity of a protective conductor.

Requirements

- Low-resistance ohmmeter.
- Earthing training board.
- Test leads.
- Inspection record.

Procedure

1. Identify the main earthing terminal.

2. Identify the protective conductor.
3. Isolate the circuit.
4. Verify that it is dead.
5. Connect the tester according to the approved test arrangement.
6. Measure the resistance.
7. Record the result.
8. Discuss the importance of a low-resistance protective path.

Expected outcome: The learner explains how protective conductor continuity contributes to electrical safety.

11.5 Practical Activity 5: Preparing an inspection and testing report

Learning objective: To prepare a report based on observations and electrical test results.

Requirements

- Sample inspection report.
- Electrical installation training board.
- Test result records.
- Writing materials.

Procedure

1. Identify the installation being examined.
2. Record the general information.
3. Write down the visual inspection findings.
4. Enter the continuity test results.
5. Enter insulation resistance results.
6. Record the earthing and polarity results.
7. Identify any faults.
8. Explain the possible causes.
9. Recommend corrective measures.
10. Prepare the final assessment.

Expected outcome: The learner prepares a clear and organised electrical inspection and testing report.

12.0 CBE INTEGRATION: COMPETENCIES, VALUES AND PERTINENT ISSUES

12.1 Specific learning outcomes

By the end of this sub-strand, the learner should be able to:

a) Describe the types of tests performed on domestic electrical installations.

b) Perform electrical tests on domestic installations.

c) Prepare an inspection and testing report for a domestic installation.

d) Appreciate the importance of inspection and testing of an electrical installation.

12.2 Core competencies developed

Core competency	How it is developed
Communication and collaboration	Learners discuss inspection procedures and share findings
Critical thinking and problem-solving	Learners analyse electrical faults and interpret test results
Creativity and imagination	Learners design inspection checklists and testing procedures
Digital literacy	Learners use digital measuring instruments and simulations
Learning to learn	Learners research electrical safety requirements
Self-efficacy	Learners perform supervised practical testing activities
Citizenship	Learners appreciate the importance of electrical safety in society

12.3 Values developed

1. Responsibility

Learners develop responsibility by following electrical safety procedures and using testing instruments correctly.

2. Integrity

Learners demonstrate integrity by recording actual test results without altering measurements.

3. Cooperation

Learners work together during inspection and testing activities.

4. Respect

Learners respect safety instructions, equipment and the work of other learners.

5. Diligence

Learners develop diligence by carefully carrying out inspection and testing procedures.

6. Accountability

Learners accept responsibility for their actions and report identified electrical hazards.

12.4 Pertinent and contemporary issues (PCIs)

1. Health and safety

Learners understand how electrical inspection and testing prevent injuries and accidents.

2. Environmental conservation

Learners appreciate the importance of maintaining electrical equipment to reduce waste and unnecessary replacement.

3. Consumer protection

Learners understand the importance of safe electrical installations in protecting households and property.

4. Entrepreneurship

Learners explore opportunities in electrical installation, inspection, testing and maintenance services.

5. Disaster risk reduction

Learners understand how electrical inspection reduces the risk of electrical fires.

6. Occupational safety

Learners develop awareness of safe working procedures when handling electrical equipment.

12.5 Suggested learning resources

1. Domestic electrical installation training board.
2. Digital multimeter.
3. Ohmmeter.
4. Insulation resistance tester.
5. Earth resistance tester.
6. Earth fault loop impedance tester.
7. RCD tester.
8. Test lamp.
9. Electrical installation drawings.
10. Sample inspection reports.
11. Electrical safety charts.
12. Personal protective equipment.
13. Digital learning resources.
14. Electrical installation standards and reference materials.

13.0 GENERAL SUMMARY OF THE SUB-STRAND

Electrical inspection and testing are essential activities performed to establish whether domestic electrical installations are correctly installed and safe for use.

Inspection involves visual examination of the installation, while testing involves using appropriate instruments to measure electrical characteristics.

The main tests include:

1. Continuity testing.
2. Insulation resistance testing.
3. Earthing testing.
4. Polarity testing.
5. Earth fault loop impedance testing.
6. RCD operation testing.
7. Functional testing.

8. Voltage testing.

The common instruments include:

- Ohmmeter.
- Digital multimeter.
- Megger.
- Earth resistance tester.
- Earth loop impedance tester.
- RCD tester.
- Test lamp.

Inspection and testing help identify open circuits, short circuits, earth faults, leakage currents and loose connections.

The results must be recorded in a formal inspection and testing report containing installation details, observations, test results, fault analysis, recommendations and the final assessment.

Electrical installations must only be commissioned after the required inspection and testing have been satisfactorily completed and dangerous defects have been corrected.

13.1 Key terms and definitions

Term	Definition
Inspection	Visual examination of an electrical installation
Testing	Measurement of electrical characteristics using suitable instruments
Continuity	Existence of a complete conducting path
Insulation resistance	Resistance offered by insulation to unwanted current flow
Earthing	Protective connection to earth through an appropriate earthing system
Polarity	Correct connection of live, neutral and protective conductors
Open circuit	A broken conducting path
Short circuit	An unintended low-impedance connection between conductors at different potentials
Earth fault	Unintended connection between a live conductor and earth
Megger	Insulation resistance testing instrument
Ohmmeter	Instrument for measuring electrical resistance

Commissioning	Verification that an installation is suitable for operation
RCD	Device that detects residual current and disconnects a circuit
Earth loop impedance	Impedance of the earth fault current path
Functional testing	Checking whether equipment operates as intended

13.2 Important examination points

1. Inspection is mainly visual; testing involves electrical measurements.
2. Continuity tests identify broken conductors and poor connections.
3. Insulation resistance tests identify deterioration of insulation.
4. Earthing provides an appropriate path for fault current.
5. Polarity testing verifies correct conductor connections.
6. Earth loop impedance testing assesses the effectiveness of automatic disconnection.
7. RCD testing checks the operating performance of residual current protection.
8. A megger is used to measure insulation resistance.
9. An ohmmeter measures resistance.
10. A test lamp indicates voltage presence but does not provide accurate voltage measurements.
11. An inspection report records the condition and test results of an installation.
12. Electrical testing must follow approved safety procedures.

PART II: TOPICAL REVISION QUESTIONS

STRAND 3.0: ELECTRICAL INSTALLATION

SUB-STRAND 3.3: INSPECTION AND TESTING

SECTION A: MULTIPLE-CHOICE QUESTIONS

30 MARKS | Each question carries 1 mark.

1. Electrical inspection of a domestic installation mainly involves:

A. Measuring the current flowing through every circuit.

B. Visual examination of electrical components and wiring.

C. Replacing all electrical cables.

D. Increasing the supply voltage.

2. Electrical testing is carried out mainly to:

A. Improve the appearance of electrical accessories.

B. Determine the electrical characteristics and safety of an installation.

C. Increase the number of electrical appliances.

D. Reduce the size of the distribution board.

3. Which of the following is an example of an electrical inspection activity?

A. Measuring insulation resistance.

B. Measuring earth loop impedance.

C. Examining damaged cable insulation.

D. Measuring earth electrode resistance.

4. The main purpose of continuity testing is to establish whether:

A. A conductor has an unbroken electrical path.

B. A circuit has the correct supply frequency.

C. A cable has the correct colour.

D. A circuit produces alternating current.

5. Which instrument is commonly used to measure insulation resistance?

A. Ammeter.

B. Megger.

C. Wattmeter.

D. Frequency meter.

6. Insulation resistance is normally expressed in:

A. Amperes.

B. Volts.

C. Megohms.

D. Watts.

7. A very high insulation resistance reading generally indicates:

A. Good insulation condition.

B. A short circuit.

C. An overloaded circuit.

D. A broken earth electrode.

8. Which of the following conditions may cause low insulation resistance?

A. Proper cable installation.

B. Dry insulating materials.

C. Damaged cable insulation.

D. Correct conductor identification.

9. The main purpose of earthing in a domestic installation is to:

A. Increase the supply voltage.

B. Provide a protective path for fault current.

C. Increase the frequency.

D. Reduce the number of electrical circuits.

10. Which instrument is used to measure earth electrode resistance?

A. Earth resistance tester.

B. Wattmeter.

C. Frequency meter.

D. Energy meter.

11. Earth fault loop impedance testing helps determine whether:

A. A lamp produces sufficient brightness.

B. A protective device can disconnect a faulty circuit within the required time.

C. A cable has the correct colour.

D. A switch has the correct physical size.

12. Polarity testing is performed to verify:

A. The number of electrical appliances.

B. The correct connection of live, neutral and protective conductors.

C. The size of the distribution board.

D. The speed of an electric motor.

13. In a correctly wired single-phase lighting circuit, a single-pole switch should interrupt the:

A. Earth conductor.

B. Neutral conductor.

C. Live conductor.

D. Protective bonding conductor.

14. Which instrument is primarily used to measure electrical resistance?

A. Ohmmeter.

B. Voltmeter.

C. Ammeter.

D. Frequency meter.

15. A test lamp is mainly used to:

A. Measure insulation resistance accurately.

B. Indicate the presence of voltage.

C. Measure earth electrode resistance.

D. Determine cable cross-sectional area.

16. An open-circuit fault occurs when:

A. Two conductors are connected through an unintended low-impedance path.

B. An electrical conducting path is broken.

C. An electrical load increases.

D. The supply voltage becomes constant.

17. Which of the following may cause an open-circuit fault?

A. Broken conductor.

B. Correct cable installation.

C. Proper terminal tightening.

D. Suitable insulation.

18. A short-circuit fault occurs when:

A. An intended conducting path is disconnected.

B. Conductors at different potentials become connected through an unintended low-impedance path.

C. An electrical appliance is switched off normally.

D. A protective conductor is correctly connected.

19. Which protective device detects an imbalance between live and neutral currents?

A. Energy meter.

B. RCD.

C. Voltmeter.

D. Transformer.

20. The main purpose of a circuit breaker in a domestic installation is to:

A. Measure electrical energy.

B. Protect a circuit against specified overcurrent conditions.

C. Increase insulation resistance.

D. Control the frequency of the supply.

21. Which of the following is an important step before performing continuity testing?

A. Increase the supply voltage.

B. Isolate the circuit and verify that it is dead.

C. Connect additional electrical appliances.

D. Remove all protective devices.

22. The prove-test-prove procedure is used when:

A. Painting a distribution board.

B. Verifying the absence of voltage.

C. Measuring room temperature.

D. Installing lighting accessories.

23. A loose electrical connection may result in:

A. Reduced resistance in every case.

B. Excessive heating and sparking.

C. Increased insulation resistance.

D. Improved electrical efficiency.

24. Which of the following is normally included in an electrical inspection and testing report?

A. Personal shopping records.

B. Fault analysis and test results.

C. Daily school attendance.

D. Household food expenditure.

25. Periodic inspection is carried out mainly to:

A. Determine whether an existing installation remains safe.

B. Increase the number of electrical sockets.

C. Replace every electrical accessory.

D. Change the building design.

26. The primary purpose of functional testing is to:

A. Measure soil resistance.

B. Confirm that electrical equipment operates as intended.

C. Determine cable colour.

D. Increase the current rating of a circuit.

27. Which of the following should be done after identifying a dangerous electrical fault?

A. Ignore the fault.

B. Continue using the installation.

C. Isolate the affected circuit and arrange corrective work.

D. Increase the circuit breaker rating.

28. Which of the following is an appropriate safety practice during insulation resistance testing?

A. Testing an energised circuit using an ordinary megger.

B. Disconnecting or protecting sensitive equipment before testing.

C. Holding exposed conductors during measurement.

D. Using damaged test leads.

29. A domestic electrical installation should be commissioned after:

A. All appliances have been purchased.

B. Required inspection and testing have been satisfactorily completed.

C. The building has been painted.

D. All switches have been removed.

30. The main importance of preparing an inspection and testing report is to:

A. Advertise electrical accessories.

B. Record installation conditions, test results and recommendations.

C. Increase the electrical load.

D. Replace electrical installation drawings.

SECTION B: STRUCTURED QUESTIONS

50 MARKS

6 Questions

Answer all questions. Show all necessary working.

QUESTION 1: Introduction to Inspection and Testing (8 marks)

a) Define the following terms:

i. Electrical inspection. (2 marks)

ii. Electrical testing. (2 marks)

b) State four reasons why domestic electrical installations should be inspected and tested before commissioning. (4 marks)

QUESTION 2: Types of Electrical Tests (8 marks)

a) State four types of electrical tests performed on domestic installations. (4 marks)

b) Explain the purpose of each of the following tests:

i. Continuity test. (1 mark)

ii. Insulation resistance test. (1 mark)

iii. Polarity test. (1 mark)

iv. Earth fault loop impedance test. (1 mark)

QUESTION 3: Electrical Measuring Instruments (8 marks)

a) Name the appropriate instrument used to perform each of the following tests:

i. Insulation resistance testing. (1 mark)

ii. Earth electrode resistance testing. (1 mark)

iii. Electrical resistance measurement. (1 mark)

iv. Earth fault loop impedance testing. (1 mark)

b) Describe four precautions that should be observed when using electrical testing instruments. (4 marks)

QUESTION 4: Electrical Faults and Their Identification (8 marks)

a) Define an open-circuit fault. (2 marks)

b) State three possible causes of a short-circuit fault in a domestic electrical installation. (3 marks)

c) Explain three possible effects of poor electrical connections in a domestic installation. (3 marks)

QUESTION 5: Inspection and Testing Report (9 marks)

A qualified electrician is inspecting a newly installed domestic electrical system in a residential building in Nakuru County.

a) State three sections that should be included in an electrical inspection and testing report. (3 marks)

b) Explain three types of information recorded under the fault analysis section of the report. (3 marks)

c) Give three recommendations that may be made after identifying defects during electrical inspection and testing. (3 marks)

QUESTION 6: Practical Testing and Safety (9 marks)

a) Describe the prove-test-prove procedure used to establish that an electrical circuit is dead. (3 marks)

b) Explain three steps involved in conducting an insulation resistance test on an isolated domestic electrical circuit. (3 marks)

c) State three reasons why electrical installations must be inspected and tested before being commissioned. (3 marks)

STRAND 4.0: ELECTRONICS

SUB-STRAND 4.1: POWER SUPPLIES

A power supply is a fundamental part of almost every electronic system. It provides the electrical energy required by electronic components such as integrated circuits, transistors, sensors, microcontrollers, amplifiers and communication devices. This sub-strand explores how power supply units operate, their components, construction, testing, troubleshooting and technological advancements.

1.0 Introduction to Power Supplies

1.1 Meaning of a Power Supply

A **power supply** is an electrical or electronic device that converts electrical energy from a source into a suitable form, voltage and current required to operate an electrical or electronic system.

Most electronic devices require a stable direct current (DC) supply, yet electricity from the mains is normally supplied as alternating current (AC). A power supply unit (PSU) converts the available electrical energy into the required form.

Examples of devices that use power supply units:

1. Mobile phone chargers.
2. Desktop and laptop computers.
3. Television sets.
4. Radios and audio amplifiers.
5. Electronic laboratory equipment.
6. CCTV cameras.
7. Routers and communication equipment.
8. Battery-powered electronic devices.
9. Industrial control systems.
10. LED lighting systems.

1.2 Functions of a Power Supply Unit

A power supply performs several important functions in an electronic system.

1. **Voltage conversion:** Changes the input voltage to a suitable level required by an electronic circuit.
2. **Rectification:** Converts alternating current (AC) into pulsating direct current (DC), where required.
3. **Filtering:** Reduces unwanted variations or ripples in the rectified output.
4. **Voltage regulation:** Maintains a nearly constant output voltage despite changes in input voltage or load current.
5. **Current supply:** Provides the current required by connected electronic components.
6. **Electrical protection:** Protects the electronic system against conditions such as overcurrent, overvoltage, short circuits and overheating.
7. **Electrical isolation:** In suitably designed supplies, separates the output circuit electrically from the input mains supply.
8. **Energy conversion:** Converts electrical energy into a form that can be used efficiently by electronic devices.

1.3 Characteristics of a Good Power Supply

A good power supply should have the following characteristics:

1. **Stable output voltage:** It should maintain the required voltage during normal operation.
2. **Adequate current capacity:** It should supply sufficient current to operate the connected load.
3. **Low ripple voltage:** Its DC output should contain minimal unwanted AC variations.
4. **High efficiency:** It should convert input power into useful output power with minimal energy losses.
5. **Good voltage regulation:** Its output should remain stable when the input voltage or load changes within its specified operating range.
6. **Reliable operation:** It should operate consistently without frequent failures.
7. **Safety:** It should provide suitable protection against electric shock, overheating and electrical faults.
8. **Compact design:** Modern power supplies should occupy minimal space where possible.
9. **Low electromagnetic interference:** It should not introduce excessive electrical noise into nearby electronic systems.

2.0 Types of Power Supplies

Power supplies are classified according to their design, operation, output characteristics and applications.

2.1 Alternating Current (AC) Power Supply

An AC power supply provides electrical energy in the form of alternating current.

In an AC circuit, the direction of current periodically changes.

Characteristics:

1. The current changes direction periodically.
2. Its voltage may be stepped up or stepped down using a transformer.
3. It is commonly used in household and industrial electrical installations.
4. It can supply AC-powered appliances directly.
5. It can serve as the input source for an AC-to-DC power supply.

Examples:

- Mains electricity.
- AC laboratory power supplies.
- AC supplies used in electrical testing equipment.

2.2 Direct Current (DC) Power Supply

A DC power supply provides electrical energy with a constant polarity. Current flows in one direction through the external circuit.

Characteristics:

1. It has positive and negative output terminals.
2. It supplies current in one direction.

3. Its output voltage may be regulated or unregulated.
4. It is commonly used in electronic circuits.
5. It may obtain energy from batteries or an AC-to-DC conversion circuit.

Examples:

- Battery supplies.
- Mobile phone chargers.
- DC adapters.
- Regulated laboratory power supplies.

2.3 Regulated Power Supply

A regulated power supply maintains a nearly constant output voltage despite reasonable variations in input voltage or load current.

Characteristics:

1. It provides a stable output voltage.
2. It reduces the effects of input voltage fluctuations.
3. It compensates for changes in load current within its operating limits.
4. It is suitable for sensitive electronic circuits.
5. It may use linear or switching regulation.

Applications:

- Microcontroller circuits.
- Communication equipment.
- Laboratory electronic instruments.
- Computer circuits.
- Audio equipment.

2.4 Unregulated Power Supply

An unregulated power supply provides an output voltage that varies depending on input voltage and load conditions.

Characteristics:

1. Its output voltage is not maintained at a precise constant value.
2. The output may increase or decrease when the load changes.
3. It is generally simpler in design.
4. It may be less expensive than a regulated supply.
5. It is suitable for applications that can tolerate variations in voltage.

2.5 Linear Power Supply

A linear power supply uses a transformer, rectifier, filter and linear voltage regulator to produce a stable DC output.

Advantages:

1. It produces relatively low electrical noise.
2. It has a simple operating principle.
3. It is suitable for sensitive analogue circuits.
4. It can provide good output regulation.
5. It is generally easy to understand and troubleshoot.

Disadvantages:

1. It may have low efficiency.
2. It can generate considerable heat.
3. It may require a large transformer.
4. It can be relatively heavy and bulky.

2.6 Switching Mode Power Supply (SMPS)

A switching mode power supply is an electronic power supply that uses high-frequency switching devices to regulate and convert electrical energy.

It switches electronic components, such as transistors or MOSFETs, rapidly on and off to control the transfer of energy.

Characteristics:

1. It operates using high-frequency switching.
2. It is generally more efficient than a conventional linear supply.
3. It is usually smaller and lighter.
4. It can provide different output voltage levels.
5. It requires electronic control and switching circuitry.
6. It may generate electrical noise that requires filtering.

Applications:

- Computer power supplies.
- Television sets.
- Mobile phone chargers.
- Laptop adapters.
- LED drivers.
- Modern electronic appliances.

2.7 Comparison Between Linear and Switching Mode Power Supplies

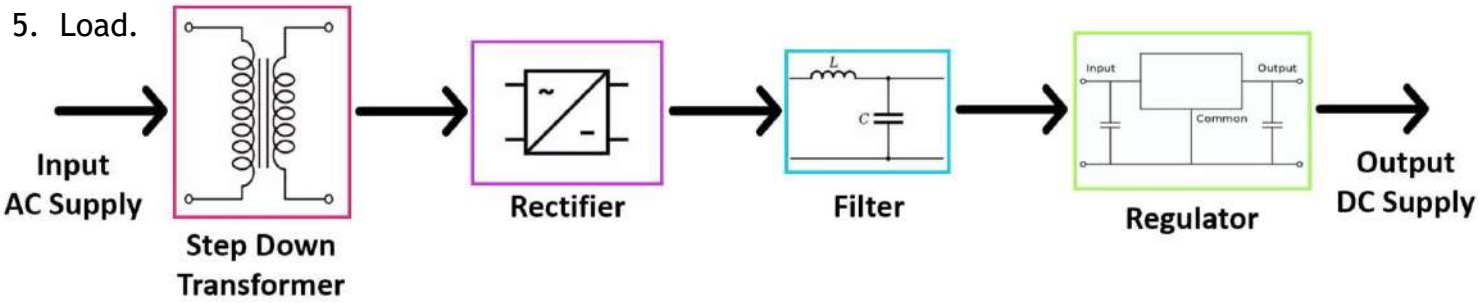
Feature	Linear power supply	Switching mode power supply

Operating principle	Uses linear voltage regulation	Uses high-frequency switching
Efficiency	Generally lower	Generally higher
Size	Usually larger	Usually smaller
Weight	Usually heavier	Usually lighter
Heat generation	Often higher	Often lower for comparable output
Electrical noise	Generally low	May produce switching noise
Circuit complexity	Relatively simple	More complex
Applications	Analogue and low-noise circuits	Computers, chargers and modern electronics

3.0 Main Components of a Conventional DC Power Supply

A conventional regulated DC power supply commonly consists of the following stages:

1. Transformer.
2. Rectifier.
3. Filter.
4. Voltage regulator.
5. Load.





3.1 Transformer

A transformer is an electrical device that transfers electrical energy between two or more coils through electromagnetic induction.

In a power supply, the transformer is commonly used to step down the mains AC voltage to a lower AC voltage suitable for the electronic circuit.

Main parts of a transformer:

1. Primary winding – receives electrical energy from the AC source.

2. Secondary winding – delivers the transformed AC voltage.
3. Magnetic core – provides a path for magnetic flux.
4. Insulation – separates the windings and prevents unwanted electrical contact.

Functions of a transformer in a power supply:

1. Steps down high AC voltage to a lower voltage.
2. Provides electrical isolation in suitably designed transformer supplies.
3. Transfers electrical energy through electromagnetic induction.
4. Helps obtain the required AC voltage before rectification.

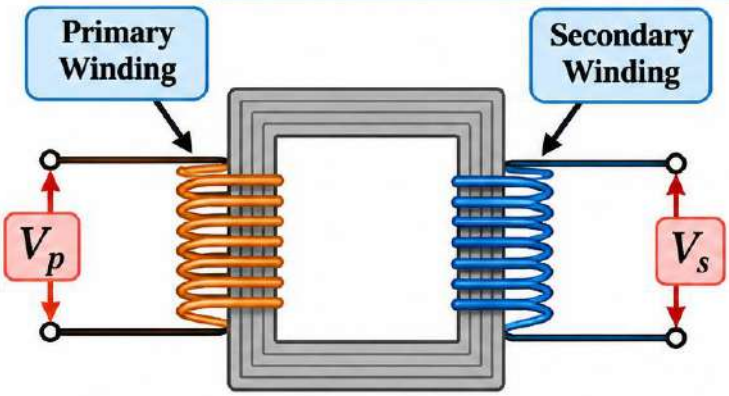
Types of transformers used in power supplies:

- Step-down transformer: reduces the output voltage.
- Step-up transformer: increases the output voltage.
- Isolation transformer: provides electrical isolation between input and output.

Example:

A step-down transformer may convert 240 V AC to 12 V AC for use in a low-voltage DC power supply. The actual secondary voltage under load depends on the transformer rating and operating conditions.

Transformer Voltage Relationship



$$\frac{V_p}{V_s} = \frac{N_p}{N_s} \quad \text{or} \quad V_s = \frac{N_s}{N_p} V_p$$

Where:

V_p = Primary voltage.
V_s = Secondary voltage.
N_p = Number of primary turns.
N_s = Number of secondary turns.

Worked Example

A transformer has 1,200 turns in its primary winding and 60 turns in its secondary winding. If the primary voltage is 240 V AC, determine the secondary voltage.

Solution:

Given:

$N_p = 1{,}200,\ N_s = 60,\ V_p = 240\ \text{V}$

Formula:

$$V_s = \frac{N_s}{N_p} V_p$$

Substitute:

$$V_s = \frac{60}{1200} \times 240$$

$$V_s = 20$$

Answer:

The secondary voltage is 12 V AC.

c

3.2 Rectifier

A rectifier is an electronic circuit that converts alternating current (AC) into direct current (DC).

It normally uses semiconductor diodes to allow current to flow in the required direction.

Functions of a rectifier:

1. Converts AC into pulsating DC.
2. Allows current to flow in a specified direction.
3. Supplies the DC input required by the filter stage.
4. Forms an important stage in conventional DC power supplies.

Types of rectifiers

(a) Half-Wave Rectifier

A half-wave rectifier uses one diode to allow only one half-cycle of the AC input to pass through the load.

Operation:

1. During the positive half-cycle, the diode is forward-biased and conducts.
2. Current flows through the load.
3. During the negative half-cycle, the diode is reverse-biased and blocks current.
4. The output consists of pulses corresponding to one half of the AC waveform.

Advantages:

1. Simple construction.
2. Uses only one diode.
3. Low component cost.

Disadvantages:

1. Uses only one half-cycle of the AC input.
2. Produces a highly pulsating output.
3. Has lower average DC output than a full-wave rectifier for the same secondary peak voltage.
4. Requires more filtering to obtain a smooth DC output.

(b) Full-Wave Rectifier

A full-wave rectifier converts both halves of the AC waveform into pulsating DC.

It may use:

- Two diodes with a centre-tapped transformer.
- Four diodes arranged in a bridge rectifier.

Advantages:

1. Uses both half-cycles of the AC input.
2. Produces a higher average DC output than a half-wave rectifier for the same peak voltage.
3. Has lower ripple frequency requirements for filtering.
4. Makes better use of the AC waveform.

(c) Bridge Rectifier

A bridge rectifier uses four diodes connected in a bridge arrangement to convert AC into pulsating DC.

Operation:

1. Four diodes are connected in a bridge arrangement.
2. During the positive half-cycle, one pair of diodes conducts.
3. During the negative half-cycle, the other pair conducts.
4. Current flows through the load in the same direction during both half-cycles.
5. The output is a full-wave pulsating DC voltage.

Advantages:

1. Does not require a centre-tapped transformer.
2. Uses both half-cycles of the AC supply.
3. Provides full-wave rectification.
4. Is widely used in DC power supply circuits.

Disadvantage:

- Current passes through two conducting diodes in each half-cycle, resulting in a voltage drop across them.

3.3 Filter Circuit

A filter circuit is an electronic circuit used to reduce the fluctuations or ripple in the pulsating DC output of a rectifier.

The most common basic filter is a capacitor connected across the load.

Functions of a filter:

1. Smooths the pulsating DC output.
2. Reduces AC ripple voltage.
3. Stores electrical energy during periods when the rectifier output is high.
4. Releases stored energy when the rectifier output falls.
5. Improves the quality of the DC supply delivered to the regulator.

Types of filters:

1. Capacitor filter – uses a capacitor to smooth the rectified output.
2. Inductor filter – uses an inductor to oppose changes in current.
3. LC filter – combines an inductor and capacitor.
4. Pi filter – commonly uses a capacitor, inductor and another capacitor in a π-shaped arrangement.

Operation of a capacitor filter:

1. The capacitor charges when the rectifier output voltage rises.
2. When the rectifier output begins to fall, the capacitor releases stored energy.
3. The capacitor supplies current to the load between charging peaks.
4. This reduces the variation in the output voltage.
5. The resulting DC output becomes smoother.

3.4 Voltage Regulator

A voltage regulator is an electronic device or circuit that maintains a nearly constant output voltage despite variations in input voltage or load current within its specified operating range.

Functions:

1. Maintains a stable DC output voltage.
2. Reduces the effect of input voltage fluctuations.
3. Compensates for changes in load current.
4. Protects sensitive electronic components from excessive voltage variations.
5. Improves the reliability of an electronic system.

Types of voltage regulators:

(a) Linear Voltage Regulator

A linear voltage regulator controls the output voltage by operating a regulating element in its linear region.

Examples include the 7805, 7812 and LM317 voltage regulator integrated circuits.

Regulator	Typical nominal output
7805	+5 V
7809	+9 V
7812	+12 V
7815	+15 V
LM317	Adjustable positive output

The actual output and operating limits depend on the specific device datasheet and circuit design.

Advantages:

1. Simple to use.
2. Provides low-noise output.
3. Requires relatively few external components.
4. Suitable for many low-power electronic circuits.

Disadvantages:

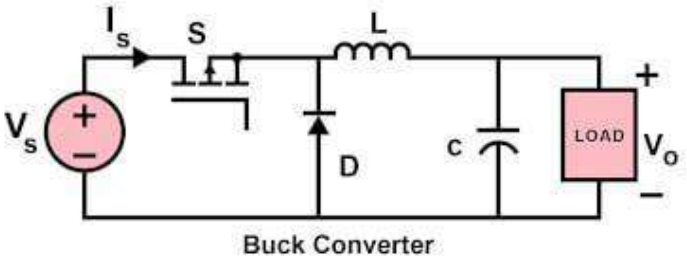
1. Can generate heat.
2. May have lower efficiency when the input voltage is much higher than the output voltage.
3. Requires adequate input-to-output voltage difference.

(b) Switching Voltage Regulator

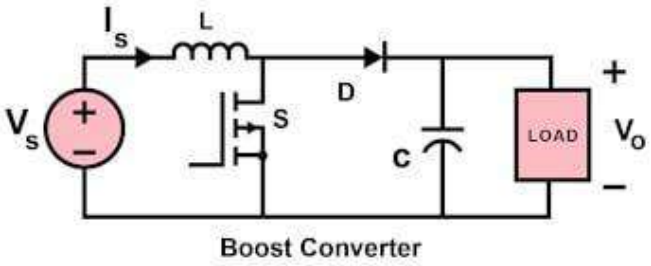
A switching regulator controls output voltage by switching electronic devices rapidly on and off.

Common types:

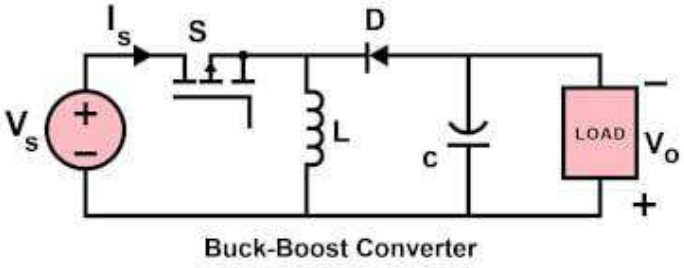
1. Buck converter – reduces DC voltage.
2. Boost converter – increases DC voltage.
3. Buck-boost converter – can increase or reduce DC voltage, depending on its design.
4. Flyback converter – commonly used in isolated switching power supplies.



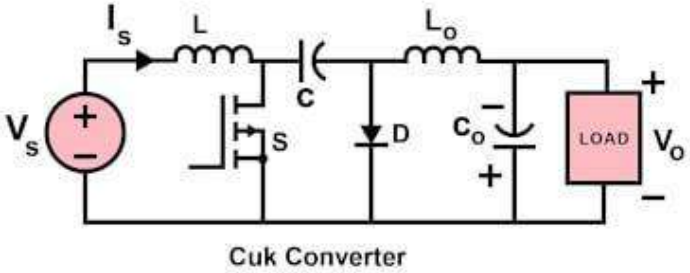
Buck Converter



Boost Converter



Buck-Boost Converter



Cuk Converter

Advantages:

1. High conversion efficiency.
2. Can provide different output voltage levels.
3. Suitable for compact electronic devices.
4. Can reduce heat losses compared with a linear regulator in many applications.

Disadvantages:

1. More complex circuit design.
2. Can generate electromagnetic interference.
3. Requires careful component selection and layout.
4. May require additional filtering.

3.5 Load

A load is the electrical or electronic device that consumes energy from a power supply.

Examples:

1. Light-emitting diodes (LEDs).
2. Resistors.
3. Integrated circuits.
4. Transistors.
5. Microcontrollers.

6. Electronic motors.
7. Audio amplifiers.

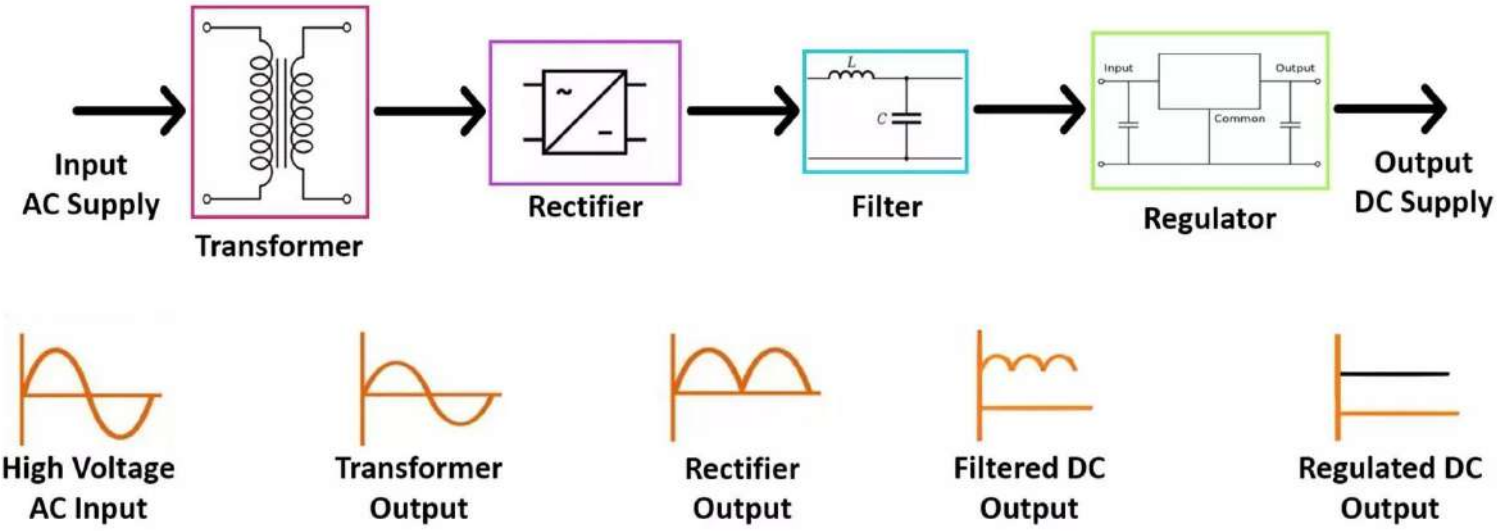
Importance of the load rating:

- The load determines the amount of current required.
- The power supply must provide the required voltage.
- The power supply must have adequate current capacity.
- The load must not exceed the rated output power of the supply.

4.0 Operation of a Complete DC Power Supply Unit

A conventional regulated DC power supply operates through a series of stages. Each stage performs a particular function to convert the AC input into a stable DC output.

4.1 Block Diagram of a Regulated DC Power Supply



The main stages are:

1. **AC input:** Supplies alternating current from the mains or another AC source.
2. **Transformer:** Steps down the AC voltage to the required level and may provide electrical isolation.
3. **Rectifier:** Converts AC into pulsating DC.
4. **Filter:** Reduces ripple in the rectified output.
5. **Voltage regulator:** Maintains a stable DC output voltage.
6. **Load:** Uses the DC electrical energy to perform a useful function.

4.2 Step-by-Step Operation

Consider a regulated power supply designed to provide approximately 5 V DC to an electronic circuit.

1. The AC input is connected to the primary winding of a suitable transformer.
2. The transformer reduces the AC voltage to the required secondary voltage.
3. The secondary AC voltage is supplied to a rectifier circuit.
4. The rectifier converts the AC voltage into pulsating DC.

5. The filter capacitor smooths the pulsating DC by storing and releasing electrical energy.
6. The voltage regulator maintains the output at the required voltage.
7. The regulated DC voltage is supplied to the electronic load.
8. The power supply continues to provide the required output as long as the input, load and operating conditions remain within the specified limits.

4.3 Why Is Each Stage Necessary?

Stage	Reason for inclusion
Transformer	Provides the required AC voltage and may provide isolation
Rectifier	Converts AC into pulsating DC
Filter	Reduces ripple
Regulator	Maintains a stable output voltage
Protection circuit	Helps protect the supply and load against electrical faults

Important: Not every power supply uses all these stages. For example, a battery-powered DC supply does not need a transformer or rectifier. A switching power supply may use a different arrangement of conversion and control stages.

5.0 Electrical Quantities in Power Supply Circuits

Understanding electrical quantities is important when constructing, testing and selecting power supply units.

5.1 Voltage

Voltage is the electrical potential difference between two points in a circuit. It provides the energy per unit charge that drives electric current.

- Symbol: V
- Unit: volt (V)
- Measuring instrument: voltmeter or multimeter set to voltage mode.

Examples:

- A USB power supply may provide 5 V DC.
- A small electronic circuit may require 9 V DC.
- A regulated supply may provide 12 V DC.

5.2 Current

Current is the rate of flow of electric charge through a conductor.

- Symbol: I*I*
- Unit: ampere (A)
- Measuring instrument: ammeter or multimeter set to current mode.

A power supply must provide sufficient current to operate the connected load safely.

Example:

A circuit requiring 0.5 A should be connected to a supply capable of providing at least the required current at the correct voltage.

A supply with a higher current rating does not automatically force that current into the load. The load draws the current it requires, provided the supply operates correctly.

5.3 Electrical Power

Electrical power is the rate at which electrical energy is transferred or consumed.

For a DC circuit:

$P=VI$

Where:

- P = power in watts (W).
- V = voltage in volts (V).
- *I* = current in amperes (A).

Worked example:

A power supply provides 12 V DC at 2 A. Calculate its output power.

$P=VI$

$P=12\times2$

$P=24W$

Therefore, the output power is **24 W**.

5.4 Efficiency of a Power Supply

Efficiency is the ratio of useful output power to input power, expressed as a percentage.

Efficiency=Output powerInput power×100%Efficiency=Input powerOutput power×100%

Worked example:

A power supply receives 100 W of input power and delivers 85 W to the load. Determine its efficiency.

$$Efficiency = \frac{85}{100} \times 100 \ = 85\%$$

Therefore, the power supply has an efficiency of **85%**.

Importance of efficiency:

1. Reduces energy wastage.
2. Minimises unwanted heat generation.
3. Reduces electricity consumption.
4. Improves battery operating time in portable devices.
5. Can reduce cooling requirements.
6. Contributes to sustainable use of electrical energy.

5.5 Ripple Voltage

Ripple voltage refers to the unwanted periodic variation remaining in the DC output after rectification and filtering.

A perfectly smooth DC supply would have no ripple, but practical power supplies may contain a small amount.

Causes of ripple:

1. Inadequate filter capacitance.
2. Excessive load current.
3. Faulty filter capacitors.
4. Poor filtering design.
5. Incorrect rectifier operation.

Methods of reducing ripple:

1. Using an appropriately rated filter capacitor.
2. Using LC or π filters.
3. Using a suitable voltage regulator.
4. Ensuring the rectifier is correctly selected.
5. Avoiding loads that exceed the power supply rating.

6.0 Construction of a Simple Regulated DC Power Supply

A learner can construct a low-voltage DC power supply using a circuit diagram, suitable components and appropriate tools.

The practical activity develops skills in circuit interpretation, component identification, assembly, soldering, testing, teamwork and troubleshooting.

6.1 Learning Objectives of the Practical Activity

By the end of the activity, the learner should be able to:

1. Interpret a power supply circuit diagram.
2. Identify the electronic components used in the circuit.
3. Explain the function of each component.
4. Assemble a simple power supply circuit.
5. Observe electrical safety precautions.
6. Test the output voltage using a multimeter.
7. Identify and correct common construction faults.
8. Record observations and communicate findings.

6.2 Materials and Components Required

A supervised low-voltage demonstration may use the following components:

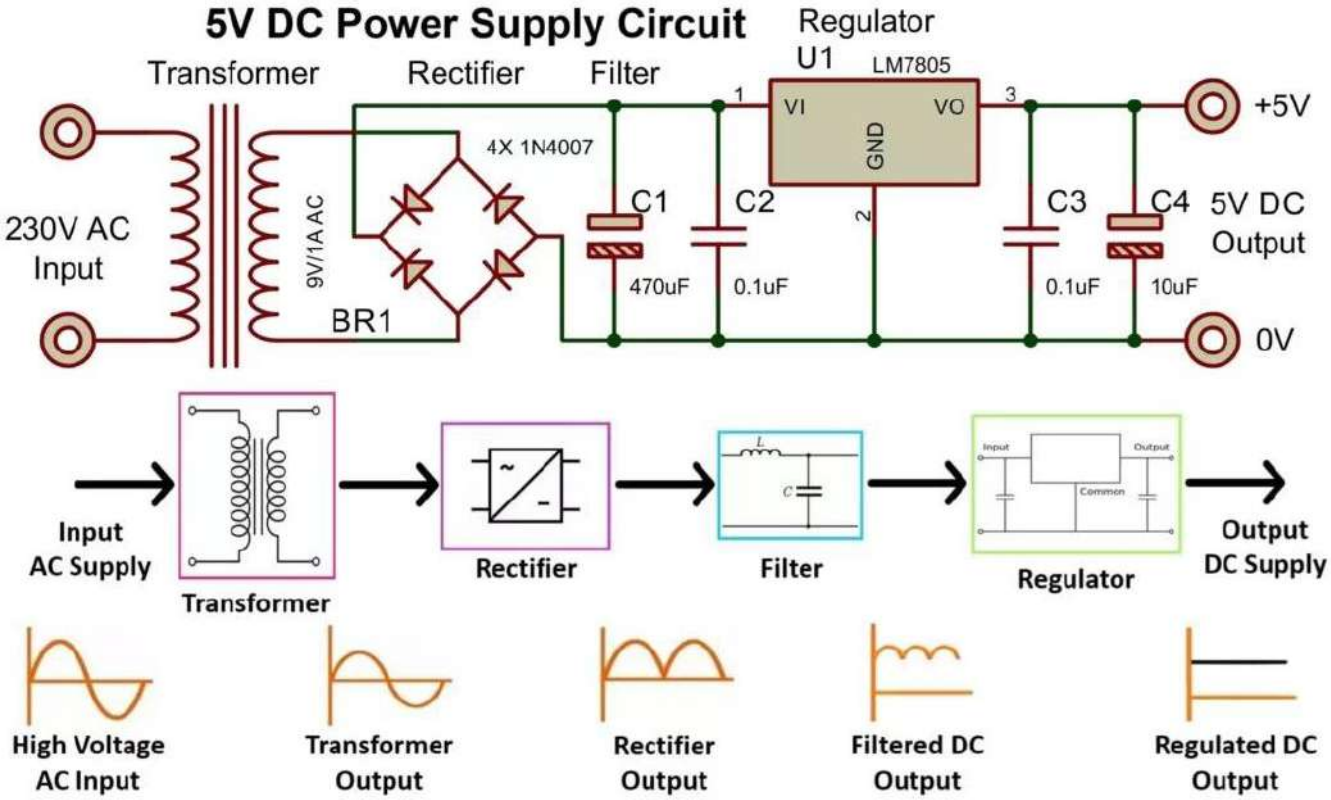
Component	Function
Suitable isolated low-voltage AC transformer	Provides a reduced AC voltage
Four rectifier diodes or bridge rectifier	Converts AC into pulsating DC
Electrolytic capacitor	Smooths the rectified output
Voltage regulator IC	Maintains a stable output voltage
Resistors	Limit current or provide required biasing
LED	Indicates power supply operation
Breadboard or copper stripboard	Supports circuit assembly
Connecting wires	Connect circuit components
Suitable input and output terminals	Provide connection points

Additional tools and equipment:

1. Digital multimeter.
2. Insulated connecting leads.
3. Soldering iron and stand.
4. Solder wire.
5. Wire stripper.
6. Side cutters.
7. Long-nose pliers.
8. Safety glasses.
9. Appropriate circuit diagram.
10. Suitable current-limited, isolated low-voltage AC source for supervised practical work.

6.3 Circuit Diagram of a Simple Regulated Power Supply

The following arrangement illustrates the main stages of a basic regulated DC power supply.



Main circuit sections:

1. AC input and transformer section.
2. Rectifier section.
3. Smoothing capacitor section.
4. Voltage regulator section.
5. DC output section.

The actual component ratings and circuit connections must be determined from the regulator datasheet and the design requirements. A 7805, for example, requires an adequate input voltage and suitable heat management.

6.4 Procedure for Constructing the Circuit

Step 1: Study the circuit diagram

- Examine the schematic carefully.
- Identify the input and output terminals.
- Identify the transformer, rectifier, capacitor and regulator.
- Note the polarity of polarised components.
- Identify the correct connection points.

Step 2: Identify and inspect components

- Check the markings on the electronic components.
- Confirm the diode types and their polarity.
- Check the voltage and capacitance ratings of the capacitor.
- Identify the regulator pin arrangement using its datasheet.
- Check the condition of the wires and connecting terminals.

Step 3: Plan the circuit layout

- Arrange the components according to the circuit diagram.
- Leave enough space between components.
- Avoid overcrowding the board.
- Ensure that the circuit layout allows easy inspection and testing.

Step 4: Assemble the rectifier section

- Connect the rectifier components according to the schematic.
- Observe the polarity and orientation of the diodes.
- Check all connections before proceeding.

Step 5: Assemble the filter section

- Connect the filter capacitor in the correct position.
- Observe the positive and negative terminals of the electrolytic capacitor.
- Ensure the capacitor's voltage rating is suitable for the expected circuit voltage.

Step 6: Assemble the regulator section

- Identify the input, common/ground and output terminals from the regulator datasheet.
- Connect the regulator correctly.
- Fit any recommended input and output capacitors.
- Provide suitable heat dissipation where necessary.

Step 7: Inspect the assembled circuit

- Check for loose connections.
- Check for solder bridges.
- Check for incorrect component orientation.
- Check for short circuits between supply rails.
- Confirm that all components are correctly positioned.

Step 8: Test the circuit

- Testing should be carried out under teacher supervision using a safe, isolated low-voltage supply.
- Measure the input and output voltages using an appropriately rated multimeter.
- Compare the measured output with the expected output.
- Record the results.

Step 9: Evaluate the performance

- Determine whether the output voltage is stable.
- Check whether the circuit supplies the required load current.
- Observe whether any component becomes unusually hot.
- Identify and correct faults before further use.

Step 10: Document the work

- Draw the completed circuit.
- List the components used.
- Record the measured values.
- Explain any difficulties encountered.
- State how identified faults were corrected.

6.5 Safety Precautions During Construction

1. Use an isolated low-voltage supply for learner construction and testing.
2. Do not allow learners to connect exposed breadboard circuits directly to mains electricity.
3. Ensure the input supply is disconnected before making or changing connections.
4. Observe the correct polarity of electrolytic capacitors.
5. Use components with suitable voltage, current and power ratings.
6. Use a soldering iron only under appropriate supervision.
7. Place a hot soldering iron on its proper stand.
8. Avoid touching hot soldering iron tips and recently soldered joints.
9. Avoid inhaling soldering fumes; use adequate ventilation or fume extraction.
10. Wear suitable eye protection when cutting wires or component leads.
11. Do not use damaged leads, probes or measuring instruments.
12. Discharge capacitors safely using an appropriate method before handling or testing circuits.
13. Never assume a capacitor is discharged simply because the power has been switched off.
14. Only suitably qualified and authorised persons should work on mains-connected power supplies.

7.0 Testing of Power Supply Circuits

Testing is the process of examining a power supply circuit to determine whether it operates correctly and produces the required output.

Testing helps identify faults, verify circuit performance and ensure that the power supply is suitable for the intended electronic system.

7.1 Reasons for Testing Power Supply Circuits

1. To confirm that the circuit has been assembled correctly.
2. To determine whether the output voltage is within the required range.
3. To establish whether the supply can provide the required current.
4. To identify faulty electronic components.
5. To detect short circuits and open circuits.
6. To check the effectiveness of the rectifier and filter.
7. To assess voltage regulation.
8. To determine the presence of excessive ripple.
9. To establish whether the power supply is safe for its intended application.

10. To verify that the power supply meets its technical specifications.

7.2 Measuring Instruments Used in Power Supply Testing

(a) Digital Multimeter

A digital multimeter is an electronic measuring instrument used to measure electrical quantities such as voltage, current and resistance.



Functions:

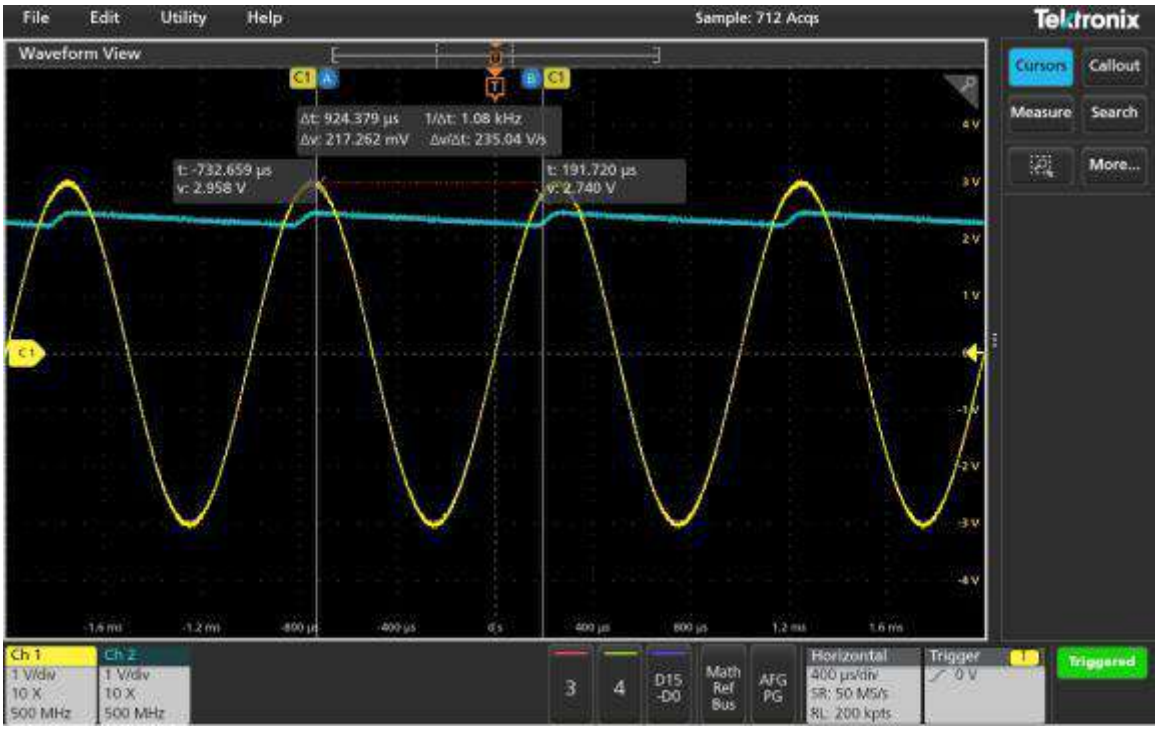
1. Measures DC voltage.
2. Measures AC voltage.
3. Measures DC current on suitable ranges.
4. Measures resistance.
5. Tests continuity.
6. Tests diode forward voltage drop on suitable models.

Uses in power supply testing:

- Measuring transformer secondary voltage.
- Measuring rectifier output voltage.
- Measuring regulated DC output voltage.
- Checking continuity of circuit connections.
- Checking resistors and diodes.

(b) Oscilloscope

An oscilloscope is an electronic instrument that displays electrical signals as waveforms on a screen.



Functions:

1. Displays AC and DC waveforms.
2. Measures signal amplitude.
3. Helps determine waveform frequency.
4. Shows changes in voltage over time.
5. Helps identify ripple and electrical noise.

Uses in power supply testing:

- Observing transformer secondary waveforms.
- Examining rectifier output waveforms.
- Measuring ripple voltage.
- Comparing filtered and unfiltered outputs.
- Detecting abnormal oscillations and noise.

(c) Ammeter

An ammeter measures electric current flowing through a circuit.

Uses:

1. Measuring the current drawn by a load.
2. Checking whether the supply can provide the required current.
3. Detecting excessive current consumption.
4. Assessing current regulation where applicable.

Important: An ammeter is normally connected in series with the circuit under test. Incorrect connection can cause a short circuit or damage the instrument.

(d) Voltmeter

A voltmeter measures the potential difference between two points in a circuit.

Uses:

1. Measuring AC input voltage.
2. Measuring transformer secondary voltage.
3. Measuring rectifier output voltage.
4. Measuring filter output voltage.
5. Measuring regulated DC output voltage.

A voltmeter is normally connected in parallel with the points being measured.

(e) Electronic Load

An electronic load is a testing device that draws a controlled amount of current from a power supply.

Functions:

1. Tests the power supply under different load conditions.
2. Determines maximum output current within specified limits.
3. Helps assess voltage regulation.
4. Tests overload protection.
5. Helps determine the output performance of the supply.

7.3 Common Tests Performed on Power Supplies

Test	Purpose	Instrument
Input voltage test	Confirms the input voltage	Multimeter
Output voltage test	Determines the DC output voltage	Multimeter
Output current test	Determines the current supplied to a load	Ammeter or electronic load
Continuity test	Checks electrical connection paths	Multimeter
Diode test	Checks the condition of rectifier diodes	Multimeter
Ripple test	Determines unwanted AC variations in DC output	Oscilloscope
Load test	Examines operation under different loads	Electronic load and multimeter
Regulation test	Determines how well output voltage is maintained	Multimeter and variable load

7.4 Measuring Output Voltage

To measure the DC output voltage of a power supply:

1. Check that the multimeter is suitable for the expected voltage.
2. Select the DC voltage function.
3. Connect the black probe to the negative or common output terminal.
4. Connect the red probe to the positive output terminal.
5. Read the displayed voltage.
6. Compare the result with the rated output voltage.
7. Record the measured value.

For a nominal 5 V DC supply, the expected output should be close to 5 V within the tolerance specified by the manufacturer.

7.5 Measuring Output Current

Output current can be determined by connecting a suitable load and measuring the current drawn.

Alternatively, current can be calculated using Ohm's law where the load resistance and voltage are known.

$I=V/R$

Where:

- I = current in amperes.
- V= voltage in volts.
- R = resistance in ohms.

Worked example:

A 12 V DC supply is connected to a 24 Ω load. Calculate the current drawn by the load, assuming the load behaves as a constant resistance.

$I=V/R$

$I=12/24$

$I=0.5A$

Therefore, the load draws **0.5 A**.

7.6 Understanding Ripple Voltage

Ripple voltage can be observed using an oscilloscope.

A rectifier without an effective filter produces a pulsating DC waveform. When a filter capacitor is connected, the voltage becomes smoother, although some ripple may remain.

Factors affecting ripple voltage:

1. Load current: Higher load current generally increases ripple.
2. Capacitance: Larger suitable capacitance generally reduces ripple.
3. Rectification method: Full-wave rectification normally produces a higher ripple frequency than half-wave rectification at the same AC supply frequency.

4. Input frequency: The supply frequency affects the charging intervals of the filter capacitor.
5. Filter condition: A deteriorated capacitor may fail to smooth the output adequately.

For a simple capacitor-input filter, an approximate relationship is:

$$V_{r(pp)} \approx \frac{I_{load}}{f_r C}$$

Where:

- $V_{r(pp)}$ = Approximate peak-to-peak ripple voltage in volts (V).
- I_{load} = Load current in amperes (A).
- f_r = Ripple frequency in hertz (Hz).
- C = Filter capacitance in farads (F).

For a full-wave rectifier, the ripple frequency is approximately twice the AC supply frequency. This approximation assumes a reasonably constant load current and a capacitor that discharges between rectifier charging peaks.

Worked example:

A full-wave rectifier operates from a 50 Hz AC supply. It supplies a load current of 0.2 A through a 2,200 µF filter capacitor. Estimate the peak-to-peak ripple voltage.

Solution

Step 1: Determine the ripple frequency.

For a full-wave rectifier:

$$f_r = 2f$$

Substituting:

$$f_r = 2 \times 50$$

$$f_r = 100Hz$$

Step 2: Convert capacitance into farads.

Given:

$$C = 2200\mu F$$

Since:

$$1\mu F = 10^{-6}F$$

Therefore:

$$C = 2200 \times 10^{-6}$$

$$C = 0.0022F$$

Step 3: Identify the load current.

$$I_{load} = 0.2A$$

Step 4: Apply the formula.

$$V_{r(pp)} \approx \frac{I_{load}}{f_r C}$$

Step 5: Substitute the values.

$$V_{r(pp)} \approx \frac{0.2}{100 \times 0.0022}$$

$$V_{r(pp)} \approx \frac{0.2}{0.22}$$

$$V_{r(pp)} \approx 0.91V$$

Therefore, the estimated ripple voltage is approximately **0.91 V peak-to-peak**.

8.0 Troubleshooting Common Faults in Power Supply Circuits

Troubleshooting is the systematic process of identifying, diagnosing and correcting faults in an electrical or electronic circuit.

A power supply may fail completely or operate abnormally because of damaged components, incorrect connections, excessive loading, overheating or poor maintenance.

8.1 Importance of Troubleshooting

1. Helps identify the cause of power supply failure.
2. Reduces unnecessary replacement of components.
3. Restores normal operation of electronic systems.
4. Prevents further damage to circuit components.
5. Improves the reliability of electronic equipment.
6. Saves time and maintenance costs.
7. Develops problem-solving and analytical skills.

8. Improves understanding of electronic circuit operation.

8.2 Common Faults, Causes and Remedies

Fault	Possible cause	Possible remedy
No output voltage	Open input connection, blown fuse, faulty rectifier or regulator	Isolate and inspect the circuit; test components and replace defective parts
Low output voltage	Incorrect transformer output, overloaded supply or faulty regulator	Check the input, load and regulator
Excessive ripple	Faulty filter capacitor or inadequate filtering	Check the filter circuit and replace defective components
Output voltage too high	Faulty regulator or incorrect circuit connections	Inspect regulator connections and associated components
Output voltage fluctuates	Poor connections, unstable input or faulty regulator	Check connections and test the input and regulator
Fuse repeatedly blows	Short circuit, excessive load or damaged component	Disconnect power and locate the cause before replacing the fuse
Excessive heating	Overload, poor heat dissipation or component failure	Check load current, component ratings and cooling arrangements
Intermittent output	Loose solder joint or broken conductor	Inspect and repair defective connections
Noisy output	Poor filtering or switching interference	Inspect filtering, grounding and circuit layout
LED indicator fails to light	Faulty LED, incorrect polarity or missing supply	Check the LED and its series resistor, polarity and supply voltage

8.3 Systematic Troubleshooting Procedure

A systematic approach prevents guesswork and unnecessary component replacement.

Step 1: Identify the problem

- Establish whether the power supply has failed completely or is producing an incorrect output.
- Ask when the fault occurs.
- Identify any unusual smell, sound or overheating reported by the user.
- Check the operating conditions under which the fault appears.

Step 2: Examine the power supply visually

Look for:

1. Burnt components.
2. Swollen or leaking electrolytic capacitors.
3. Cracked components.
4. Loose wires.
5. Poor solder joints.
6. Damaged circuit boards.
7. Signs of overheating.
8. Damaged connectors.

Step 3: Check the input supply

- Confirm that the correct input source is available.
- Check input connections and protective devices.
- For mains-powered equipment, input-side checks must be performed only by qualified and authorised personnel using appropriate safety procedures.

Step 4: Check the transformer or conversion stage

- Confirm whether the required secondary or converted voltage is available.
- Check for signs of winding damage or overheating.
- Compare measured values with the transformer or supply specifications.

Step 5: Check the rectifier

- Inspect the rectifier connections.
- Use the multimeter's diode-test function where appropriate.
- Identify open-circuit or short-circuit diodes.
- Replace defective components with suitable equivalents.

Step 6: Check the filter

- Inspect the filter capacitor for swelling, leakage or damage.
- Check the capacitance and condition using suitable equipment.
- Observe the rectifier output and filtered output where an oscilloscope is available.

Step 7: Check the voltage regulator

- Verify the regulator's input voltage.
- Check its output voltage.
- Inspect its connections and heat dissipation.
- Consult the component datasheet for correct operating conditions.

Step 8: Check the load

- Confirm that the load is within the power supply's current and power ratings.
- Check for short circuits in the connected device.
- Disconnect the load when appropriate and permitted by the circuit design.

Step 9: Correct the fault

- Replace defective components with correctly rated parts.
- Repair poor connections.
- Correct component polarity or wiring errors.
- Ensure that protective devices have the correct ratings.

Step 10: Retest the power supply

- Recheck the output voltage.
- Assess performance under the intended load.
- Check for excessive heating or abnormal noise.
- Record the final results.

8.4 Examples of Fault Diagnosis

Example 1: Power supply has no DC output

Possible causes:

1. No input supply.
2. Open transformer winding.
3. Faulty rectifier.
4. Broken circuit connection.
5. Blown protective fuse.

Diagnosis:

- Begin with visual inspection and safe isolation.
- Check continuity of appropriate de-energised circuit paths.
- Have a qualified person verify the input and transformer operation where mains-connected sections are involved.
- Test the rectifier and inspect the connections.

Example 2: Power supply produces excessive ripple

Possible causes:

1. Deteriorated filter capacitor.
2. Incorrect capacitor value.
3. Faulty rectifier diode.
4. Excessive load current.

Diagnosis:

- Observe the output waveform using an oscilloscope.
- Compare the ripple with the manufacturer's specification.
- Inspect and test the filter capacitor and rectifier.
- Check whether the load exceeds the rated output current.

Example 3: Power supply overheats

Possible causes:

1. Excessive load.
2. Inadequate heat sinking.
3. Incorrect input voltage.
4. Damaged regulator.
5. Poor ventilation.

Remedies:

- Check the load rating.
- Confirm that the regulator is correctly installed.
- Provide suitable heat dissipation.
- Ensure adequate ventilation.
- Replace damaged components with correctly rated parts.

8.5 Developing a Troubleshooting Guide

A troubleshooting guide is a document that provides an organised method of identifying and correcting faults.

An effective guide should contain:

1. Fault description.
2. Possible causes.
3. Inspection method.
4. Testing instrument required.
5. Diagnostic procedure.
6. Corrective action.
7. Retesting procedure.
8. Safety precautions.

Sample troubleshooting guide

Problem	What to check	Expected observation	Corrective action
No output	Output terminals	No DC voltage	Trace the fault through the supply stages
Low output	Regulator output	Below specified value	Check regulator input, load and regulator condition
High ripple	Filter output	Excessive waveform variation	Inspect filter capacitor and rectifier

Overheating	Regulator and load	Temperature exceeds normal operating conditions	Check load, heat sink and ventilation
Intermittent output	Connections	Output changes when a connection is disturbed	Repair the loose or damaged connection

9.0 Interpretation of Technical Specifications of Power Supply Units

Technical specifications are details provided by a manufacturer to describe the electrical characteristics, performance, operating conditions and limitations of a power supply.

They are normally found on:

- The power supply nameplate.
- The manufacturer's product catalogue.
- Product packaging.
- Technical data sheets.
- Installation and operating manuals.

Understanding technical specifications helps technicians and users select the correct power supply for an electronic device.

9.1 Important Technical Specifications

(a) Input Voltage

Input voltage is the voltage required at the input terminals of the power supply for correct operation.

It may be expressed in volts AC or volts DC.

Examples:

- Input: 240 V AC, 50 Hz.
- Input: 12 V DC.
- Input: 100–240 V AC, 50/60 Hz.

A power supply must be connected to an input source within its specified range.

(b) Output Voltage

Output voltage is the voltage supplied by the power supply to the connected electronic device.

It may be expressed as AC or DC.

Examples:

- Output: 5 V DC.
- Output: 9 V DC.
- Output: 12 V DC.
- Output: 24 V DC.

Importance of output voltage:

1. Determines the voltage required by the load.
2. Helps prevent damage caused by overvoltage.

3. Ensures correct operation of electronic components.
4. Helps users select a compatible power supply.

(c) Output Current Rating

The output current rating is the maximum current that a power supply is designed to deliver under its specified operating conditions.

It is expressed in amperes (A) or milliamperes (mA).

Examples:

- 5 V, 1 A.
- 12 V, 2 A.
- 24 V, 3 A.

A power supply should have sufficient current capacity for the connected load.

(d) Power Rating

Power rating is the maximum output power that a power supply is designed to deliver within its specified operating conditions.

It is measured in watts (W).

For a DC power supply:

$P=VI$

Worked example:

A power supply is rated at 12 V and 3 A. Calculate its maximum rated output power.

$P=12\times3$

$P=36W$

Therefore, the rated output power is **36 W**.

(e) Frequency

Frequency refers to the number of complete cycles of an alternating electrical waveform per second.

It is measured in hertz (Hz).

Examples:

- 50 Hz.
- 60 Hz.
- 50/60 Hz.

The frequency specification is particularly important when selecting AC-powered equipment.

(f) Efficiency

Efficiency indicates how effectively a power supply converts input electrical power into useful output power.

It is expressed as a percentage.

A higher efficiency generally means less power is lost as heat.

(g) Output Ripple and Noise

This specification indicates the amount of unwanted variation and electrical noise present at the output.

Low ripple and noise are important when supplying sensitive electronic circuits.

(h) Voltage Regulation

Voltage regulation describes the ability of a power supply to maintain its output voltage when input voltage or load current changes within specified operating conditions.

Good regulation is important for electronic devices that require stable voltage.

(i) Protection Features

Modern power supplies may include:

1. Overcurrent protection.
2. Overvoltage protection.
3. Short-circuit protection.
4. Overtemperature protection.
5. Overload protection.
6. Surge protection.

These features help protect the power supply and connected equipment from damage.

(j) Operating Temperature

This is the temperature range within which the power supply is designed to operate safely and reliably.

Excessive temperatures may reduce performance and shorten component life.

(k) Isolation and Safety Rating

Some power supplies provide electrical isolation between the input and output circuits. Their safety design and insulation ratings must be appropriate for the intended application.

(l) Power Factor

Power factor describes how effectively AC input power is converted into useful real power.

It is particularly relevant to larger AC-powered electronic equipment and some switching power supplies.

9.2 Sample Technical Specification of a DC Power Supply

Consider the following illustrative product specification:

DC REGULATED POWER SUPPLY



Model: PS-12V-24W

Illustrative specification

Example for learning purposes

Specification	Rating
Input voltage	100–240 V AC
Input frequency	50/60 Hz
Output voltage	12 V DC
Output current	2 A maximum
Output power	24 W maximum
Efficiency	85%
Output polarity	Centre positive
Protection	Overcurrent and short circuit
Operating temperature	As stated by manufacturer

9.3 Interpretation of the Sample Specification

1. **Input voltage of 100–240 V AC:** The supply is designed to operate from an AC source within this voltage range.
2. **Frequency of 50/60 Hz:** It can operate on either 50 Hz or 60 Hz input, subject to the manufacturer's conditions.
3. **Output voltage of 12 V DC:** It provides a nominal 12 V DC output.
4. **Output current of 2 A maximum:** It can deliver up to 2 A within its rated operating conditions.
5. **Output power of 24 W maximum:** Its maximum rated output power is 24 W.
6. **Efficiency of 85%:** Approximately 85% of the input power is converted into useful output power under the stated test conditions.
7. **Centre-positive polarity:** The centre contact of the output connector is positive, while the outer contact is negative.
8. **Protection features:** The supply has protection against specified overcurrent and short-circuit conditions.

9.4 Selecting a Suitable Power Supply for an Electronic Device

When selecting a power supply, consider the following:

1. **Correct voltage:** The output voltage must match the device's requirements.
2. **Adequate current capacity:** The supply must provide at least the current required by the device.

3. **Correct polarity:** Positive and negative terminals must match the device.
4. **Correct AC or DC output:** The supply must provide the type of electrical supply required.
5. **Adequate power rating:** The output power must be sufficient for the load.
6. **Efficiency:** Prefer an efficient supply that reduces energy losses.
7. **Protection features:** Select a supply with suitable protective features.
8. **Physical compatibility:** Connectors and dimensions must be suitable.
9. **Environmental conditions:** Consider operating temperature, ventilation, humidity and dust exposure.
10. **Safety and quality:** Use appropriately certified products from reliable manufacturers.

Worked example: Selecting a power supply

An electronic device requires 9 V DC and draws a maximum current of 1.2 A. Two power supplies are available:

- Supply A: 9 V DC, 1 A.
- Supply B: 9 V DC, 2 A.

Which supply is more suitable?

Solution:

- The device requires 9 V DC.
- Supply A provides the correct voltage but only 1 A, which is below the device's stated maximum current requirement.
- Supply B provides the correct voltage and has a 2 A current capacity.

Therefore, **Supply B is the more suitable option**, provided its polarity, connector and other specifications are compatible.

10.0 Applications of Different Power Supply Units in Electronic Devices

Power supplies are used in many electronic systems. Their design depends on the power requirements and operating conditions of the equipment.

10.1 Mobile Phone Chargers



Mobile phone chargers convert electrical energy from an AC mains supply into a suitable DC output for charging mobile phone batteries.

Functions:

1. Convert AC input into regulated DC output.
2. Provide the required charging voltage and current.
3. Communicate with compatible devices to support charging modes where applicable.
4. Provide protection against specified abnormal operating conditions.

10.2 Computer Power Supply Units

A computer power supply unit converts AC mains electricity into regulated DC voltages required by computer components.

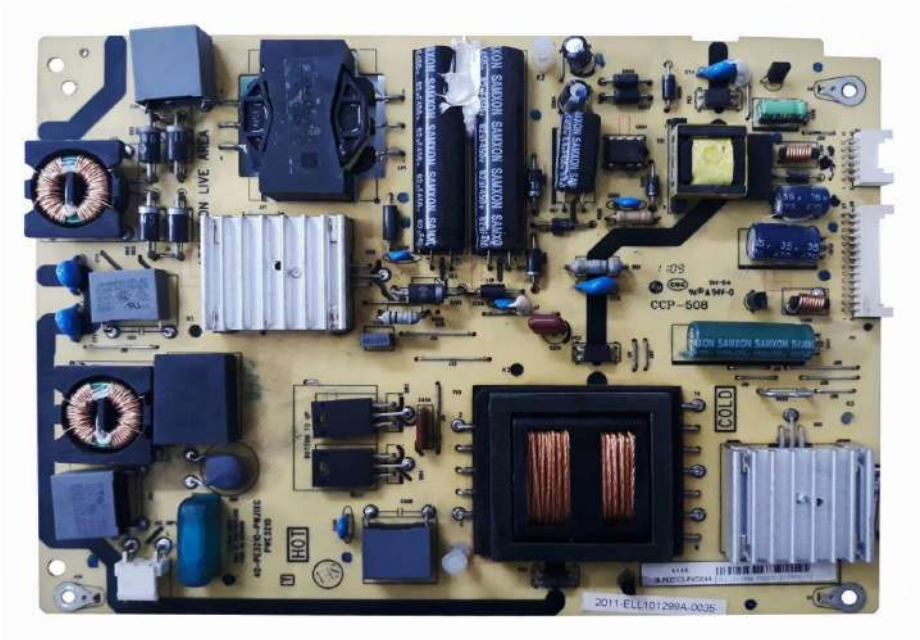
Common output rails include:

- +3.3 V DC.
- +5 V DC.
- +12 V DC.

Applications:

1. Supplying the motherboard.
2. Powering storage devices.
3. Supplying cooling fans.
4. Supplying expansion cards.
5. Supporting processor and graphics power circuits through the computer's designed power connections.

10.3 Television Power Supplies



Television power supplies provide different DC voltage levels required by the television's internal electronic circuits.

Functions:

1. Supply power to the main circuit board.
2. Provide power to the display system.

3. Supply energy to audio circuits.
4. Provide regulated outputs for control circuits.

10.4 Audio Amplifier Power Supplies

Audio amplifiers require power supplies that provide suitable DC voltage and sufficient current.

Functions:

1. Supply electrical energy to amplifier circuits.
2. Support the operation of audio signal-processing components.
3. Provide stable voltage during changes in audio output demand.
4. Reduce unwanted electrical noise that may affect sound quality.

10.5 CCTV and Security Systems



Power supplies are used to operate CCTV cameras, digital video recorders and security control equipment.

Applications:

1. Supplying power to surveillance cameras.
2. Operating monitoring equipment.
3. Powering access control systems.
4. Supporting security alarm circuits.

10.6 Industrial Control Systems

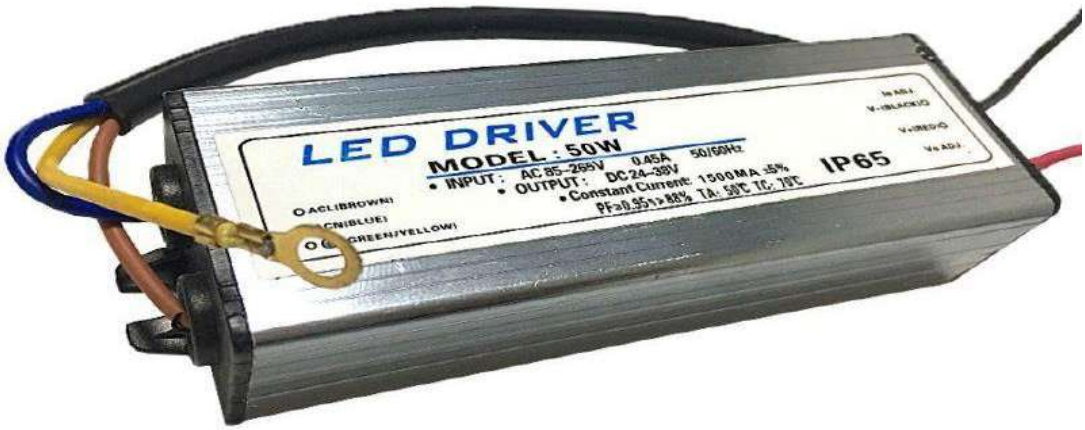


Industrial control systems use power supplies to provide suitable DC voltage for electronic control components.

Applications:

1. Powering sensors.
2. Operating programmable logic controllers (PLCs).
3. Supplying control relays.
4. Powering electronic monitoring devices.
5. Supporting automation equipment.

10.7 LED Lighting Systems



LED lighting systems use power supplies or LED drivers to provide suitable electrical conditions for light-emitting diodes.

Some LED drivers provide regulated constant current, while others provide regulated constant voltage, depending on the LED system design.

Functions:

1. Control current supplied to LEDs.
2. Maintain suitable operating conditions.
3. Improve lighting system reliability.
4. Provide protection against specified electrical faults.

11.0 Advancements in Power Supply Technology

Power supply technology continues to develop to meet the increasing demand for efficient, compact, reliable and environmentally friendly electronic devices.

11.1 High-Efficiency Switching Power Supplies

Modern switching power supplies are designed to reduce energy losses and improve conversion efficiency.

Advantages:

1. Reduce electricity wastage.
2. Generate less heat for a comparable output.
3. Support smaller and lighter electronic devices.
4. Improve energy utilisation.
5. Reduce cooling requirements.

11.2 USB-C Power Delivery Technology



USB-C Power Delivery (USB PD) is a technology that enables compatible devices and chargers to negotiate suitable power delivery levels.

Features:

1. Supports different voltage and current combinations according to the applicable USB PD specification.
2. Allows compatible devices to request suitable charging power.
3. Supports charging of mobile phones, tablets and laptops.
4. Reduces the need for different charger types.
5. Can support higher power levels than conventional basic USB charging.

11.3 Wireless Power Transfer



Wireless power transfer is a technology that transfers electrical energy without a direct conducting connection between the power source and the receiving device.

A common method is inductive charging.

Applications:

1. Wireless smartphone charging.
2. Wireless charging of compatible accessories.
3. Charging some electric vehicle systems.
4. Medical and specialised electronic equipment.

Advantages:

- Reduces dependence on physical charging connectors.
- Can improve convenience.
- Reduces wear on charging ports.
- Can support sealed device designs.

Limitations:

- Charging efficiency may be lower than a direct wired connection.
- Correct positioning may be necessary.
- Some systems generate heat during charging.
- Compatible transmitters and receivers are required.

11.4 Renewable Energy Power Supplies

Solar energy systems use solar panels to convert sunlight into electrical energy. Power electronic devices help regulate, store and convert the electrical energy for different applications.

Main components:

1. Solar photovoltaic panels.
2. Charge controller.
3. Battery storage system, where required.
4. Inverter, where AC output is needed.

5. Protection and monitoring devices.

Applications:

- Solar-powered lighting.
- Remote communication equipment.
- Solar-powered security systems.
- Off-grid electronic systems.
- Educational and laboratory installations.

11.5 Programmable Power Supplies

A programmable power supply allows a user to set output parameters electronically.

Features:

1. Adjustable output voltage.
2. Adjustable current limits.
3. Digital displays.
4. Computer-based control on supported models.
5. Programmable test sequences on advanced models.

Applications:

- Electronics laboratories.
- Research institutions.
- Product testing.
- Electronic equipment development.
- Technical training workshops.

11.6 Smart Power Management

Smart power management uses electronic control systems to monitor and regulate energy use.

Features:

1. Monitors voltage and current.
2. Controls energy distribution.
3. Reduces unnecessary energy consumption.
4. Supports automatic shutdown and standby modes.
5. Communicates with compatible electronic systems.

11.7 Gallium Nitride (GaN) and Silicon Carbide (SiC) Power Devices

Gallium nitride and silicon carbide are semiconductor materials used in modern power electronic devices.

They can offer advantages over conventional silicon devices in certain applications.

Advantages may include:

1. Faster switching.

2. Higher operating-frequency capability.
3. Improved efficiency in suitably designed circuits.
4. Reduced size of some power conversion components.
5. Better performance in certain high-voltage or high-power applications.

Applications:

- Compact fast chargers.
- Electric vehicle power converters.
- Solar inverters.
- Industrial power electronics.
- High-efficiency switching supplies.

11.8 Comparison of Traditional and Modern Power Supply Technologies

Feature	Traditional power supplies	Modern power supplies
Size	Often bulky	Often compact
Efficiency	May be lower	Generally improved
Control	Often simple or manual	May use digital control
Monitoring	Limited	May include smart monitoring
Communication	Usually limited	May support digital communication
Energy management	Less advanced	More advanced
Applications	Conventional electronic equipment	Modern portable, industrial and smart devices

11.9 Importance of Embracing Power Supply Advancements

1. Promotes technological development.
2. Improves energy efficiency.
3. Reduces electronic waste through improved designs and longer service life.
4. Supports renewable energy systems.
5. Encourages innovation and creativity.
6. Improves the performance of electronic devices.
7. Creates opportunities for technical careers.
8. Supports development of local electronic products and services.

12.0 Maintenance of Power Supply Units

Maintenance refers to activities carried out to keep a power supply in good working condition and prevent unexpected failure.

12.1 Preventive Maintenance

Preventive maintenance is carried out regularly to reduce the possibility of equipment failure.

Activities include:

1. Cleaning dust from equipment using approved methods.
2. Checking ventilation openings.
3. Inspecting cables and connectors.
4. Checking for signs of overheating.
5. Inspecting the casing for damage.
6. Checking that cooling fans operate correctly.
7. Ensuring that the power supply is not overloaded.
8. Checking protective devices.
9. Following the manufacturer's maintenance instructions.
10. Keeping maintenance records.

12.2 Corrective Maintenance

Corrective maintenance involves repairing or replacing defective components after a fault has occurred.

Activities include:

1. Identifying the defective component.
2. Diagnosing the cause of failure.
3. Replacing damaged components.
4. Repairing faulty connections.
5. Retesting the equipment.
6. Recording the maintenance work.

12.3 Safety During Maintenance

1. Disconnect equipment from its energy source before carrying out work that requires isolation.
2. Follow the manufacturer's service instructions.
3. Allow components to cool before handling.
4. Be aware that capacitors can retain dangerous electrical charge after disconnection.
5. Use suitable insulated tools.
6. Use correctly rated measuring instruments.
7. Avoid touching exposed conductive parts.
8. Do not bypass protective devices.
9. Use appropriate personal protective equipment.
10. Mains-connected repairs should only be carried out by suitably qualified and authorised personnel.

13.0 CBE Practical Learning Activities

The following activities support the development of practical skills, critical thinking, communication, collaboration and problem-solving.

Activity 1: Identifying Components of a Power Supply

Task: Learners examine a model or safe, de-energised power supply unit.

Procedure:

1. Observe the power supply.
2. Identify the transformer or switching conversion section.
3. Identify the rectifier section where present.
4. Identify filter capacitors.
5. Identify voltage regulators.
6. Identify input and output terminals.
7. Record the functions of the identified components.
8. Present findings to classmates.

Expected outcome: Learners identify power supply components and explain their functions.

Activity 2: Comparing Different Power Supplies

Task: Learners compare different power supplies used in electronic devices.

Examples:

- Mobile phone charger.
- Computer power supply.
- Regulated laboratory supply.
- Solar DC power supply.

Procedure:

1. Observe the available power supplies.
2. Read their labels.
3. Record input and output voltage.
4. Record current and power ratings.
5. Identify their applications.
6. Compare their features.
7. Present findings in groups.

Activity 3: Constructing a Simple DC Power Supply

Task: Learners construct a simple low-voltage DC power supply using an approved schematic.

Procedure:

1. Interpret the schematic.
2. Identify the components.

3. Plan the layout.
4. Assemble the rectifier circuit.
5. Connect the filter.
6. Connect the regulator.
7. Inspect the circuit.
8. Test the output under supervision.
9. Record results.
10. Present the completed work.

Expected outcome: Learners construct and test a simple DC power supply using safe, supervised low-voltage equipment.

Activity 4: Diagnosing Power Supply Faults

Task: Learners examine prepared fault samples or simulated power supply circuits.

Possible faults:

1. Open connection.
2. Shorted diode.
3. Incorrect capacitor polarity in a simulated fault exercise.
4. Faulty regulator.
5. Loose connection.
6. Incorrect component value.

Procedure:

1. Observe the fault sample.
2. Describe the symptoms.
3. Identify possible causes.
4. Select a suitable testing instrument.
5. Carry out appropriate safe tests.
6. Identify the likely fault.
7. Suggest a corrective action.
8. Present a troubleshooting report.

Activity 5: Interpreting Technical Data Sheets

Task: Learners study manufacturer datasheets for different power supply units.

Procedure:

1. Obtain technical datasheets from print or digital sources.
2. Identify the input voltage.
3. Identify the output voltage.
4. Identify the output current.

5. Determine the power rating.
6. Identify the efficiency.
7. Identify the protection features.
8. Compare the different power supplies.
9. Recommend a suitable supply for a given electronic device.

Activity 6: Researching Modern Power Supply Technology

Task: Learners research advancements in power supply technology.

Suggested areas:

1. Switching mode power supplies.
2. USB-C Power Delivery.
3. Wireless charging.
4. Solar power supplies.
5. Programmable power supplies.
6. GaN and SiC semiconductor devices.
7. Smart energy management.

Learners should prepare group presentations showing the advantages, limitations and applications of the technologies researched.

15.0 Glossary of Key Terms

Term	Meaning
Power supply	A device or system that provides suitable electrical energy to a load
PSU	Power Supply Unit
AC	Alternating current
DC	Direct current
Transformer	A device that transfers electrical energy between windings through electromagnetic induction
Rectifier	A circuit that converts AC into pulsating DC
Diode	A semiconductor component that allows current to flow mainly in one direction
Bridge rectifier	A four-diode arrangement used for full-wave rectification
Filter	A circuit that reduces ripple in a rectified output

Capacitor	An electronic component that stores electrical charge and energy in an electric field
Voltage regulator	A circuit or device that maintains a nearly constant output voltage
Linear regulator	A regulator that controls output voltage using a device operating in its linear region
Switching regulator	A regulator that controls output using high-frequency switching
SMPS	Switching Mode Power Supply
Load	A device that consumes electrical energy
Ripple voltage	Unwanted variation remaining in a DC output
Efficiency	Ratio of useful output power to input power, expressed as a percentage
Troubleshooting	A systematic process of identifying and correcting faults
Datasheet	A manufacturer's document containing technical information about a component or device
Overcurrent	Current exceeding the specified safe or rated limit
Overvoltage	Voltage exceeding the specified safe or rated limit
Short circuit	An unintended low-resistance connection between points at different potentials
Open circuit	A break in the conducting path that prevents normal current flow
Buck converter	A switching DC-to-DC converter that reduces voltage
Boost converter	A switching DC-to-DC converter that increases voltage
Wireless power transfer	Transfer of electrical energy without a direct conducting connection

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Self-Assessment Questions

A. Short Answer Questions

1. Define the term power supply.
2. State five functions of a power supply unit.
3. Differentiate between AC and DC power supplies.
4. Explain the meaning of a regulated power supply.
5. State four characteristics of a good power supply.
6. Name the four main stages of a conventional DC power supply.
7. Explain the function of a transformer in a power supply.
8. What is rectification?
9. Differentiate between half-wave and full-wave rectification.
10. State four advantages of a bridge rectifier.
11. Explain the importance of a filter capacitor.
12. State four functions of a voltage regulator.
13. Differentiate between a linear regulator and a switching regulator.
14. State five instruments used in power supply testing.
15. Explain why an oscilloscope is used when testing a power supply.
16. Define ripple voltage.
17. State five common faults in power supply circuits.
18. Explain the meaning of troubleshooting.
19. Identify six technical specifications found on a power supply datasheet.
20. State five factors to consider when selecting a power supply.
21. Explain how the efficiency of a power supply is calculated.
22. State four applications of switching mode power supplies.
23. Explain the importance of USB-C Power Delivery technology.
24. State four advantages of wireless power transfer.
25. Explain the importance of preventive maintenance of power supplies.

B. Structured Questions

1. (a) Define a power supply unit. (2 marks)

(b) Explain six functions of a power supply in an electronic system. (6 marks)

(c) State four characteristics of a good power supply. (4 marks)

2. (a) Identify four major stages of a conventional regulated DC power supply. (4 marks)

(b) Explain the operation of each stage. (8 marks)

3. (a) Differentiate between half-wave and full-wave rectification. (4 marks)

(b) Explain the operation of a bridge rectifier. (4 marks)

(c) State four advantages of a bridge rectifier. (4 marks)

4. (a) Explain the meaning of voltage regulation. (2 marks)

(b) Differentiate between linear and switching voltage regulators. (4 marks)

(c) State four applications of switching mode power supplies. (4 marks)

5. (a) A power supply provides an output voltage of 12 V and a current of 2.5 A. Calculate its output power. (3 marks)

(b) The supply receives 40 W of input power and delivers 30 W of useful output power. Calculate its efficiency. (3 marks)

(c) State four ways of improving the efficiency of power supply systems. (4 marks)

6. (a) State six instruments used in testing power supply circuits. (6 marks)

(b) Explain how a digital multimeter is used to measure the output voltage of a DC power supply. (4 marks)

7. A regulated power supply produces no output voltage.

(a) State four possible causes of the fault. (4 marks)

(b) Explain four systematic troubleshooting steps that can be followed to identify the fault. (4 marks)

(c) State two safety precautions to observe during troubleshooting. (2 marks)

8. (a) Explain the meaning of technical specifications of a power supply. (2 marks)

(b) State six important technical specifications found on a power supply datasheet. (6 marks)

(c) A device requires 5 V DC and draws 1.5 A. Two power supplies are available:

- Supply A: 5 V DC, 1 A.
- Supply B: 5 V DC, 2 A.

Identify the more suitable supply and give a reason. (2 marks)

9. (a) Explain four applications of power supplies in electronic devices. (4 marks)

(b) Discuss four recent advancements in power supply technology. (4 marks)

(c) State two benefits of embracing modern power supply technology. (2 marks)

10. (a) Explain four preventive maintenance practices for power supply units. (4 marks)

(b) State four electrical safety precautions to observe when constructing or testing power supply circuits. (4 marks)

(c) Explain two ways in which energy-efficient power supplies contribute to environmental conservation. (2 marks)

STRAND 4.0: ELECTRONICS

SUB-STRAND 4.2: SINGLE-STAGE BIPOLAR JUNCTION TRANSISTOR (BJT) AMPLIFIER

1.0 Introduction to Single-Stage BJT Amplifiers

Electronic devices such as radios, televisions, public-address systems, mobile phones, intercoms and audio systems use amplifier circuits to increase the strength of weak electrical signals.

A microphone, for example, produces a very small electrical signal when a person speaks. This signal may be too weak to drive a loudspeaker directly. An amplifier increases the signal strength so that it can be used by a subsequent stage or output device.

One of the electronic components commonly used to construct amplifiers is the **Bipolar Junction Transistor (BJT)**.

A single-stage BJT amplifier uses one transistor as its main amplifying component. It is designed to increase the amplitude of an input signal while maintaining the essential shape of the signal, provided the amplifier operates correctly.

1.1 Meaning of a BJT

A **Bipolar Junction Transistor (BJT)** is a three-terminal semiconductor device used for amplification and switching of electrical signals.

It is called bipolar because both electrons and holes take part in the conduction process.

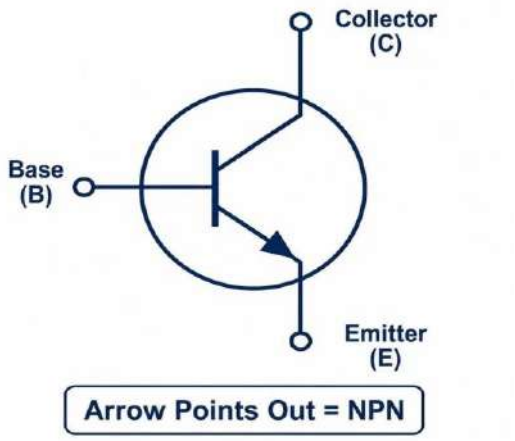
The three terminals of a BJT are:

1. **Emitter (E):** Supplies charge carriers into the transistor's base region.
2. **Base (B):** Controls the flow of current between the emitter and collector.
3. **Collector (C):** Collects charge carriers passing through the base region.

1.2 Types of BJT

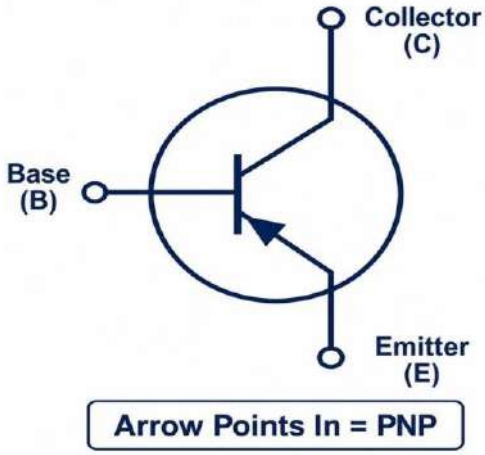
There are two main types of bipolar junction transistors:

- NPN transistor.
- PNP transistor.



NPN transistor

The emitter arrow points outwards.



PNP transistor

The emitter arrow points inwards.

NPN transistor

- Consists of a thin P-type semiconductor layer between two N-type semiconductor layers.
- Electrons are the majority charge carriers.
- It is widely used in electronic amplifier circuits.
- It is normally switched on by making the base sufficiently positive relative to the emitter.

PNP transistor

- Consists of a thin N-type semiconductor layer between two P-type semiconductor layers.
- Holes are the majority charge carriers.
- It is used in amplifier and switching circuits.
- It is normally switched on by making the base sufficiently negative relative to the emitter.

1.3 Basic structure of a BJT

A BJT consists of three semiconductor regions and two PN junctions.

The three regions are:

1. Emitter region.
2. Base region.
3. Collector region.

The two junctions are:

- Emitter-base junction.
- Collector-base junction.

Characteristics of the three regions

Region	Main characteristics	Function
Emitter	Heavily doped	Supplies charge carriers

Base	Very thin and lightly doped	Controls charge-carrier movement
Collector	Moderately doped and physically larger	Collects charge carriers and dissipates heat

1.4 Meaning of an amplifier

An **amplifier** is an electronic circuit or device that increases the amplitude of an electrical signal using energy supplied by a power source.

The amplifier does not create energy. It uses energy from its power supply to produce an output signal that is greater in amplitude or power than the input signal.

Examples of signals that can be amplified include:

- Audio signals from microphones.
- Radio-frequency signals.
- Signals from electronic sensors.
- Signals from musical instruments.
- Signals from communication equipment.

1.5 Meaning of a single-stage BJT amplifier

A **single-stage BJT amplifier** is an electronic amplifier circuit that uses one bipolar junction transistor as the main active component to increase the amplitude of an input signal.

It normally consists of:

- One transistor.
- Biasing resistors.
- Collector resistor.
- Emitter resistor, where used.
- Coupling capacitors.
- Bypass capacitor, where used.
- DC power supply.
- Input and output terminals.

1.6 Applications of single-stage BJT amplifiers in Kenya

Single-stage transistor amplifiers are important in many electronic systems used in homes, schools, workshops and businesses.

Examples include:

1. **Radio receivers:** Amplify weak audio or intermediate-frequency signals.
2. **Public-address systems:** Amplify signals in microphone and audio preamplifier sections.
3. **Television receivers:** Amplify signals in different analogue electronic stages.
4. **Intercom systems:** Amplify voice signals for communication.
5. **Electronic instruments:** Amplify weak signals from sensors.
6. **Audio equipment:** Increase the strength of small audio signals.

7. **Communication equipment:** Amplify signals before further processing.
8. **Electronic alarm systems:** Amplify weak signals from sensing circuits.

7. Applications of single-stage BJT amplifiers in Kenya

Single-stage BJT amplifiers are used in electronic circuits where weak electrical signals need to be increased before further processing.

Examples include:

1. **Radio receivers**
   - ✓ Amplify weak signals received through an antenna.
   - ✓ Make audio signals strong enough to drive a speaker or another amplification stage.
2. **Public-address systems**
   - ✓ Amplify weak signals from microphones.
   - ✓ Help produce audible sound through loudspeakers when used as part of a larger amplifier system.
3. **Television receivers**
   - ✓ Amplify certain audio and radio-frequency signals in receiver circuits.
   - ✓ Discrete transistor stages may be found in some electronic designs.
4. **Intercom systems**
   - ✓ Amplify voice signals from microphones.
   - ✓ Improve communication between rooms or buildings.
5. **Electronic musical instruments**
   - ✓ Amplify weak signals from pickups and sensors.
   - ✓ Help process sound before it reaches a power amplifier.
6. **Electronic alarm systems**
   - ✓ Amplify signals from sensors such as light-dependent resistors, microphones and other transducers.
   - ✓ Help electronic circuits detect small changes in input signals.
7. **Laboratory instruments**
   - ✓ Amplify weak signals during electronic measurements.
   - ✓ Support experiments in schools, colleges and technical training institutions.
8. **Communication equipment**
   - ✓ Amplify signals in certain transmitter and receiver circuits.
   - ✓ Support the processing of low-level electrical signals.

Kenyan application: In schools, technical training centres, churches, community halls and small businesses, transistor amplifier circuits can be used in learning projects involving microphones, radios, intercoms and electronic sound systems.

8. Operating regions of a bipolar junction transistor

A BJT can operate in different regions depending on the biasing of its two junctions.

The main operating regions are cut-off, active and saturation. Breakdown is an undesirable condition during normal amplifier operation.

8.1 Cut-off region

The cut-off region is the condition in which the transistor is switched OFF.

Characteristics:

- The base-emitter junction is not sufficiently forward-biased.

- The base current is approximately zero.
- The collector current is approximately zero, apart from very small leakage current.
- The transistor behaves like an open switch.
- It does not amplify the input signal in this condition.

Application: Cut-off operation is commonly used in transistor switching circuits.

8.2 Active region

The active region is the operating condition used when a BJT is functioning as an amplifier.

Characteristics:

- The base-emitter junction is forward-biased.
- The collector-base junction is reverse-biased.
- A small base current controls a much larger collector current.
- Changes in the input signal produce corresponding changes in collector current.
- The transistor can amplify analogue signals when correctly biased.

For a typical silicon NPN transistor, the base-emitter voltage is often approximately 0.6–0.7 V when conducting. The actual value depends on the transistor, current and temperature.

8.3 Saturation region

Saturation occurs when the transistor is driven fully ON.

Characteristics:

- Both the base-emitter and collector-base junctions are forward-biased.
- The collector current is limited mainly by the external circuit.
- The collector-emitter voltage becomes very small.
- The transistor behaves approximately like a closed switch.
- It is not suitable for faithful linear amplification because the output becomes distorted.

8.4 Breakdown region

Breakdown occurs when the voltage across a transistor junction exceeds its specified limit.

Characteristics:

- Excessive voltage causes a rapid increase in current.
- The transistor may become damaged.
- Excessive heat may be produced.
- The transistor may fail permanently.

Safety precaution: Always operate a transistor within the maximum voltage, current and power ratings stated in its datasheet.

Comparison of BJT operating regions

Operating region	Transistor condition	Main characteristic
Cut-off	OFF	Almost no collector current
Active	Amplifying	Small input changes control collector current
Saturation	Fully ON	Very small collector-emitter voltage
Breakdown	Abnormal	Excessive current may damage the tran-

Operating region	Transistor condition	Main characteristic
		sistor

9. Transistor current relationships

A BJT has three terminals: emitter, base and collector. Current flows through these terminals according to the transistor's operating condition.

For a transistor operating normally:

$$I_E = I_C + I_B$$

Where:

- I_E = emitter current, measured in amperes (A).
- I_C = collector current, measured in amperes (A).
- I_B = base current, measured in amperes (A).

9.1 Current gain in a common-emitter transistor

The common-emitter current gain is represented by beta (β).

$$\beta = \frac{I_C}{I_B}$$

Therefore:

$$I_C = \beta I_B$$

And:

$$I_B = \frac{I_C}{\beta}$$

Example 1

A transistor has a base current of 40 μA and a collector current of 4 mA. Calculate its current gain.

Solution

Given:

$$I_B = 40\ \mu A = 0.00004\ A$$

$$I_C = 4\ mA = 0.004\ A$$

Using:

$$\beta = \frac{I_C}{I_B}$$

Substituting:

$$\beta = \frac{0.004}{0.00004}$$

$$\boxed{\beta = 100}$$

The transistor has a current gain of 100.

9.2 Common-base current gain

The common-base current gain is represented by alpha (α).

$$\alpha = \frac{I_C}{I_E}$$

Since:

$$I_E = I_C + I_B$$

The relationship between alpha and beta is:

$$\alpha = \frac{\beta}{\beta + 1}$$

And:

$$\beta = \frac{\alpha}{1 - \alpha}$$

Example 2

A transistor has a common-base current gain of 0.98. Calculate its common-emitter current gain.

Solution

Given:

$$\alpha = 0.98$$

Using:

$$\beta = \frac{\alpha}{1 - \alpha}$$

Substituting:

$$\beta = \frac{0.98}{1 - 0.98}$$

$$\beta = \frac{0.98}{0.02}$$

$$\boxed{\beta = 49}$$

10. Types of BJT amplifier configurations

A BJT amplifier can be connected in three main configurations depending on the terminal that is common to both the input and output circuits.

These are:

9. Common-emitter (CE) amplifier.
10. Common-collector (CC) amplifier.
11. Common-base (CB) amplifier.

10.1 Common-emitter amplifier

A common-emitter amplifier is a transistor amplifier in which the emitter terminal is common to both the input and output circuits, usually through an AC ground connection.

Characteristics

- Provides high voltage gain.
- Provides high current gain.
- Provides considerable power gain.
- Produces a 180° phase reversal between input and output voltage signals.
- Has moderate input impedance.
- Has moderate output impedance.
- Is widely used for voltage amplification.

Advantages

- Provides useful voltage and power amplification.
- Can amplify weak audio signals.
- Has a relatively simple circuit arrangement.
- Is suitable for many analogue electronic applications.

Disadvantages

- Output signal is inverted.
- Its performance depends on correct biasing.
- Temperature changes can affect its operating point.
- Excessive input signals may cause distortion.

Applications

- Audio pre-amplifier circuits.
- Radio-frequency amplifier stages.
- Microphone signal amplification.
- General-purpose analogue signal amplification.

10.2 Common-collector amplifier

A common-collector amplifier is a transistor amplifier in which the collector terminal is common to both the input and output circuits. It is also called an emitter follower.

Characteristics

- Has a voltage gain slightly less than or approximately equal to one.
- Has high current gain.
- Has high input impedance.
- Has low output impedance.
- Does not produce a 180° phase reversal.
- The output voltage follows the input voltage.

Advantages

- Provides good impedance matching.
- Can drive a relatively low-resistance load from a higher-resistance source.
- Provides current amplification.
- Has a simple circuit arrangement.

Disadvantages

- Does not provide significant voltage amplification.

- Its output voltage is generally lower than the input voltage by approximately the base-emitter voltage in a simple emitter follower.

Applications

- Buffer circuits.
- Impedance matching.
- Signal isolation between electronic stages.
- Driving loads that require more current.

10.3 Common-base amplifier

A common-base amplifier is a transistor amplifier in which the base terminal is common to both the input and output circuits.

Characteristics

- Has low input impedance.
- Has high output impedance.
- Provides high voltage gain in suitable circuit conditions.
- Has current gain slightly less than one.
- Does not produce a 180° phase reversal.
- Can operate effectively at high frequencies.

Advantages

- Suitable for high-frequency applications.
- Can provide useful voltage amplification.
- Has good high-frequency performance in suitable designs.

Disadvantages

- Has low input impedance.
- Does not provide current gain greater than one.
- Requires suitable circuit design to match the input source.

Applications

- High-frequency amplifier circuits.
- Radio-frequency circuits.
- Impedance matching between low-impedance sources and higher-impedance stages.

10.4 Comparison of BJT amplifier configurations

Characteristic	Common emitter	Common collector	Common base
Common terminal	Emitter	Collector	Base
Voltage gain	High	Approximately 1	High
Current gain	High	High	Less than 1
Power gain	High	Useful	Useful
Input impedance	Medium	High	Low
Output impedance	Medium	Low	High
Phase relationship	180° reversal	No reversal	No reversal
Main application	Voltage amplification	Buffering	High-frequency amplification

11. Common-emitter single-stage amplifier circuit

The common-emitter amplifier is one of the most widely studied BJT amplifier circuits.

It is used to increase the amplitude of weak alternating electrical signals.

11.1 Main components of a common-emitter amplifier

The circuit consists of the following components:

1. Bipolar junction transistor (Q1)

- It is the main active component.
- It controls the collector current using a small base current.
- It operates in the active region during normal amplification.

2. Collector resistor (R_C)

- Connected between the collector and the positive supply.
- Limits collector current.
- Develops an output voltage when collector current changes.
- Helps determine the voltage gain of the amplifier.

3. Emitter resistor (R_E)

- Connected between the emitter and ground.
- Helps stabilise the transistor's operating point.
- Reduces the effect of temperature changes.
- Improves thermal stability.

4. Base bias resistors (R_1 and R_2)

- Form a voltage-divider bias network.
- Establish a suitable DC voltage at the base.
- Help maintain the transistor in the active region.

5. Input coupling capacitor (C_1)

- Connects the input signal to the transistor base.
- Allows the AC input signal to pass.
- Blocks unwanted DC from the signal source.

6. Output coupling capacitor (C_2)

- Transfers the amplified AC output signal to the load.
- Blocks DC from reaching the load.
- Helps prevent changes in the load from disturbing the transistor's DC bias.

7. Emitter bypass capacitor (C_E)

- Connected in parallel with the emitter resistor.
- Provides a low-impedance path for AC signals at suitable frequencies.
- Reduces AC negative feedback through the emitter resistor.
- Increases voltage gain over the frequencies where it is effective.

8. DC power supply (V_{CC})

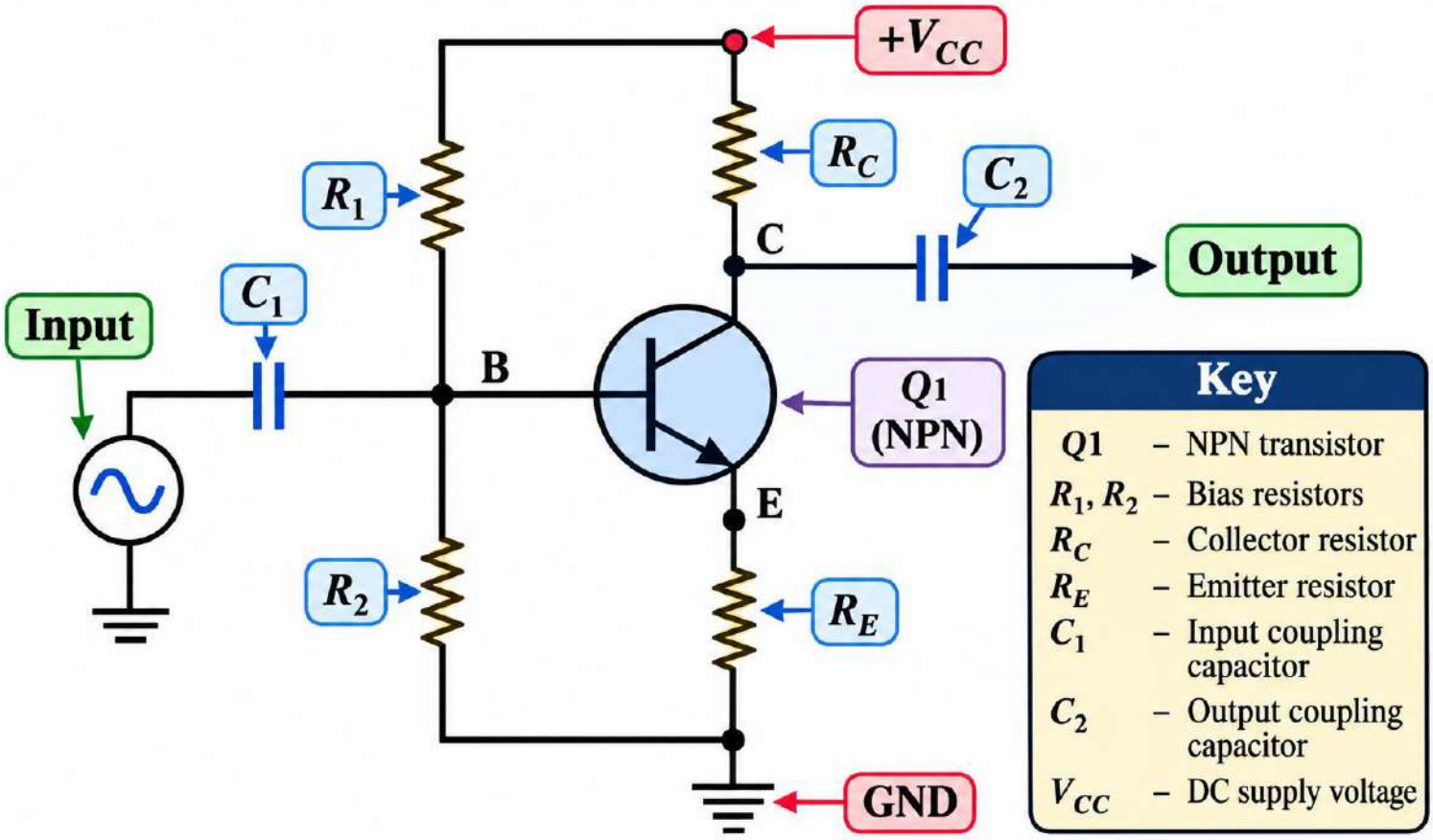
- Provides the energy required for amplification.
- Establishes the DC operating conditions of the transistor.
- The amplifier does not create energy; it uses the supply to produce a larger output signal.

9. Load resistor (R_L)

- Represents the circuit or device receiving the amplified signal.
- May represent the input resistance of another amplifier stage or a suitable output load.

11.2 Simplified common-emitter amplifier schematic

The following is a simplified teaching schematic. It shows the main connections but is not a substitute for a complete component-specific circuit diagram.



The emitter bypass capacitor C_E, when used, is connected in parallel with R_E. The load R_L is connected to the output through C_2.

Important: The physical positions of the emitter, base and collector terminals vary between transistor types and packages. Always check the manufacturer's datasheet before connecting a transistor.

12. Working principle of a common-emitter amplifier

The common-emitter amplifier operates by using a small input signal to control a larger change in collector current.

Step 1: DC biasing

- The DC power supply provides voltage to the circuit.
- The voltage-divider resistors establish the base voltage.
- The base-emitter junction becomes forward-biased.
- The collector-base junction remains reverse-biased.

- The transistor is set to operate in the active region.

Step 2: Application of the input signal

- A weak AC signal is applied at the input.
- The input coupling capacitor allows the AC signal to reach the base.
- The capacitor prevents the input source from changing the DC bias directly.

Step 3: Change in base current

- During the positive half-cycle of the input signal, the base current of an NPN transistor increases.
- During the negative half-cycle, the base current decreases.
- These changes occur around the established DC operating point.

Step 4: Change in collector current

The collector current is related to the base current by:

$$I_C = \beta I_B$$

Therefore, a small change in base current produces a larger change in collector current.

Step 5: Development of output voltage

- The collector resistor converts changes in collector current into changes in voltage.
- When collector current increases, the voltage drop across R_C increases.
- The collector voltage consequently decreases.
- When collector current decreases, the voltage drop across R_C decreases.
- The collector voltage consequently increases.

Step 6: Phase reversal

- When the input voltage increases, the collector output voltage decreases.
- When the input voltage decreases, the collector output voltage increases.
- The output signal is therefore inverted relative to the input.
- This represents a phase difference of approximately 180° for an ideal mid-band common-emitter amplifier.

Step 7: Delivery of the amplified signal

- The output coupling capacitor transfers the amplified AC signal to the load.
- The capacitor blocks the collector's DC voltage.
- The load receives the amplified alternating signal.

Summary of signal amplification

The important principle is that the input signal controls the transistor, while the DC power supply provides the energy delivered to the amplified output signal.

13. Transistor biasing

Biasing is the process of applying suitable DC voltages and currents to a transistor to establish its operating condition.

In an amplifier, correct biasing ensures that the transistor remains in the active region during the required signal swing.

13.1 Importance of transistor biasing

Biasing is necessary because it:

1. Establishes the quiescent operating point.
2. Keeps the transistor in the active region.
3. Reduces signal distortion.
4. Improves amplifier stability.
5. Helps prevent unwanted cut-off and saturation.
6. Reduces the effects of temperature variations.
7. Ensures consistent amplifier performance.

13.2 Quiescent operating point (Q-point)

The quiescent point is the DC operating point of a transistor when no AC input signal is applied.

It is commonly described by the collector current and collector-emitter voltage:

$$Q = (I_{CQ}, V_{CEQ})$$

Where:

- I_{CQ} = quiescent collector current.
- V_{CEQ} = quiescent collector-emitter voltage.

A suitable Q-point allows the output signal to swing in both directions without excessive clipping.

13.3 Methods of transistor biasing

A. Fixed bias

- Uses a resistor to supply base current from the DC supply.
- Has a simple circuit arrangement.
- Is easy to understand and construct.
- Is sensitive to changes in transistor current gain and temperature.
- Is less stable than voltage-divider bias.

B. Collector-to-base feedback bias

- Uses a resistor connected between the collector and base.
- Provides negative feedback that helps stabilise the operating point.
- When collector current increases, the collector voltage decreases.
- The reduced collector voltage tends to reduce base current.
- This helps oppose the original increase in collector current.

C. Voltage-divider bias

- Uses two resistors connected across the DC supply.
- The junction of the resistors provides the base bias voltage.
- An emitter resistor is commonly included.
- Provides better operating-point stability than simple fixed bias.
- Is widely used in common-emitter amplifier circuits.

14. Load lines in a common-emitter amplifier

A load line is a straight line drawn on a transistor output characteristic graph to show the relationship between collector current and collector-emitter voltage for a particular external circuit.

It helps determine the possible operating conditions of a transistor.

14.1 DC load line

The DC load line shows the relationship between I_C and V_{CE} under DC conditions.

For a simplified circuit containing a collector resistor and no emitter resistor:

$$V_{CC} = I_C R_C + V_{CE}$$

Rearranging:

$$\boxed{V_{CE} = V_{CC} - I_C R_C}$$

Where:

- V_{CC} = DC supply voltage.
- I_C = collector current.
- R_C = collector resistance.
- V_{CE} = collector-emitter voltage.

14.2 DC load line intercepts

At cut-off:

When collector current is approximately zero:

$$I_C = 0$$

Therefore:

$$V_{CE} = V_{CC}$$

This is the cut-off point.

At saturation:

For a simplified calculation, when V_{CE} is taken as approximately zero:

$$I_C = \frac{V_{CC}}{R_C}$$

This gives the approximate saturation current.

In a real transistor, the saturation voltage is small but not exactly zero.

14.3 Example: calculating the DC load line

A common-emitter amplifier has a supply voltage of 12 V and a collector resistor of 1 kΩ. Calculate:

d) The collector-emitter voltage at cut-off.

e) The approximate collector current at saturation.

Solution

Given:

$$V_{CC} = 12V$$

$$R_C = 1k\Omega = 1000\Omega$$

a) At cut-off

$$I_C = 0$$

$$V_{CE} = V_{CC}$$

$$\boxed{V_{CE} = 12V}$$

b) At saturation

$$I_C = \frac{V_{CC}}{R_C}$$

$$I_C = \frac{12}{1000}$$

$$I_C = 0.012A$$

$$\boxed{I_C = 12mA}$$

The approximate load-line intercepts are therefore:

- Cut-off: $V_{CE} = 12V,\ I_C = 0$.
- Saturation: $V_{CE} \approx 0V,\ I_C = 12mA$.

14.4 AC load line

The AC load line shows how the transistor's collector current and collector-emitter voltage vary when an AC signal is applied.

Important points:

- It passes through the quiescent operating point.
- Its slope depends on the effective AC load.
- The effective AC collector load may be the parallel combination of R_C and R_L.
- It helps determine the maximum undistorted output signal swing.

For a simple circuit:

$$R_{AC} = R_C \parallel R_L$$

Where:

$$R_{AC} = \frac{R_C R_L}{R_C + R_L}$$

The AC load line is generally different from the DC load line because the load capacitor may allow the external load to affect AC operation while blocking DC.

15. Characteristics of a single-stage BJT amplifier

The performance of a transistor amplifier is determined by several electrical characteristics.

15.1 Voltage gain

Voltage gain is the ratio of output voltage to input voltage.

$$\boxed{A_v = \frac{V_o}{V_i}}$$

Where:

- A_v = voltage gain.
- V_o = output voltage.

- V_i = input voltage.

Example 1

An amplifier receives an input signal of 20 mV and produces an output signal of 2 V. Calculate the voltage gain.

Solution

Given:

$$V_i = 20mV = 0.02V$$

$$V_o = 2V$$

$$A_v = \frac{V_o}{V_i}$$

$$A_v = \frac{2}{0.02}$$

$$\boxed{A_v = 100}$$

The voltage gain is 100.

15.2 Current gain

Current gain is the ratio of output current to input current.

$$\boxed{A_i = \frac{I_o}{I_i}}$$

Where:

- A_i = current gain.
- I_o = output current.
- I_i = input current.

15.3 Power gain

Power gain is the ratio of output power to input power.

$$\boxed{A_p = \frac{P_o}{P_i}}$$

Where:

- P_o = output power.
- P_i = input power.

For compatible voltage and current gain definitions:

$$A_p = A_v \times A_i$$

The exact relationship depends on the input and output impedances and how the gains are defined.

15.4 Power in an electrical circuit

For a resistive load:

$$P = VI$$

Also:

$$P = I^2R$$

And:

$$P = \frac{V^2}{R}$$

Example 2

An amplifier delivers an output voltage of 4 V across a 100 Ω resistive load. Calculate the output power.

Solution

Given:

$$V = 4V$$

$$R = 100\Omega$$

Using:

$$P = \frac{V^2}{R}$$

$$P = \frac{4^2}{100}$$

$$P = \frac{16}{100}$$

$$\boxed{P = 0.16W}$$

15.5 Gain expressed in decibels

Voltage gain can be expressed in decibels (dB).

$$\boxed{A_v(dB) = 20\log_{10}|A_v|}$$

Power gain in decibels is:

$$\boxed{A_p(dB) = 10\log_{10}\left(\frac{P_o}{P_i}\right)}$$

Example 3

An amplifier has a voltage gain of 100. Calculate the voltage gain in decibels.

Solution

$$A_v(dB) = 20\log_{10}(100)$$

$$= 20 \times 2$$

$$\boxed{A_v = 40dB}$$

The absolute value is used because the formula expresses gain magnitude. The 180° phase inversion of a common-emitter amplifier is described separately.

16. Frequency response of a BJT amplifier

Frequency response describes how the gain of an amplifier changes with the frequency of the input signal.

A single-stage amplifier does not necessarily provide the same gain at all frequencies.

16.1 Low-frequency response

At low frequencies:

- The reactance of coupling capacitors increases.
- The reactance of the emitter bypass capacitor also increases.
- Some of the input signal may be lost across the capacitors.
- The voltage gain decreases.

16.2 Mid-frequency response

At mid-frequencies:

- The coupling capacitors provide relatively low reactance.
- The emitter bypass capacitor provides effective AC bypassing.
- The amplifier usually produces its intended and relatively stable gain.
- The output signal is generally amplified with less frequency-related loss.

16.3 High-frequency response

At high frequencies:

- Internal transistor capacitances become significant.
- Wiring and circuit capacitances may affect performance.
- The transistor's gain may decrease.
- The output signal may become weaker.

16.4 Cut-off frequencies

The lower cut-off frequency is the frequency below which the amplifier's gain begins to fall significantly.

The upper cut-off frequency is the frequency above which the gain falls significantly.

They are commonly measured at the points where voltage gain falls to approximately 70.7% of its mid-band value.

16.5 Bandwidth

Bandwidth is the range of frequencies over which an amplifier operates effectively.

$$\boxed{BW = f_H - f_L}$$

Where:

- BW = bandwidth.
- f_H = upper cut-off frequency.
- f_L = lower cut-off frequency.

Example

An amplifier has a lower cut-off frequency of 100 Hz and an upper cut-off frequency of 20 kHz. Calculate its bandwidth.

Solution

$$BW = f_H - f_L$$

$$BW = 20{,}000 - 100$$

$$\boxed{BW = 19{,}900Hz}$$

17. Distortion and noise in BJT amplifiers

17.1 Distortion

Distortion occurs when the output signal does not maintain the required shape of the input signal.

Common causes include:

8. Incorrect transistor biasing.
9. Excessive input signal amplitude.
10. Incorrect component values.
11. Transistor operation outside the active region.
12. Poor power supply regulation.
13. Incorrect load connection.

17.2 Clipping

Clipping occurs when part of the output waveform is cut off because the transistor cannot produce the required voltage swing.

Types of clipping

- **Top clipping:** The upper portion of the waveform is cut off.
- **Bottom clipping:** The lower portion of the waveform is cut off.
- **Both-sided clipping:** Both the positive and negative portions are cut off.

Ways of reducing distortion

- Set the correct Q-point.
- Use appropriate supply voltage.
- Select suitable transistor and resistor values.
- Avoid excessive input signal amplitude.
- Use correctly rated components.
- Ensure that the transistor operates in the active region.

17.3 Noise

Noise is an unwanted electrical signal that interferes with the desired input or output signal.

Sources of noise include:

- Poor grounding.
- Electrical interference from nearby equipment.
- Poorly connected wires.
- Faulty components.
- Power supply ripple.
- Long, poorly arranged signal wires.

Ways of reducing noise

1. Use proper grounding.
2. Keep signal wires short where practical.
3. Use suitable shielding.
4. Use a stable DC power supply.
5. Make firm connections.
6. Keep sensitive signal wiring away from high-current wiring.

18. Construction of a single-stage BJT amplifier

Constructing a single-stage amplifier involves selecting components, interpreting the circuit diagram, assembling the circuit and testing its operation.

18.1 Tools and equipment required

Tool/equipment	Function
Breadboard	Holds components and allows temporary circuit connections
Digital multimeter	Measures voltage, current and resistance
Oscilloscope	Displays input and output waveforms
DC power supply	Provides the required operating voltage
Signal generator	Produces the input AC signal
Jumper wires	Connect circuit components
Soldering iron	Makes permanent electrical joints where required
Wire stripper	Removes insulation from wires
Component datasheets	Provide ratings and terminal information

18.2 Materials and components

- NPN or PNP BJT selected for the design.
- Base bias resistors.
- Collector resistor.
- Emitter resistor.
- Input coupling capacitor.
- Output coupling capacitor.
- Emitter bypass capacitor, where required.
- Suitable load resistor.
- DC power supply.
- Connecting wires.

18.3 Procedure for constructing the amplifier

Step 1: Study the circuit diagram

- Identify the transistor terminals.
- Identify all resistors and capacitors.
- Determine the correct supply polarity.
- Identify the input and output connections.

Step 2: Select suitable components

- Select a transistor suitable for the intended amplifier.
- Check its maximum collector current.
- Check its maximum collector-emitter voltage.
- Check its power rating.
- Select resistors and capacitors according to the design.

Step 3: Identify transistor terminals

- Check the transistor datasheet for the emitter, base and collector arrangement.
- Do not assume that all transistors have the same pin arrangement.
- Confirm the terminal identification before placing the transistor on the breadboard.

Step 4: Assemble the biasing network

- Connect the base bias resistors.
- Connect the emitter resistor.
- Connect the collector resistor.
- Check that the DC supply connections are correct.

Step 5: Connect the coupling capacitors

- Connect the input capacitor to the base input circuit.
- Connect the output capacitor to the output terminal.
- Observe polarity when using electrolytic capacitors.

Step 6: Connect the emitter bypass capacitor

- Connect it in parallel with the emitter resistor where the design requires it.
- Observe capacitor polarity.
- Ensure that the capacitor's voltage rating is suitable.

Step 7: Inspect the circuit

- Check for loose connections.
- Check for accidental short circuits.
- Confirm that the transistor terminals are correctly connected.
- Check the resistor and capacitor values.

Step 8: Apply the DC supply

- Set the supply to the specified voltage.
- Apply power carefully.
- Measure the DC voltages at the base, emitter and collector.
- Confirm that the transistor is operating at the intended Q-point.

Step 9: Apply an input signal

- Connect the signal generator to the amplifier input.
- Begin with a small AC signal.
- Observe the input and output waveforms.
- Check whether the output is amplified and inverted.

Step 10: Record observations

- Record input voltage.
- Record output voltage.
- Calculate voltage gain.
- Observe waveform distortion.
- Compare the results with expected values.

19. Testing and measurement of a BJT amplifier

Testing confirms whether a constructed amplifier operates correctly.

19.1 Using a digital multimeter

A digital multimeter can be used to:

- Measure the DC supply voltage.
- Measure the base-emitter voltage.
- Measure collector-emitter voltage.
- Measure resistance of disconnected components.
- Measure current using the correct series connection and meter range.

Precaution: Never connect an ammeter directly across a voltage supply. This may cause a short circuit and damage the meter or circuit.

19.2 Using an oscilloscope

An oscilloscope is used to observe electrical waveforms.

It helps determine:

- Input waveform shape.
- Output waveform shape.
- Voltage amplitude.
- Phase relationship.
- Clipping and distortion.
- Approximate frequency and time period.

19.3 Using a signal generator

A signal generator provides a controlled AC input signal.

It can be used to:

1. Produce sine-wave signals.
2. Adjust input frequency.
3. Adjust input amplitude.
4. Test amplifier gain.
5. Investigate frequency response.

20. Troubleshooting a single-stage BJT amplifier

Troubleshooting is the process of identifying and correcting faults in an electronic circuit.

20.1 Common amplifier faults

Fault or symptom	Possible cause	Corrective action

Fault or symptom	Possible cause	Corrective action
No output signal	No DC supply	Check the power supply and connections
No output signal	Faulty transistor	Test and replace the transistor if necessary
No output signal	Open input coupling capacitor	Check and replace the capacitor
No output signal	Incorrect transistor pin connections	Verify the transistor datasheet
Very low gain	Faulty emitter bypass capacitor	Test and replace the capacitor
Very low gain	Incorrect resistor values	Measure and replace incorrect resistors
Distorted output	Incorrect Q-point	Check the biasing network
Clipped output	Excessive input amplitude	Reduce the input signal
Clipped output	Insufficient supply voltage	Check the design and supply voltage
Transistor overheating	Excessive collector current	Check the bias and circuit connections
Transistor overheating	Short circuit	Switch off the supply and inspect the circuit
Hum in output	Poor grounding	Improve grounding and connections
Unstable output	Loose connections	Secure the connections
Weak output	Excessive loading	Check the load resistance and design

20.2 Systematic troubleshooting procedure

1. Switch off the power supply before inspecting the circuit.
2. Study the circuit diagram.
3. Inspect the physical connections.
4. Check the supply voltage.
5. Check the transistor pin arrangement.
6. Measure the base, emitter and collector voltages.
7. Check the biasing resistors.
8. Test the coupling capacitors.
9. Apply a small input signal.
10. Observe the output waveform using an oscilloscope.
11. Identify the faulty component or connection.
12. Replace or correct the faulty component.
13. Repeat the test to confirm proper operation.

20.3 Safety precautions during troubleshooting

- Switch off the supply before changing connections.
- Avoid touching exposed conductors when the circuit is powered.
- Use insulated test leads.
- Do not exceed the transistor's voltage and current ratings.
- Observe capacitor polarity.
- Discharge capacitors safely before handling a circuit.

- Use the correct meter range.
- Avoid shorting adjacent breadboard connections.
- Report damaged equipment to the teacher or laboratory technician.

21. Factors affecting the performance of a single-stage amplifier

The performance of an amplifier may be affected by:

1. **Transistor current gain:** Different transistors have different current gain values.
2. **Biasing conditions:** Incorrect biasing may cause distortion or poor amplification.
3. **Supply voltage:** An unsuitable supply voltage may limit the output signal swing.
4. **Collector resistance:** Influences collector voltage changes and amplifier gain.
5. **Emitter resistance:** Affects bias stability and AC gain.
6. **Capacitor values:** Affect low-frequency response and signal coupling.
7. **Load resistance:** Influences the effective AC load and voltage gain.
8. **Temperature:** May change transistor characteristics and operating current.
9. **Input signal amplitude:** Excessive input may cause clipping.
10. **Operating frequency:** Gain varies with frequency.
11. **Component tolerance:** Actual resistor and capacitor values may differ from their marked values.
12. **Circuit layout:** Poor wiring may introduce unwanted noise and instability.

22. Advantages and limitations of single-stage BJT amplifiers

22.1 Advantages

- Simple circuit construction.
- Relatively low component cost.
- Useful voltage and current amplification.
- Suitable for learning basic analogue electronics.
- Can amplify weak electrical signals.
- Can be constructed using readily available electronic components.
- Provides a foundation for understanding multi-stage amplifiers.

22.2 Limitations

- May not provide enough gain for some applications.
- Can be affected by temperature changes.
- May produce distortion if incorrectly biased.
- Has a limited operating frequency range.
- Can be affected by noise.
- Its performance depends on transistor characteristics.
- May require additional stages to drive high-power loads.

23. Relationship between a single-stage and multi-stage amplifier

A single-stage amplifier uses one transistor amplification stage, while a multi-stage amplifier uses two or more amplification stages connected together.

Single-stage amplifier	Multi-stage amplifier
Uses one amplification stage	Uses two or more stages
Has simpler construction	Has more complex construction
Usually provides lower overall gain	Can provide higher overall gain
Easier to construct and troubleshoot	Requires more careful design and testing
Suitable for basic signal amplification	Suitable for applications requiring greater amplification

Example: A weak microphone signal may first pass through a single transistor pre-amplifier stage and then through additional stages before reaching a loudspeaker power amplifier.

REVISION QUESTIONS

SECTION A: MULTIPLE-CHOICE QUESTIONS

Instructions: Choose the correct answer from the alternatives A, B, C and D. Each question carries 1 mark.

1. What is the main function of a single-stage BJT amplifier?

A. To convert AC into DC
B. To increase the amplitude of an electrical signal
C. To store electrical energy
D. To reduce the frequency of a signal

2. Which of the following is a terminal of a bipolar junction transistor?

A. Gate
B. Drain
C. Emitter
D. Cathode

3. A bipolar junction transistor consists of:

A. Two semiconductor layers
B. Three semiconductor layers
C. Four semiconductor layers
D. Five semiconductor layers

4. Which of the following represents an NPN transistor?

A. P-type material between two N-type materials
B. N-type material between two P-type materials
C. Two P-type materials joined together
D. Two N-type materials joined together

5. Which transistor operating region is used for amplification?

A. Cut-off
B. Saturation
C. Active
D. Breakdown

6. In a common-emitter amplifier, which terminal is common to the input and output circuits?

A. Collector
B. Base
C. Emitter
D. Gate

7. Which amplifier configuration produces an output signal with approximately 180° phase reversal?

A. Common-base
B. Common-emitter
C. Common-collector
D. Emitter follower

8. Which component is mainly responsible for converting changes in collector current into output voltage changes?

A. Collector resistor
B. Input capacitor
C. Base resistor
D. Emitter bypass capacitor

9. What is the function of the input coupling capacitor?

A. To increase DC supply voltage
B. To block AC signals

C. To allow AC signals to pass while blocking DC
D. To increase collector current directly

10. Which component is connected in parallel with the emitter resistor to increase AC gain?

A. Output capacitor
B. Emitter bypass capacitor
C. Collector resistor
D. Base resistor

11. What does the symbol β represent in a common-emitter transistor?

A. Voltage gain
B. Current gain
C. Power supply voltage
D. Resistance

12. Which equation represents the relationship between emitter, collector and base currents?

A. $I_E = I_C - I_B$
B. $I_E = I_C + I_B$
C. $I_B = I_C + I_E$
D. $I_C = I_E + I_B$

13. A transistor has a collector current of 6 mA and a base current of 60 µA. Calculate its current gain.

A. 10
B. 60
C. 100
D. 600

14. Which of the following is the main function of the emitter resistor?

A. To stabilise the transistor's operating point
B. To block the input signal
C. To increase the supply voltage
D. To convert DC into AC

15. Which amplifier configuration is also known as an emitter follower?

A. Common-base
B. Common-emitter
C. Common-collector
D. Common-gate

16. Which characteristic is associated with a common-collector amplifier?

A. Low input impedance
B. High input impedance
C. High voltage gain
D. 180° phase reversal

17. Which amplifier configuration has a low input impedance and high output impedance?

A. Common-emitter
B. Common-collector

C. Common-base
D. Emitter follower

18. What is meant by the Q-point of a transistor amplifier?

A. The maximum input frequency
B. The DC operating point of the transistor
C. The maximum output power
D. The resistance of the collector

19. Which biasing method uses two resistors connected across the DC supply to establish the base voltage?

A. Fixed bias
B. Voltage-divider bias
C. Collector feedback bias
D. Reverse bias

20. What is the purpose of a DC load line?

A. To show the relationship between collector current and collector-emitter voltage
B. To measure the frequency of the input signal
C. To show the resistance of the base
D. To calculate the capacitance of the transistor

21. An amplifier has an input voltage of 0.05 V and an output voltage of 5 V. What is its voltage gain?

A. 10
B. 50
C. 100
D. 250

22. Calculate the voltage gain of an amplifier if the input voltage is 0.5 V and the output voltage is 10 V.

A. 5

B. 10

C. 20

D. 25

23. What is the main purpose of an oscilloscope when testing an amplifier?

A. To measure resistance only
B. To display electrical waveforms
C. To supply DC power
D. To store electrical energy

24. What is clipping in an amplifier?

A. An increase in supply voltage
B. A condition where part of the output waveform is cut off
C. A reduction in transistor size
D. A method of connecting resistors

25. Which of the following may cause an amplifier to produce no output signal?

A. Correct transistor biasing
B. A faulty input coupling capacitor
C. A suitable DC supply
D. Correct component connections

26. Which instrument is used to provide a controlled AC input signal when testing an amplifier?

A. Signal generator
B. Soldering iron
C. Wire stripper
D. Screwdriver

27. What is the unit of bandwidth?

A. Ohm
B. Ampere
C. Hertz
D. Volt

28. Which of the following is a possible cause of transistor overheating?

A. Correct biasing
B. Excessive collector current
C. Suitable supply voltage
D. Proper component selection

29. Which of the following is an application of a single-stage BJT amplifier?

A. Amplifying weak microphone signals
B. Measuring room temperature directly
C. Storing water
D. Generating mechanical energy

30. Why should the transistor datasheet be checked before constructing an amplifier?

A. To determine the colour of the breadboard
B. To identify transistor terminals and operating ratings
C. To increase the size of the transistor
D. To change the type of electrical supply

SECTION B: STRUCTURED QUESTIONS

Instructions: Answer all questions. Show all working in calculation questions. Total: 50 marks.

Question 1: Introduction to BJT amplifiers (8 marks)

a) Define a bipolar junction transistor. (2 marks)

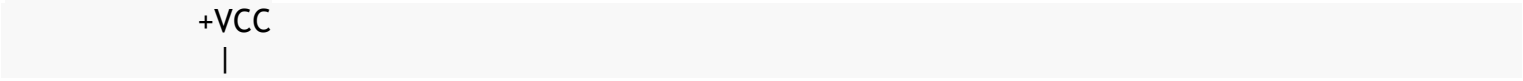
b) State the three terminals of a BJT. (3 marks)

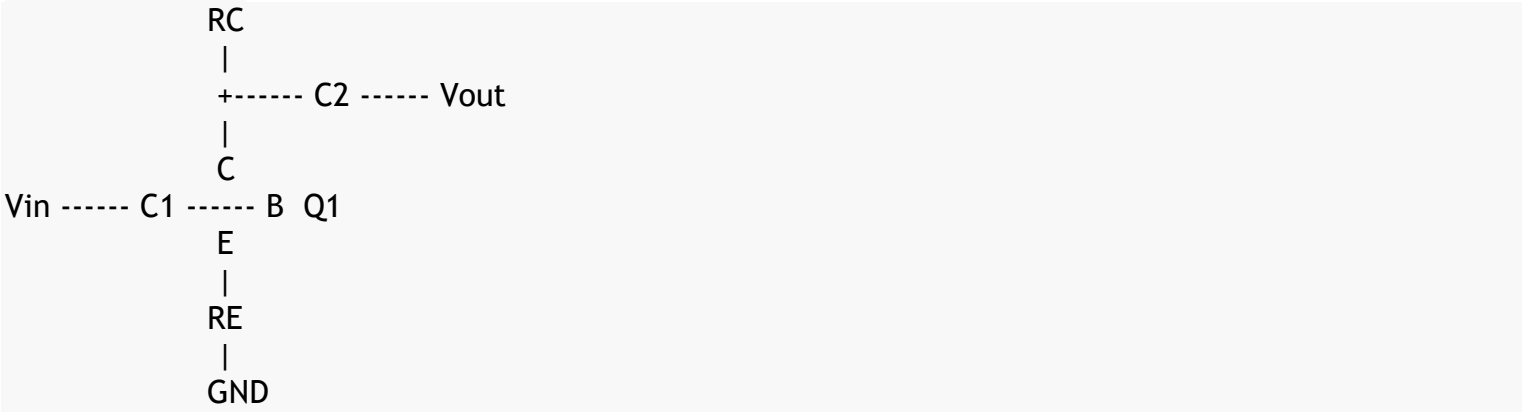
c) Distinguish between an NPN transistor and a PNP transistor. (2 marks)

d) State one application of a BJT amplifier in everyday life. (1 mark)

Question 2: Common-emitter amplifier (8 marks)

Study the simplified common-emitter amplifier arrangement shown below.





a) Identify the amplifier configuration shown. (1 mark)

b) State the function of each of the following components:

ii. R_C (1 mark)

iii. R_E (1 mark)

iv. C_1 (1 mark)

v. C_2 (1 mark)

c) Explain how amplification takes place in the common-emitter circuit. (2 marks)

d) State the phase relationship between the input and output signals. (1 mark)

Question 3: Transistor current and gain calculations (8 marks)

a) A transistor has a base current of 50 μA and a collector current of 5 mA.

Calculate its common-emitter current gain. (3 marks)

b) A transistor has a collector current of 12 mA and a base current of 0.12 mA.

Calculate the emitter current. (2 marks)

c) An amplifier receives an input voltage of 25 mV and produces an output voltage of 2.5 V.

Calculate the voltage gain. (3 marks)

Question 4: Biasing and load lines (8 marks)

a) Define transistor biasing. (2 marks)

b) State three reasons why correct biasing is important in a BJT amplifier. (3 marks)

c) A common-emitter amplifier has a DC supply voltage of 15 V and a collector resistor of 1.5 kΩ.

Calculate:

vi. The collector-emitter voltage at cut-off. (1 mark)

vii. The approximate collector current at saturation, assuming $V_{CE} \approx 0V$. (2 marks)

Question 5: Amplifier configurations and performance (9 marks)

a) Name the three main BJT amplifier configurations. (3 marks)

b) State one characteristic of each of the following:

i. Common-emitter amplifier. (1 mark)

ii. Common-collector amplifier. (1 mark)

iii. Common-base amplifier. (1 mark)

c) An amplifier has a lower cut-off frequency of 200 Hz and an upper cut-off frequency of 15 kHz.

Calculate its bandwidth. (3 marks)

Question 6: Construction, testing and troubleshooting (9 marks)

a) State three tools or instruments used when constructing and testing a single-stage BJT amplifier. (3 marks)

b) Explain three steps followed when constructing a single-stage amplifier on a breadboard. (3 marks)

c) State three possible causes of a distorted output signal in a common-emitter amplifier. (3 marks)

practical project

Project title: Construction and testing of a single-stage common-emitter BJT amplifier.

Task: Working in groups, construct a single-stage common-emitter amplifier using a suitable transistor, resistors, capacitors, a breadboard and a DC power supply.

Expected outcomes:

13. A correctly assembled amplifier circuit.
14. A labelled circuit diagram.
15. Measured DC voltages at the base, emitter and collector.
16. Observed input and output waveforms.
17. Calculated voltage gain.
18. An explanation of the phase reversal.
19. A brief report describing faults encountered and how they were corrected.

Project assessment rubric

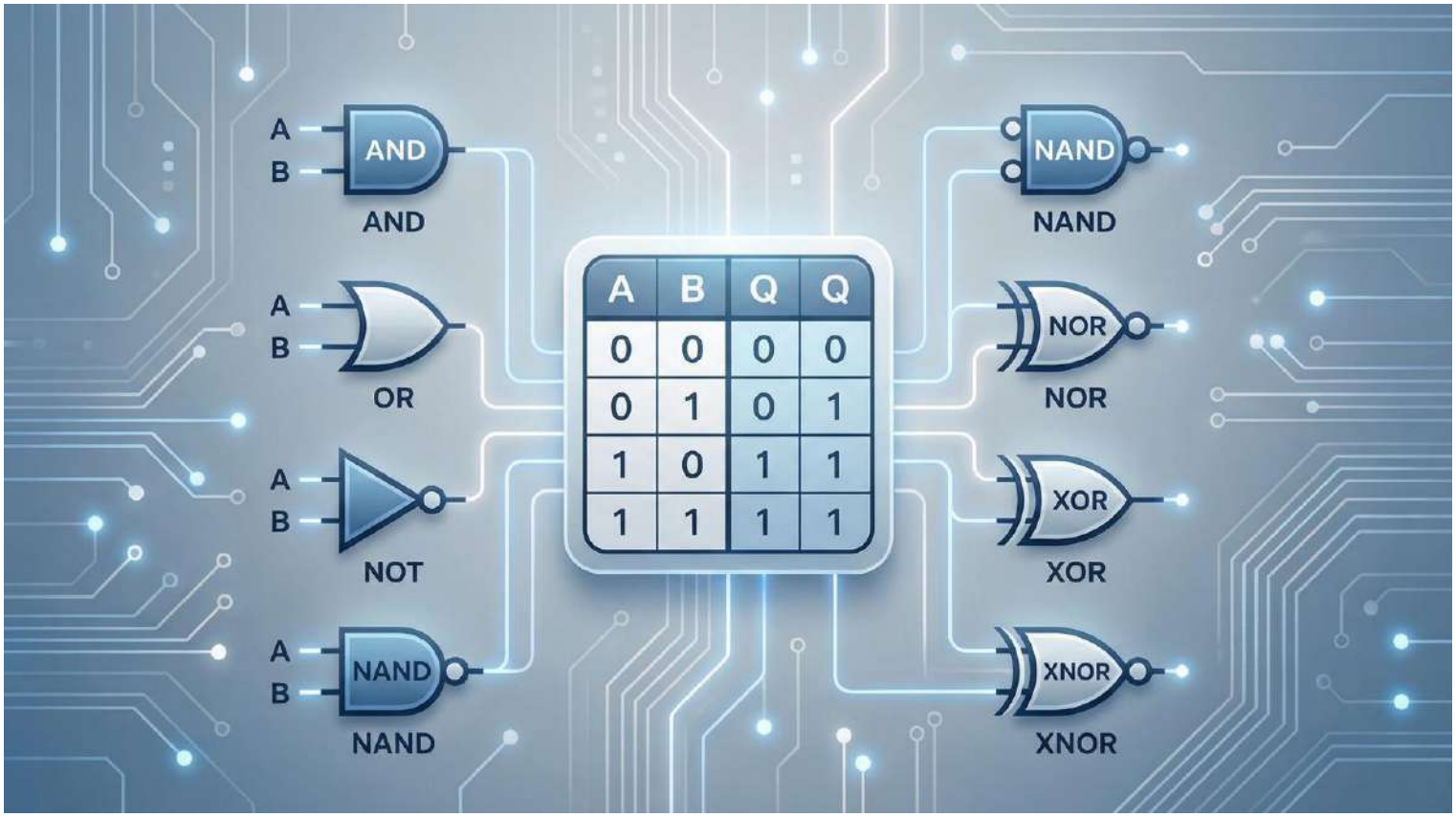
Assessment area	Marks
Correct interpretation of circuit diagram	4
Appropriate component selection	4
Correct circuit construction	6
Safe handling of tools and equipment	4
Correct testing and measurements	4
Accurate calculations and observations	4
Explanation of circuit operation	4
Teamwork and presentation	2
Total	**32**

Teacher's note: Actual amplifier construction should follow the selected transistor's datasheet and the approved circuit design. Learners should use a current-limited, low-voltage DC supply during practical work and should not connect an experimental breadboard amplifier directly to mains electricity.

STRAND 4.0: ELECTRONICS

SUB-STRAND 4.3: INTRODUCTION TO DIGITAL ELECTRONICS

COMPREHENSIVE TEACHING AND LEARNING NOTES | COMPETENCY-BASED EDUCATION (CBE) | KENYA



1.0 Introduction to Digital Electronics

1.1 Meaning of Digital Electronics

Digital electronics is a branch of electronics that deals with the processing, storage, transmission and control of information using discrete signal levels, usually represented by binary digits (0 and 1).

Digital electronic systems use electronic components such as logic gates, transistors, integrated circuits, microprocessors and digital memory devices to process information.

Unlike analogue electronics, which uses continuously varying signals, digital electronics represents information using distinct levels or states.

Examples of digital electronic devices:

1. Digital clocks and watches.
2. Calculators.
3. Mobile phones.
4. Computers and laptops.
5. Digital television receivers.
6. Electronic voting equipment.
7. Digital thermometers.
8. Electronic calculators.
9. Digital measuring instruments.
10. Programmable logic controllers (PLCs).
11. Automated control systems.
12. Electronic security systems.

1.2 Meaning of an Analogue Signal

An **analogue signal** is an electrical signal whose magnitude varies continuously with time and can take any value within a given range.

The signal represents information through continuously changing quantities such as voltage or current.

Examples of analogue signals:

1. Sound signals produced by a microphone.
2. Temperature changes represented by a suitable analogue sensor.
3. Radio signals before digital processing.
4. Voltage produced by some light sensors.
5. Electrical signals from analogue pressure sensors.
6. Signals from traditional analogue audio equipment.

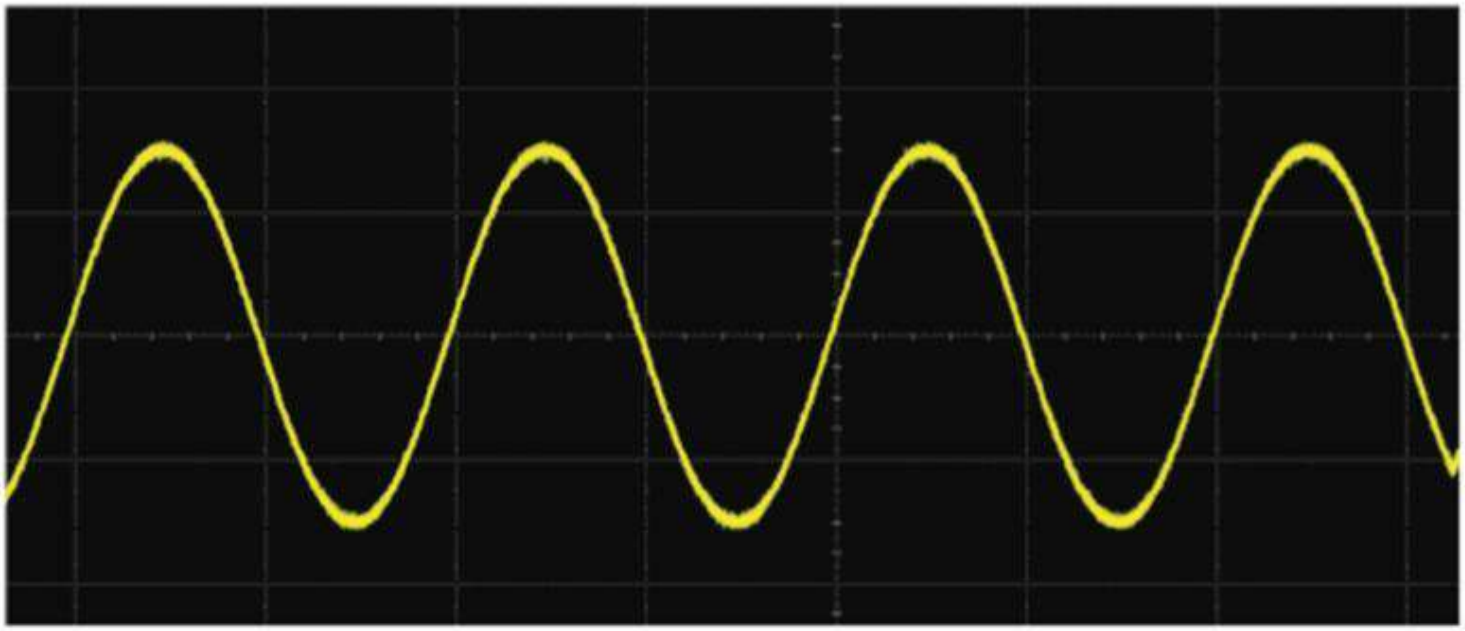


Figure 3. A sine wave.

Characteristics of analogue signals:

1. They vary continuously with time.
2. They can take an unlimited number of values within a specified range in theory.
3. They can represent naturally varying physical quantities.
4. They are susceptible to noise and interference.
5. Their quality may deteriorate during transmission or repeated copying.
6. They can be processed using analogue electronic circuits.
7. Their voltage or current magnitude carries the information.

Example:

A temperature sensor may produce an analogue voltage that increases gradually as temperature rises. If the temperature changes from 20°C to 30°C, the sensor voltage may also change continuously over its operating range.

1.3 Meaning of a Digital Signal

A **digital signal** is an electrical signal that represents information using a limited number of distinct values or states.

In ordinary binary digital electronics, the two states are:

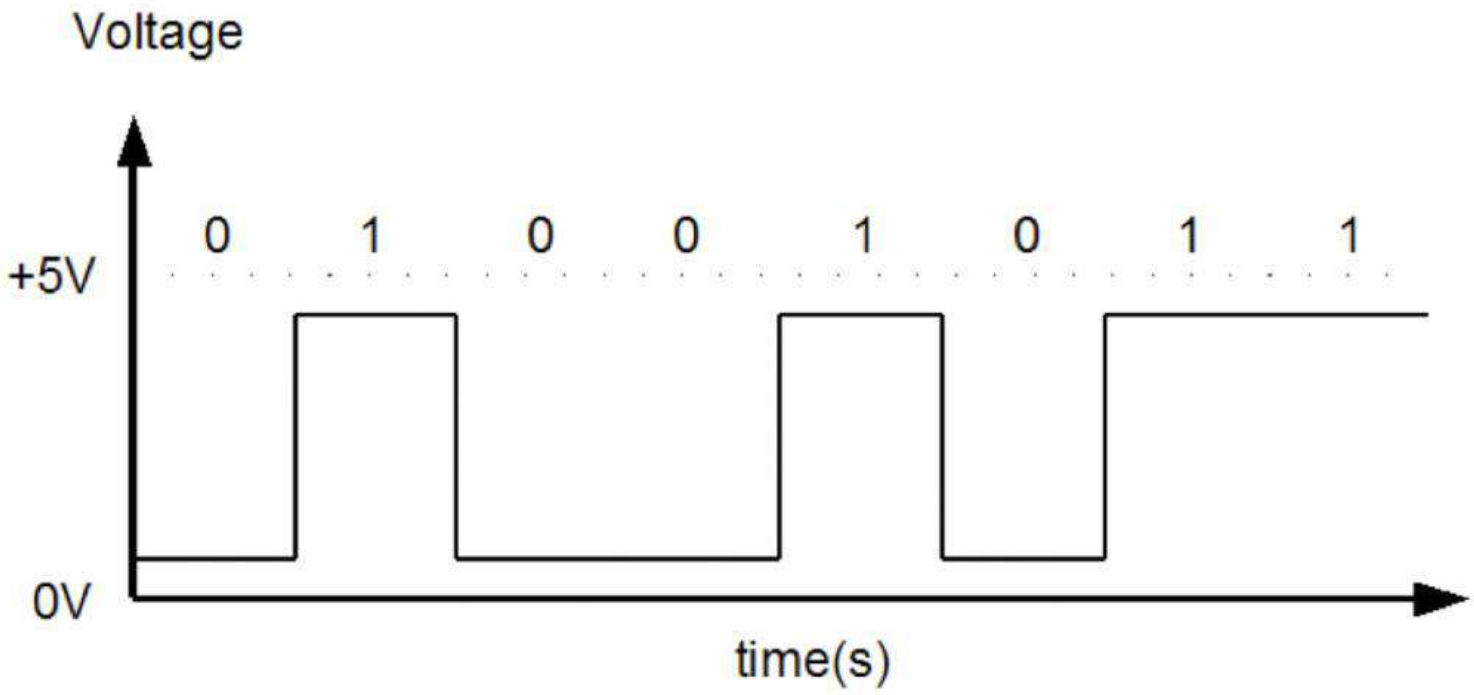
- Logic 1 – represents the HIGH state.
- Logic 0 – represents the LOW state.

The two states are represented by voltage ranges determined by the electronic logic family and device specifications.

For a simple illustrative 5 V logic system:

- Logic 1 may be represented by a voltage close to 5 V.
- Logic 0 may be represented by a voltage close to 0 V.

The actual voltage ranges recognised as HIGH and LOW depend on the integrated circuit being used.



Characteristics of digital signals:

1. They use discrete signal levels.
2. Binary systems commonly use two states: 0 and 1.
3. They are suitable for computer-based processing.
4. They can be stored in digital memory.
5. They are generally more resistant to small amounts of noise when the signal remains within valid logic limits.
6. They can be processed by logic gates and microprocessors.
7. They are widely used in modern communication and control systems.

1.4 Difference Between Analogue and Digital Signals

Analogue signals	Digital signals
Vary continuously	Use discrete levels
Can take many values within a range	Use a limited number of defined states
Commonly represented by smooth waveforms	Commonly represented by square waveforms
More affected by accumulated noise during transmission	Can tolerate some noise within valid logic margins
Used in traditional analogue audio systems	Used in computers and digital devices
Information is represented by signal magnitude	Information is represented by coded digital values
May be processed by analogue circuits	Processed using logic gates and digital circuits

1.5 Advantages of Analogue Systems

1. **Continuous representation:** They can represent naturally varying quantities such as sound, temperature and pressure.
2. **Simple circuit design in some applications:** Certain analogue functions can be implemented using relatively simple circuits.
3. **Real-time response:** Analogue circuits can respond directly to changing input signals without requiring digital conversion.
4. **High resolution in principle:** An analogue signal is not restricted to a fixed number of digital steps, although practical accuracy is limited by noise and component characteristics.
5. **Useful in sensor interfaces:** Many physical sensors naturally produce analogue signals.

1.6 Disadvantages of Analogue Systems

1. They are more susceptible to electrical noise and interference.
2. Signal quality may deteriorate during long-distance transmission.
3. Repeated copying may introduce additional noise.
4. Analogue information may be difficult to store and reproduce accurately.
5. Precise processing may require careful component adjustment.
6. Component ageing and temperature changes can affect circuit performance.

1.7 Advantages of Digital Systems

1. **Noise resistance:** Digital circuits can tolerate a certain amount of noise without changing the recognised logic state.
2. **Easy storage:** Digital information can be stored in memory devices.
3. **Easy processing:** Digital information can be processed using logic gates and programmable devices.

4. **Reliable transmission:** Digital information can be transmitted using techniques that detect or correct errors.
5. **Reproducibility:** Digital data can be copied repeatedly without the gradual quality loss associated with many analogue copying processes.
6. **Programmability:** Digital systems can be programmed to perform different tasks.
7. **Compact design:** Integrated circuits allow many digital components to be placed on small semiconductor chips.
8. **Automation:** Digital systems can control machines and electronic processes automatically.
9. **Security:** Digital data can be encrypted and protected using suitable techniques.
10. **Versatility:** The same digital hardware can perform different functions through software changes.

1.8 Disadvantages of Digital Systems

1. They often require analogue-to-digital conversion when receiving real-world analogue information.
2. They require suitable digital processing hardware.
3. Quantisation may introduce small errors when analogue signals are converted into digital form.
4. Some digital circuits require stable clock signals.
5. Digital systems may be affected by electromagnetic interference and timing errors.
6. They may require specialised knowledge to design and troubleshoot.
7. They depend on electrical power to operate.
8. Digital devices may become obsolete as technology advances.

1.9 Applications of Digital Electronics in Kenya

Digital electronics is widely used in Kenyan homes, schools, industries, hospitals, businesses and public services.

1. **Education:** Computers, digital projectors, electronic learning platforms and digital examination systems.
2. **Banking:** Automated teller machines (ATMs), point-of-sale terminals and mobile banking equipment.
3. **Communication:** Smartphones, routers, digital television receivers and communication networks.
4. **Healthcare:** Digital patient monitors, electronic thermometers and medical diagnostic equipment.
5. **Transport:** Electronic ticketing, traffic control systems and vehicle monitoring equipment.
6. **Agriculture:** Digital irrigation controllers, soil monitoring systems and automated greenhouse equipment.
7. **Security:** CCTV systems, electronic access control and alarm systems.
8. **Industry:** Programmable logic controllers, automated production systems and digital measuring instruments.
9. **Commerce:** Electronic weighing scales, barcode scanners and electronic payment systems.
10. **Energy:** Digital electricity meters, solar charge controllers and electronic inverter systems.

2.0 Binary Number System

2.1 Meaning of a Number System

A **number system** is a method of representing numbers using a set of symbols or digits according to specific rules and a particular base.

Different number systems are used in mathematics, computing and digital electronics.

Common number systems include:

1. Decimal number system.
2. Binary number system.
3. Octal number system.
4. Hexadecimal number system.

2.2 Meaning of the Binary Number System

The **binary number system** is a number system that uses only two digits, namely 0 and 1.

It is the fundamental number system used in digital electronics and computer systems.

The binary system has a base of 2.

Binary digits are called bits.

Examples of binary numbers:

- 0
- 1
- 10
- 11
- 101
- 1101
- 10110
- 110011

2.3 Why Digital Electronics Uses the Binary Number System

Digital electronic circuits commonly use binary because electronic components can be designed to operate in two distinguishable states.

For example:

1. A transistor may be used as an electronic switch that is either ON or OFF.
2. A logic circuit may recognise a LOW voltage range as logic 0.
3. The same circuit may recognise a HIGH voltage range as logic 1.
4. These two states can represent binary information.
5. Large amounts of information can be represented by combining many bits.

The notes below have been rewritten neatly from the supplied material. The original topics and examples have been retained, with mathematical expressions, tables and calculations arranged clearly.

2.3 Examples of Binary State Representation

In digital electronics, information is represented using two binary states: **0 and 1**.

Electronic condition	Binary representation
Switch OFF	0
Switch ON	1
Logic LOW	0
Logic HIGH	1
No signal state in a simple binary example	0
Signal state in a simple binary example	1

Note: Logic 0 does not always mean that a circuit has absolutely zero voltage. Similarly, logic 1 does not always mean exactly 5 V. Logic states are defined by specified voltage ranges.

2.4 Place Values in the Binary Number System

The binary number system uses powers of 2.

Starting from the right-hand side, the place values are:

$$2^0,\ 2^1,\ 2^2,\ 2^3,\ 2^4,\ 2^5, \ldots$$

These correspond to the following values:

Position from the right	Power	Place value
1st	2^0	1
2nd	2^1	2
3rd	2^2	4
4th	2^3	8
5th	2^4	16
6th	2^5	32
7th	2^6	64
8th	2^7	128

2.5 Binary Place Value Example

Example: Convert the binary number 1011_2 into decimal.

Write the place values below each digit:

Binary digit	1	0	1	1
Place value	8	4	2	1
Product	8	0	2	1

Add the products:

$$8 + 0 + 2 + 1 = 11$$

Therefore:

$$\boxed{1011_2 = 11_{10}}$$

3.0 DECIMAL NUMBER SYSTEM

3.1 Meaning of the Decimal Number System

The decimal number system is a number system that uses ten digits, namely:

$$0,1,2,3,4,5,6,7,8,9$$

It has a **base of 10** and is the number system commonly used in everyday counting and calculations.

3.2 Place Values in the Decimal System

The decimal system uses powers of 10.

Position from the right	Power	Place value
1st	10^0	1
2nd	10^1	10
3rd	10^2	100
4th	10^3	1,000
5th	10^4	10,000

3.3 Example of Decimal Place Value

Example: Express the decimal number 3527 in expanded form.

The expanded form is:

$$(3 \times 1000) + (5 \times 100) + (2 \times 10) + (7 \times 1)$$

$$= 3000 + 500 + 20 + 7$$

$$\boxed{= 3527}$$

3.4 Comparison Between Binary and Decimal Number Systems

Feature	Binary system	Decimal system
Base	2	10
Number of digits	2	10
Digits used	0 and 1	0 to 9
Place values	Powers of 2	Powers of 10
Main application	Digital electronics and computing	Everyday counting and arithmetic
Smallest place value	$2^0 = 1$	$10^0 = 1$

4.0 CONVERSION OF BINARY NUMBERS TO DECIMAL NUMBERS

4.1 Meaning of Binary-to-Decimal Conversion

Binary-to-decimal conversion is the process of changing a number written in base 2 into its equivalent value in base 10.

The process involves multiplying each binary digit by its corresponding power of 2 and adding the results.

4.2 Steps for Converting Binary to Decimal

1. Write the binary number.
2. Identify the place values from right to left.
3. Start with 2^0 at the rightmost position.
4. Multiply each binary digit by its corresponding place value.
5. Add all the products.
6. Write the answer in decimal notation.

4.3 Worked Example 1

Convert 1010_2 into decimal.

Step 1: Write the binary number and place values.

Digit	1	0	1	0
Place value	8	4	2	1
Product	8	0	2	0

Step 2: Add the products.

$$8 + 0 + 2 + 0 = 10$$

Therefore:

$$\boxed{1010_2 = 10_{10}}$$

4.4 Worked Example 2

Convert 11001_2 into decimal.

Digit	1	1	0	0	1
Place value	16	8	4	2	1
Product	16	8	0	0	1

Add the products:

$$16 + 8 + 0 + 0 + 1 = 25$$

Therefore:

$$\boxed{11001_2 = 25_{10}}$$

4.5 Worked Example 3

Convert 101101_2 into decimal.

Expand the binary number using its place values:

$$= (1 \times 32) + (0 \times 16) + (1 \times 8)$$

$$+(1 \times 4) + (0 \times 2) + (1 \times 1)$$

Evaluate:

$$= 32 + 0 + 8 + 4 + 0 + 1$$

$$= 45$$

Therefore:

$$\boxed{101101_2 = 45_{10}}$$

4.6 Practice Examples

Convert the following binary numbers into decimal numbers:

1. 101_2
2. 111_2
3. 1001_2
4. 1110_2
5. 10101_2
6. 11010_2
7. 100111_2
8. 111111_2

5.0 CONVERSION OF DECIMAL NUMBERS TO BINARY NUMBERS

5.1 Meaning of Decimal-to-Binary Conversion

Decimal-to-binary conversion is the process of changing a number from base 10 into its equivalent representation in base 2.

One common method used is **repeated division by 2**.

5.2 Steps for Converting Decimal to Binary Using Repeated Division

1. Divide the decimal number by 2.
2. Record the remainder.
3. Divide the quotient by 2 again.
4. Continue dividing by 2 until the quotient becomes zero.
5. Read the remainders from bottom to top.
6. The resulting digits form the binary equivalent.

5.3 Worked Example 1

Convert 13_{10} into binary.

Divide repeatedly by 2:

Division	Quotient	Remainder
$13 \div 2$	6	1
$6 \div 2$	3	0
$3 \div 2$	1	1
$1 \div 2$	0	1

Read the remainders from bottom to top:

$$1101$$

Therefore:

$$\boxed{13_{10} = 1101_2}$$

5.4 Worked Example 2

Convert 25_{10} into binary.

Division	Quotient	Remainder
$25 \div 2$	12	1
$12 \div 2$	6	0
$6 \div 2$	3	0
$3 \div 2$	1	1
$1 \div 2$	0	1

Reading the remainders from bottom to top gives:

$$11001$$

Therefore:

$$\boxed{25_{10} = 11001_2}$$

5.5 Worked Example 3

Convert 45_{10} into binary.

Division	Quotient	Remainder
$45 \div 2$	22	1
$22 \div 2$	11	0
$11 \div 2$	5	1
$5 \div 2$	2	1
$2 \div 2$	1	0
$1 \div 2$	0	1

Read the remainders from bottom to top:

$$101101$$

Therefore:

$$\boxed{45_{10} = 101101_2}$$

5.6 Conversion Using Powers of Two

Decimal numbers can also be converted into binary by expressing them as a sum of powers of 2.

Example: Convert 19_{10} into binary.

The powers of 2 are:

$$16,\ 8,\ 4,\ 2,\ 1$$

Express 19 as a sum:

$$19 = 16 + 2 + 1$$

Write 1 where a place value is used and 0 where it is not used.

Place value	16	8	4	2	1

Place value	16	8	4	2	1
Binary digit	1	0	0	1	1

Therefore:

$$\boxed{19_{10} = 10011_2}$$

6.0 BINARY CODED DECIMAL (BCD)

6.1 Meaning of Binary Coded Decimal

Binary Coded Decimal (BCD) is a coding system in which each decimal digit is represented separately using its four-bit binary equivalent.

In the commonly taught **8421 BCD system**, each decimal digit is represented using four binary bits with place weights of 8, 4, 2 and 1.

Unlike ordinary binary representation, BCD encodes each decimal digit separately.

6.2 BCD Coding Table

Decimal digit	BCD code
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001

Note: The four-bit patterns from 1010 to 1111 are not valid digit codes in standard 8421 BCD.

6.3 Conversion of Decimal Numbers to BCD

To convert a decimal number into BCD:

1. Separate the decimal number into individual digits.
2. Convert each digit into its four-bit BCD equivalent.
3. Join the groups together in the same order.

Worked Example 1: Convert 25 into BCD.

Separate the digits:

- 2
- 5

From the BCD table:

- 2 = 0010
- 5 = 0101

Therefore:

$$\boxed{25_{10} = 0010\ 0101_{BCD}}$$

Worked Example 2: Convert 347 into BCD.

Separate the digits and convert each one:

- 3 = 0011
- 4 = 0100
- 7 = 0111

Therefore:

$$\boxed{347_{10} = 0011\ 0100\ 0111_{BCD}}$$

6.4 Conversion of BCD to Decimal

To convert BCD into decimal:

4. Divide the binary code into groups of four bits, starting from the right.
5. Convert each group into its decimal equivalent.
6. Combine the decimal digits in their original order.

Worked Example: Convert $0101\ 1001_{BCD}$ into decimal.

Separate into groups:

- 0101 = 5
- 1001 = 9

Therefore:

$$\boxed{0101\ 1001_{BCD} = 59_{10}}$$

6.5 Difference Between Ordinary Binary and BCD

Consider the decimal number 25.

Ordinary binary conversion:

$$25_{10} = 11001_2$$

BCD conversion:

- 2 = 0010
- 5 = 0101

Therefore:

$$25_{10} = 0010\ 0101_{BCD}$$

Comparison:

Feature	Ordinary binary	BCD
Method	Represents the entire number as a binary value	Represents each decimal digit separately
Bits per decimal digit	Varies	Four bits per digit
Example for decimal 25	11001	0010 0101

Feature	Ordinary binary	BCD
Storage requirement	Usually more compact	May require more bits
Applications	General digital processing	Digital displays, calculators and decimal counters

6.6 Applications of BCD

BCD is used in:

1. Digital clocks.
2. Electronic calculators.
3. Digital weighing scales.
4. Digital measuring instruments.
5. Electronic counters.
6. Industrial display systems.
7. Digital panel meters.
8. Some point-of-sale and accounting equipment.

7.0 BINARY ARITHMETIC

Binary arithmetic refers to mathematical operations performed using binary numbers.

The basic binary arithmetic operations include:

1. Binary addition.
2. Binary subtraction.
3. One's complement.
4. Two's complement.

These operations are important in digital computers, calculators, microprocessors and other digital electronic systems.

7.1 Binary Addition

Binary addition is the process of adding binary numbers using the rules of the binary number system.

Since binary uses only 0 and 1, addition follows four basic rules.

Rules of Binary Addition

Operation	Answer
0 + 0	0
0 + 1	1
1 + 0	1
1 + 1	10

The expression:

$$1 + 1 = 10_2$$

means that the answer is zero in the current column, with a carry of 1 to the next column.

Important Binary Addition Rules

5. Add the digits starting from the rightmost column.
6. Write the result digit in the current column.

7. Carry any extra value to the next column.
8. Continue until all columns have been added.
9. Include any final carry in the answer.

Worked Example 1: Add 101_2 and 010_2.

Arrange the numbers vertically:

```
  101
+ 010

---

  111
```

Therefore:

$$101_2 + 010_2 = 111_2$$

Verification in decimal:

$$5 + 2 = 7$$

And:

$$111_2 = 7_{10}$$

Worked Example 2: Add 1011_2 and 0110_2.

Arrange the numbers vertically:

```
   1 1 1
    1011
  + 0110

---

   10001
```

Step-by-step working:

10. Rightmost column: $1 + 0 = 1$.
11. Second column: $1 + 1 = 10_2$. Write 0 and carry 1.
12. Third column: $0 + 1 + 1 = 10_2$. Write 0 and carry 1.
13. Fourth column: $1 + 0 + 1 = 10_2$. Write 0 and carry 1.
14. Write the final carry.

Therefore:

$$\boxed{1011_2 + 0110_2 = 10001_2}$$

Verification:

$$11 + 6 = 17$$

$$10001_2 = 17_{10}$$

Worked Example 3: Add 1101_2 and 1011_2.

Arrange the numbers vertically:

```
  1 1 1
   1101
 + 1011

---

  11000
```

Therefore:

$$\boxed{1101_2 + 1011_2 = 11000_2}$$

Verification:

$$13 + 11 = 24$$

$$11000_2 = 24_{10}$$

7.2 Binary Subtraction

Binary subtraction is the process of finding the difference between two binary numbers.

Rules of Binary Subtraction

Operation	Answer
0 – 0	0
1 – 0	1
1 – 1	0
0 – 1	1, after borrowing

When subtracting 1 from 0, borrowing is required from the next column to the left.

In binary, borrowing 1 from the next column gives a value of 10_2 in the current column.

Worked Example 1: Subtract 0011_2 from 0111_2.

Arrange the numbers vertically:

```
  0111
- 0011

---

  0100
```

Therefore:

$$\boxed{0111_2 - 0011_2 = 0100_2}$$

Verification:

$$7 - 3 = 4$$

Worked Example 2: Subtract 0101_2 from 1100_2.

Arrange the numbers vertically:

```
  1100
```

```
  - 0101
---
    0111
```

Therefore:

$$\boxed{1100_2 - 0101_2 = 0111_2}$$

Verification:

$$12 - 5 = 7$$

Worked Example 3: Subtract 0011_2 from 1000_2.

Arrange the numbers vertically:

```
    1000
  - 0011
---
    0101
```

Therefore:

$$\boxed{1000_2 - 0011_2 = 0101_2}$$

Verification:

$$8 - 3 = 5$$

7.3 One's Complement

One's complement is a method of representing a binary number by changing every 0 into 1 and every 1 into 0.

It is obtained by inverting all the bits of a binary number.

Rules for Finding One's Complement

- Change 0 to 1.
- Change 1 to 0.

Worked Example 1

Find the one's complement of 10110010_2.

Change each bit:

Original bit	1	0	1	1	0	0	1	0
Complement	0	1	0	0	1	1	0	1

Therefore:

$$\boxed{10110010_2 = 01001101_2}$$

The one's complement is 01001101_2.

Worked Example 2

Find the one's complement of 11001100_2.

Change every bit:

$$11001100 \rightarrow 00110011$$

Therefore, the one's complement is:

$$\boxed{00110011_2}$$

7.4 Applications of One's Complement

One's complement is used in:

15. Some methods of representing signed binary numbers.
16. Explaining binary subtraction techniques.
17. Understanding negative number representation in digital systems.
18. Learning two's complement.

7.5 Two's Complement

Two's complement is a method of representing signed binary numbers and performing subtraction using binary addition.

It is obtained by taking the one's complement of a binary number and adding 1 to the result.

Steps for Finding Two's Complement

19. Write the binary number using a fixed number of bits.
20. Find its one's complement by inverting all the bits.
21. Add 1 to the complemented number.
22. The result is the two's complement.

Worked Example 1

Find the two's complement of 00000101_2.

Step 1: Write the original number.

$$00000101$$

Step 2: Find the one's complement.

Invert all the bits:

$$00000101 \rightarrow 11111010$$

Step 3: Add 1.

```
  11111010
+ 00000001

---

  11111011
```

Therefore:

$$\boxed{\text{Two's complement} = 11111011_2}$$

Worked Example 2

Find the two's complement of 00101100_2.

Step 1: Write the original number.

$$00101100$$

Step 2: Find the one's complement.

$$00101100 \rightarrow 11010011$$

Step 3: Add 1.

```
  11010011
+ 00000001

---

  11010100
```

Therefore:

$$\boxed{\text{Two's complement} = 11010100_2}$$

7.6 Using Two's Complement to Perform Binary Subtraction

Binary subtraction can be carried out by adding the two's complement of the number being subtracted.

General Procedure

23. Write the two binary numbers using the same number of bits.
24. Find the two's complement of the number to be subtracted.
25. Add the two's complement to the first number.
26. Discard the final carry if it occurs in a fixed-width calculation.
27. Interpret the result according to the chosen signed-number representation.

Worked Example: Calculate $9 - 5$ Using Two's Complement.

Step 1: Write the numbers as 8-bit binary values.

$$9_{10} = 00001001_2$$

$$5_{10} = 00000101_2$$

Step 2: Find the two's complement of 5.

First, find the one's complement:

$$00000101 \rightarrow 11111010$$

Add 1:

```
  11111010
+ 00000001

---

  11111011
```

Therefore, the two's complement of 5 is:

$$11111011_2$$

Step 3: Add the two's complement to 9.

```
  00001001
+ 11111011

---

 1 00000100
```

Step 4: Discard the final carry.

$$00000100_2$$

Step 5: Convert the answer into decimal.

$$00000100_2 = 4_{10}$$

Therefore:

$$\boxed{9 - 5 = 4}$$

7.7 Comparison Between One's Complement and Two's Complement

One's complement	Two's complement
Obtained by inverting all bits.	Obtained by inverting all bits and adding 1.
Changes 0 to 1 and 1 to 0.	Uses one's complement followed by addition of 1.
Has two representations of zero in conventional signed representation.	Has one representation of zero.
Less commonly used for general signed integer arithmetic in modern processors.	Widely used in modern digital computers and processors.

7.8 Importance of Binary Arithmetic in Digital Electronics

Binary arithmetic is important in digital electronics because it:

1. Enables digital computers to perform calculations.
2. Supports arithmetic operations in microprocessors.
3. Helps in processing numerical information.
4. Supports data manipulation and storage.
5. Enables digital calculators to perform mathematical operations.
6. Supports the operation of digital control systems.
7. Helps in understanding computer number representation.

SUMMARY OF IMPORTANT CONCEPTS

Concept	Meaning
Binary number system	A base-2 number system using 0 and 1.
Decimal number system	A base-10 number system using digits 0–9.
Binary-to-decimal conversion	Changing a base-2 number into base 10.
Decimal-to-binary conversion	Changing a base-10 number into base 2.
BCD	Representing each decimal digit separately using four bits.
Binary addition	Adding binary numbers using binary addition rules.

Concept	Meaning
Binary subtraction	Subtracting binary numbers using borrowing or complements.
One's complement	Inverting every bit in a binary number.
Two's complement	Finding one's complement and adding 1.

Important Rules to Remember

1. Binary uses only two digits: 0 and 1.
2. Binary has a base of 2.
3. Decimal has a base of 10.
4. Binary place values are powers of 2.
5. Decimal place values are powers of 10.
6. To convert binary to decimal, multiply each digit by its place value and add.
7. To convert decimal to binary using repeated division, read the remainders from bottom to top.
8. In BCD, each decimal digit is represented by four bits.
9. In binary addition, $1 + 1 = 10_2$.
10. One's complement is obtained by inverting all bits.
11. Two's complement is obtained by inverting all bits and adding 1.

8.0 Logic States in Digital Electronics

8.1 Meaning of a Logic State

A **logic state** is one of the two basic binary conditions used to represent information in a digital circuit.

In ordinary binary logic, the two states are:

1. Logic 1 – HIGH state.
2. Logic 0 – LOW state.

A logic state is represented by a voltage level within the recognised input or output range of a digital electronic device.

8.2 Logic 1 (HIGH State)

Logic 1 represents the HIGH state in a digital circuit.

In an illustrative 5 V logic circuit, logic 1 may be represented by a voltage close to +5 V.

Characteristics:

1. Represents binary digit 1.
2. Commonly associated with a HIGH voltage level.
3. Can represent the ON state in a simple switching demonstration.
4. May indicate an active condition in a digital circuit.
5. Is used by logic gates to represent a TRUE condition in positive logic.

8.3 Logic 0 (LOW State)

Logic 0 represents the LOW state in a digital circuit.

In an illustrative 5 V logic circuit, logic 0 may be represented by a voltage close to 0 V.

Characteristics:

1. Represents binary digit 0.
2. Commonly associated with a LOW voltage level.
3. Can represent the OFF state in a simple switching demonstration.
4. May indicate an inactive condition in a digital circuit.
5. Is used by logic gates to represent a FALSE condition in positive logic.

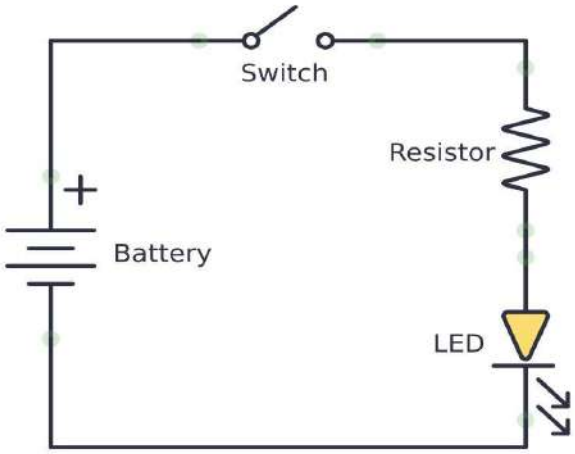
8.4 Relationship Between Binary Digits and Logic States

Binary digit	Logic state	Illustrative voltage in a simple 5 V system
0	LOW	Approximately 0 V
1	HIGH	Approximately 5 V

Important: The exact HIGH and LOW voltage limits depend on the logic family and integrated circuit. Modern digital systems may use 3.3 V, 1.8 V or other logic voltage levels. A voltage between the recognised LOW and HIGH ranges may be undefined and should not be treated as a valid logic state.

8.5 Demonstrating Logic States Using a Switch and Bulb

A simple low-voltage circuit can demonstrate the relationship between switching states and binary values.



Procedure:

1. Obtain a suitable low-voltage DC source, LED, current-limiting resistor and switch.
2. Connect the components in a simple series circuit.
3. Open the switch.
4. Observe that the LED is OFF.
5. Close the switch.
6. Observe that the LED is ON.
7. Relate the two conditions to the binary states 0 and 1 in the demonstration.

Switch condition	LED condition	Demonstration state

Open	OFF	0
Closed	ON	1

This is a simple representation of two possible states. A real logic circuit uses specified voltage levels and input/output thresholds rather than relying only on a physical switch and bulb.

9.0 Logic Gates

9.1 Meaning of a Logic Gate

A **logic gate** is an electronic circuit that performs a logical operation on one or more binary inputs to produce a single binary output.

Logic gates are the basic building blocks of digital electronic systems.

They are commonly constructed using transistors and other electronic components and are often manufactured as integrated circuits.

Examples of logic gates:

1. AND gate.
2. OR gate.
3. NOT gate.
4. NAND gate.
5. NOR gate.
6. XOR gate.
7. XNOR gate.

For this sub-strand, the main focus is on the AND, OR and NOT gates.

9.2 Importance of Logic Gates

1. Perform logical operations in digital circuits.
2. Process binary information.
3. Control the operation of electronic devices.
4. Form the building blocks of computers.
5. Support decision-making in digital systems.
6. Enable the construction of arithmetic circuits.
7. Support digital memory and control circuits.
8. Help automate electronic systems.
9. Are used in communication equipment.
10. Support the operation of microprocessors and microcontrollers.

9.3 Truth Tables

A **truth table** is a table that shows all possible combinations of input values and the corresponding output of a logic gate or digital circuit.

In binary logic, inputs and outputs are represented by 0 and 1.

Truth tables help learners understand and predict how logic gates operate.

For a gate with one input, there are two possible input combinations.

For a gate with two inputs, there are four possible input combinations:

22=422=4

For three inputs:

23=823=8

In general, a circuit with n*n* independent binary inputs has:

2n2*n*

possible input combinations.

10.0 AND Gate

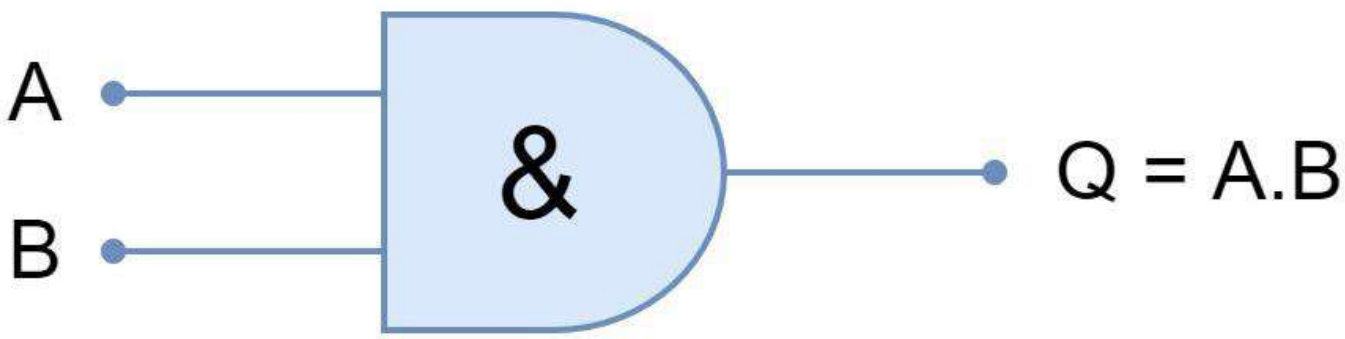
10.1 Meaning of an AND Gate

An **AND gate** is a digital logic gate that produces an output of logic 1 only when all its inputs are logic 1.

If any input is 0, the output is 0.

A two-input AND gate has two inputs, usually labelled A and B, and one output, Y.

10.2 AND Gate Symbol



10.3 Boolean Expression for an AND Gate

The Boolean expression is:

Y=A·B*Y*=*A*·*B*

It may also be written as:

Y=AB*Y*=*AB*

Where:

- A = first input.
- B = second input.
- Y = output.

10.4 Truth Table of a Two-Input AND Gate

Input A	Input B	Output Y

0	0	0
0	1	0
1	0	0
1	1	1

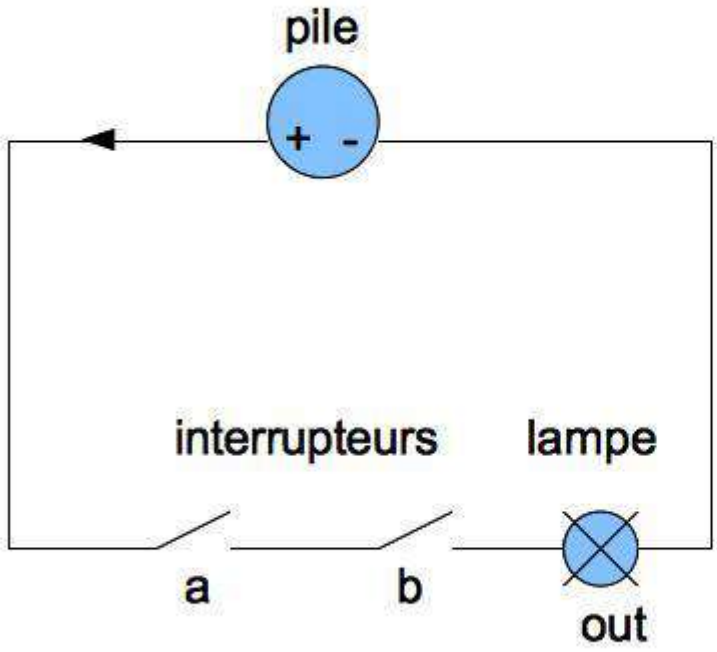
10.5 Explanation of AND Gate Operation

1. When both inputs are 0, the output is 0.
2. When input A is 0 and input B is 1, the output is 0.
3. When input A is 1 and input B is 0, the output is 0.
4. When both inputs are 1, the output is 1.

Therefore, an AND gate gives a HIGH output only when all its inputs are HIGH.

10.6 Demonstration of an AND Gate Using Switches

Two switches can be connected in series with a low-voltage indicator circuit to demonstrate the AND function.



a = 1 b = 1 out = 1
out = 0 sinon

Operation:

1. Switch A represents input A.
2. Switch B represents input B.
3. The LED represents the output.
4. When both switches are open, the LED remains OFF.
5. When only one switch is closed, the LED remains OFF.
6. When both switches are closed, the LED lights.

Truth table for the switch demonstration:

Switch A	Switch B	LED
Open	Open	OFF
Open	Closed	OFF
Closed	Open	OFF
Closed	Closed	ON

10.7 Applications of AND Gates

1. Security systems that require two conditions to be satisfied before activation.
2. Industrial control systems that require two safety conditions before a machine operates.
3. Electronic interlocking circuits.
4. Computer processing circuits.
5. Digital control systems.
6. Alarm circuits.
7. Automatic lighting systems that operate only when specified conditions are met.

Practical example:

A machine may operate only when:

- The safety guard is closed.
- The start command is activated.

The machine's control logic can use an AND function to ensure that both conditions are satisfied before operation is permitted. Real machinery must also use properly designed safety-rated control systems.

11.0 OR Gate

11.1 Meaning of an OR Gate

An **OR gate** is a digital logic gate that produces an output of logic 1 when at least one of its inputs is logic 1.

Its output is 0 only when all its inputs are 0.

A two-input OR gate has two inputs, A and B, and one output, Y.

11.2 OR Gate Symbol

11.3 Boolean Expression for an OR Gate

The Boolean expression is:

$Y=A+BY=A+B$

Where:

- A = first input.

- B = second input.
- Y = output.

In Boolean algebra, the plus sign represents the OR operation, not ordinary arithmetic addition.

11.4 Truth Table of a Two-Input OR Gate

Input A	Input B	Output Y
0	0	0
0	1	1
1	0	1
1	1	1

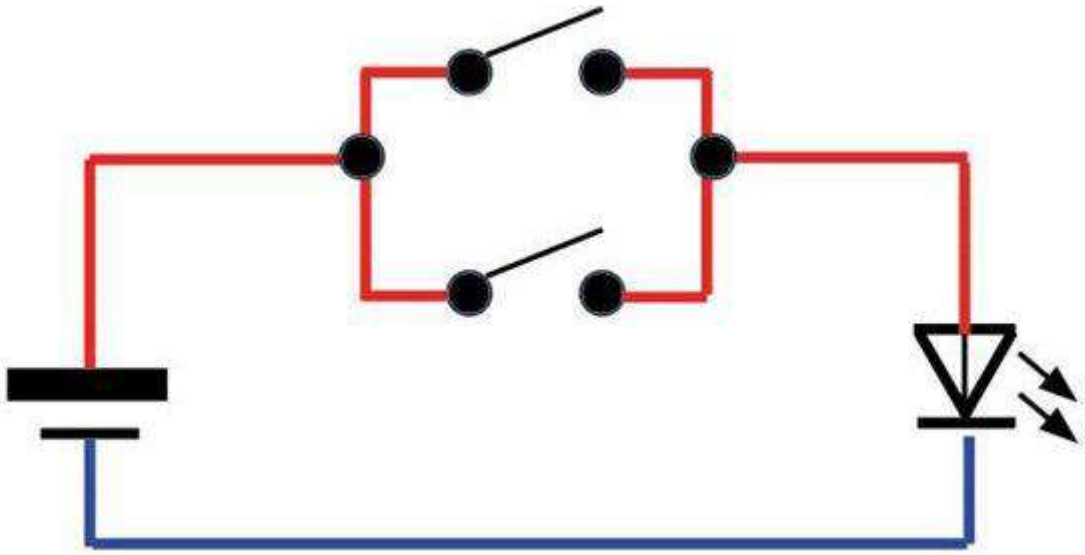
11.5 Explanation of OR Gate Operation

1. When both inputs are 0, the output is 0.
2. When input A is 0 and input B is 1, the output is 1.
3. When input A is 1 and input B is 0, the output is 1.
4. When both inputs are 1, the output is 1.

Therefore, an OR gate produces a HIGH output when one or more inputs are HIGH.

11.6 Demonstration of an OR Gate Using Switches

Two switches can be connected in parallel in a low-voltage indicator circuit to demonstrate the OR function.



Operation:

1. Switch A represents input A.
2. Switch B represents input B.
3. The LED represents the output.

4. When both switches are open, the LED remains OFF.
5. When either switch is closed, the LED lights.
6. When both switches are closed, the LED remains ON.

Truth table for the switch demonstration:

Switch A	Switch B	LED
Open	Open	OFF
Open	Closed	ON
Closed	Open	ON
Closed	Closed	ON

11.7 Applications of OR Gates

1. Alarm systems that can be activated by any one of several sensors.
2. Emergency warning systems.
3. Industrial monitoring systems.
4. Digital control systems.
5. Computer circuits.
6. Security systems.
7. Automatic lighting systems.

Practical example:

A school security alarm may be activated when either a door sensor or a window sensor detects unauthorised opening.

The OR function allows either sensor to activate the alarm.

12.0 NOT Gate

12.1 Meaning of a NOT Gate

A **NOT gate** is a digital logic gate that produces an output opposite to its input.

It is also called an inverter because it changes logic 1 into logic 0 and logic 0 into logic 1.

Unlike AND and OR gates, a NOT gate has only one input and one output.

12.2 NOT Gate Symbol

12.3 Boolean Expression for a NOT Gate

The Boolean expression is:

$Y=A^{-}Y=A$

It may also be written as:

$Y=\neg AY=\neg A$

Where:

- A = input.
- Y = output.
- The bar or NOT symbol indicates inversion.

12.4 Truth Table of a NOT Gate

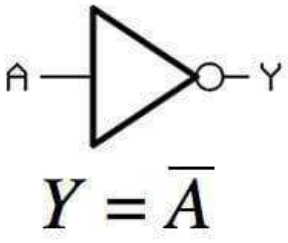
Input A	Output Y
0	1
1	0

12.5 Explanation of NOT Gate Operation

1. When the input is 0, the output becomes 1.
2. When the input is 1, the output becomes 0.
3. The output is always the opposite of the input.
4. It is used to invert or reverse a logic condition.

12.6 Demonstration of a NOT Gate

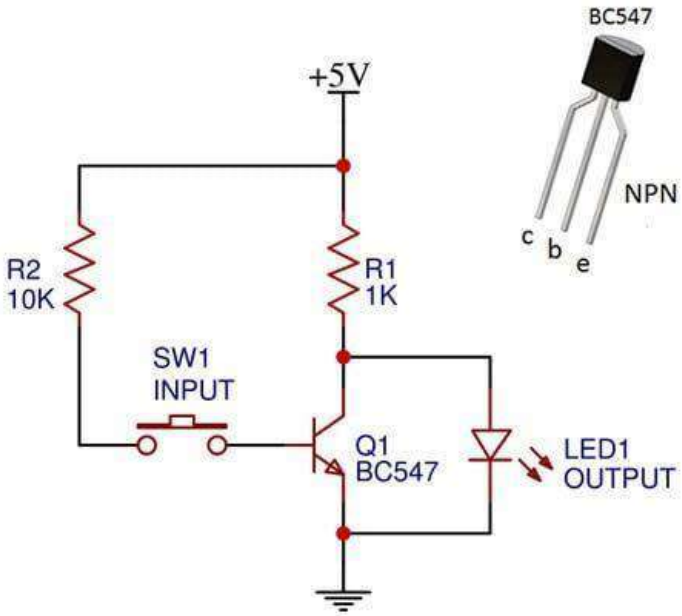
A NOT function can be demonstrated using a low-voltage electronic inverter circuit.



$$Y = \overline{A}$$

Porta NOT	
Input	Output
A	Y
0	1
1	0

tecdicas



Operation:

1. Apply logic 0 to the input.
2. Observe logic 1 at the output.
3. Apply logic 1 to the input.

4. Observe logic 0 at the output.
5. Record the results in a truth table.

12.7 Applications of NOT Gates

1. Inverting digital signals.
2. Producing complementary signals.
3. Digital control circuits.
4. Computer logic circuits.
5. Alarm and warning systems.
6. Signal conditioning.
7. Forming other logic circuits such as NAND and NOR gates when combined with other gates.

Practical example:

A warning system may be designed so that an indicator is ON when a particular input condition is absent. A NOT gate can reverse the input state to achieve the required output logic.

13.0 Comparison of AND, OR and NOT Gates

The AND, OR and NOT gates are the basic logic gates used to perform fundamental logical operations in digital electronic circuits.

Feature	**AND gate**	**OR gate**	**NOT gate**
Number of inputs	Two or more	Two or more	One
Number of outputs	One	One	One
Main function	Produces 1 when all inputs are 1	Produces 1 when at least one input is 1	Produces the opposite of the input
Boolean expression	Y=A·BY=*A*·*B*	Y=A+BY=*A*+*B*	Y=A¯Y=*A*
Output when all inputs are 0	0	0	1 when its input is 0
Output when all inputs are 1	1	1	0 when its input is 1

13.1 Combined Truth Table

A	**B**	**AND A·B*A*·*B***	**OR A+B*A*+*B***
0	0	0	0
0	1	0	1

1	0	0	1
1	1	1	1

For the NOT gate:

A	NOT A $\bar{A}$
0	1
1	0

13.2 Important Differences in Their Operations

1. An AND gate requires all inputs to be HIGH to produce a HIGH output.
2. An OR gate requires at least one input to be HIGH to produce a HIGH output.
3. A NOT gate reverses the state of its input.
4. AND and OR gates can have two or more inputs.
5. A NOT gate has only one input.
6. All three gates are used in the design of more complex digital electronic circuits.

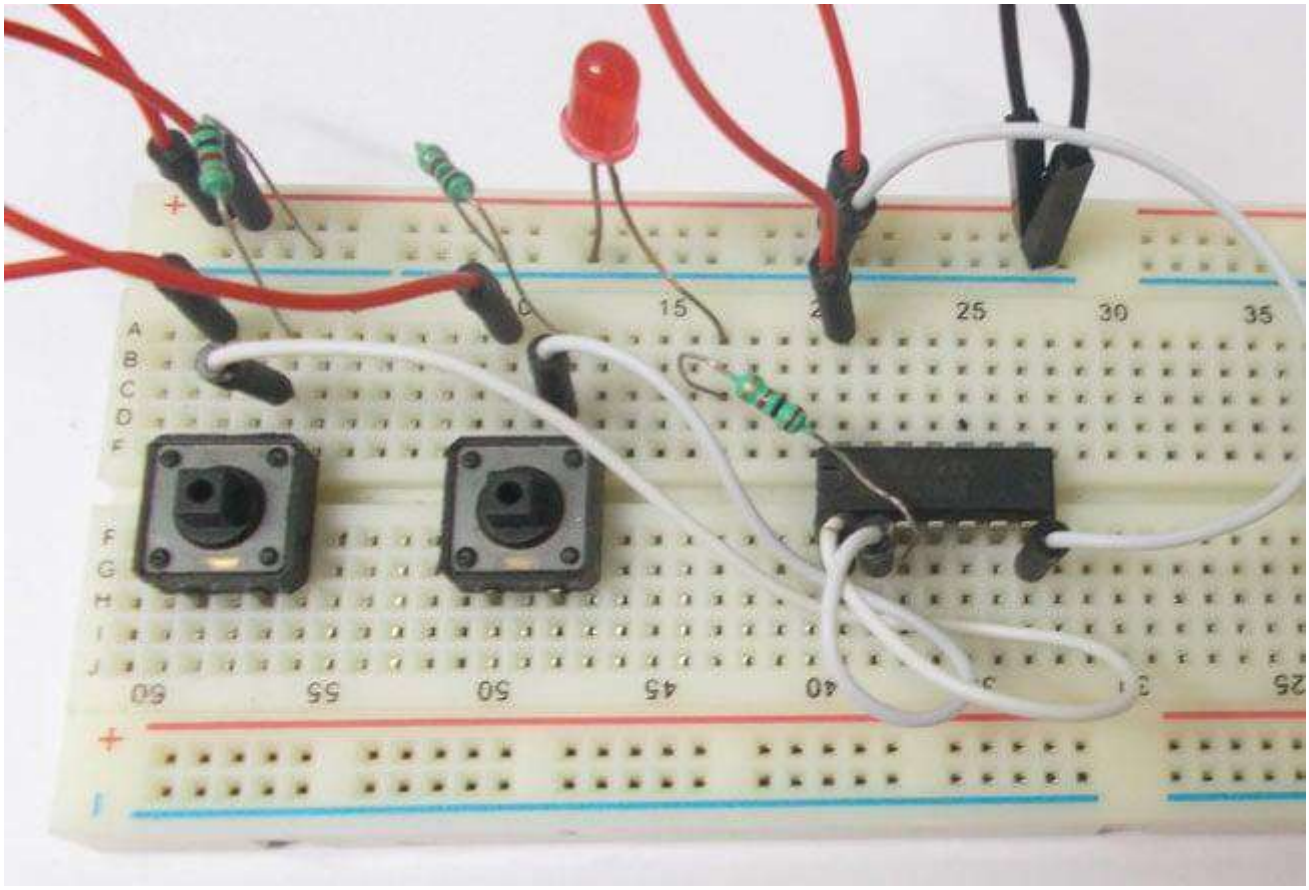
14.0 Construction of Basic Logic Gate Circuits

Learners can construct simple circuits to demonstrate the operation of AND, OR and NOT logic functions.

These activities develop practical skills in circuit assembly, testing, observation and interpretation of truth tables.

14.1 Materials and Equipment Required

1. Low-voltage DC power source.
2. Breadboard.
3. Connecting wires.
4. Push-button switches or toggle switches.
5. LEDs.
6. Suitable current-limiting resistors.
7. Basic logic gate integrated circuits.
8. Digital multimeter.
9. Integrated circuit datasheets.
10. Appropriate circuit diagrams.



14.2 Construction of an AND Gate Circuit

Objective: To demonstrate the operation of a two-input AND gate.

Components:

- Two switches representing inputs A and B.
- A two-input AND gate integrated circuit.
- An LED and suitable current-limiting resistor.
- A suitable regulated low-voltage supply.
- Breadboard and connecting wires.

Procedure:

1. Study the AND gate circuit diagram.
2. Identify the two input terminals and output terminal.
3. Identify the supply and ground pins using the manufacturer's datasheet.
4. Connect the integrated circuit to the appropriate regulated supply.
5. Connect the two switches to the inputs using suitable logic-level connections.
6. Connect the output to an LED indicator through an appropriate resistor and driver arrangement where required.
7. Apply the approved supply.
8. Set both inputs to LOW and observe the output.
9. Set A to LOW and B to HIGH and observe the output.
10. Set A to HIGH and B to LOW and observe the output.

11. Set both inputs to HIGH and observe the output.
12. Record the results in a truth table.

Expected result: The output becomes HIGH only when both inputs are HIGH.

14.3 Construction of an OR Gate Circuit

Objective: To demonstrate the operation of a two-input OR gate.

Procedure:

1. Obtain a two-input OR gate circuit or suitable integrated circuit.
2. Identify its input and output terminals.
3. Connect the circuit according to its datasheet.
4. Connect two switches to represent inputs A and B.
5. Connect an appropriate output indicator.
6. Set both inputs to LOW.
7. Observe the output.
8. Set A to LOW and B to HIGH.
9. Observe the output.
10. Set A to HIGH and B to LOW.
11. Observe the output.
12. Set both inputs to HIGH.
13. Record all observations.

Expected result: The output becomes HIGH when at least one input is HIGH.

14.4 Construction of a NOT Gate Circuit

Objective: To demonstrate the operation of a NOT gate.

Procedure:

1. Obtain a NOT gate circuit or suitable inverter integrated circuit.
2. Identify the input, output, supply and ground terminals.
3. Connect the circuit according to the datasheet.
4. Connect a switch to represent the input.
5. Connect an appropriate output indicator.
6. Apply logic 0 to the input.
7. Observe the output.
8. Apply logic 1 to the input.
9. Observe the output.
10. Record the results in a truth table.

Expected result: The output is always the opposite of the input.

14.5 Comparison of Experimental Results

Gate	Input condition	Expected output
AND	Both inputs LOW	LOW
AND	Both inputs HIGH	HIGH
OR	Both inputs LOW	LOW
OR	At least one input HIGH	HIGH
NOT	Input LOW	HIGH
NOT	Input HIGH	LOW

14.6 Safety Precautions During Logic Gate Construction

1. Use a suitable regulated low-voltage DC power supply.
2. Check the integrated circuit datasheet before connecting it.
3. Observe the correct polarity of the power supply.
4. Avoid short circuits between the supply terminals.
5. Disconnect power before changing circuit connections.
6. Avoid applying voltages above the specified input limits.
7. Use current-limiting resistors with LEDs.
8. Avoid touching integrated circuit pins unnecessarily to reduce electrostatic discharge damage.
9. Use appropriate tools and equipment.
10. Work under teacher supervision.

15.0 Applications of Logic Gates in Digital Electronic Circuits

Logic gates are used in many digital systems to process information and control electronic operations.

15.1 Computers

Computers use logic gates to perform arithmetic and logical operations.

Applications:

1. Processing binary information.
2. Performing addition and subtraction.
3. Making logical decisions.
4. Controlling data movement.
5. Supporting processor operations.

15.2 Digital Security Systems

Logic gates are used to control electronic security systems.

Example:

A security alarm may be activated when either a door sensor or a window sensor detects unauthorised entry.

This arrangement demonstrates the OR function.

15.3 Industrial Automation

Logic gates are used in automated manufacturing and industrial control systems.

Applications:

1. Controlling production processes.
2. Monitoring machine conditions.
3. Operating electronic interlocks.
4. Processing sensor signals.
5. Controlling automatic machinery.

15.4 Automatic Lighting Systems

Digital logic can be used to control lighting according to sensor inputs.

For example, a lighting system may switch on when a darkness sensor detects low light and a movement sensor detects a person.

The control logic can be represented by an AND function.

15.5 Electronic Alarm Systems

Logic gates help determine when an alarm should be activated.

For example:

- A fire sensor may provide one input.
- A smoke sensor may provide another input.
- An OR gate can activate an alarm if either sensor detects a warning condition.

15.6 Digital Clocks and Counters

Logic gates form part of the circuits used in digital clocks and electronic counters.

Functions:

1. Counting pulses.
2. Controlling display updates.
3. Detecting particular counting conditions.
4. Generating timing and control signals.

15.7 Communication Systems

Logic gates are used in digital communication equipment to process and control digital information.

Applications:

1. Data processing.
2. Signal control.
3. Digital switching.

4. Error detection circuits.
5. Communication interface circuits.

15.8 Medical Electronic Equipment

Digital circuits are used in medical devices such as:

1. Digital thermometers.
2. Patient monitoring equipment.
3. Electronic blood pressure monitors.
4. Digital diagnostic instruments.
5. Medical imaging control systems.

15.9 Applications in Kenyan Institutions

1. Schools use digital computers, electronic projectors and digital learning equipment.
2. Hospitals use digital patient monitoring and diagnostic equipment.
3. Banks use digital systems for processing financial transactions.
4. Industries use digital controllers to automate production.
5. Farmers use digital monitoring and irrigation control systems.
6. Security companies use electronic alarm and surveillance systems.
7. Businesses use digital weighing machines and electronic payment terminals.

16.0 Troubleshooting Basic Digital Logic Circuits

Troubleshooting is the systematic process of identifying and correcting faults in an electronic circuit.

Digital logic circuits may fail to operate correctly because of incorrect connections, faulty components, unsuitable supply voltage or damaged integrated circuits.

16.1 Common Faults in Digital Logic Circuits

Fault	Possible cause	Corrective action
No output	Missing power supply or incorrect connections	Check the supply and circuit connections
Output always HIGH	Input wiring fault or damaged gate	Inspect the input connections and test the gate
Output always LOW	Missing logic HIGH input or faulty IC	Check the input signals and integrated circuit
Unstable output	Floating input or poor connection	Ensure inputs have defined logic levels
IC becomes hot	Incorrect supply polarity or short circuit	Disconnect power and inspect the circuit

LED does not light	Incorrect LED polarity or faulty connection	Check the LED, resistor and output connection
Incorrect truth table	Wrong IC or wiring arrangement	Confirm the gate type and pin connections
Circuit operates intermittently	Loose wires or poor breadboard contact	Inspect and secure the connections

16.2 Systematic Troubleshooting Procedure

1. **Identify the problem:** Establish what the circuit is expected to do and what it is actually doing.
2. **Inspect the circuit:** Check for loose wires, incorrect connections and damaged components.
3. **Check the power supply:** Confirm that the correct supply voltage is available.
4. **Check the integrated circuit:** Confirm the type and pin arrangement using the datasheet.
5. **Check the inputs:** Ensure that the input signals have defined logic levels.
6. **Test the output:** Measure or observe the output using a suitable instrument.
7. **Compare with the truth table:** Determine whether the output matches the expected logical operation.
8. **Correct the fault:** Repair incorrect connections or replace defective components.
9. **Retest the circuit:** Repeat the input combinations and confirm correct operation.
10. **Record the results:** Document the fault, cause and corrective action.

16.3 Importance of Troubleshooting Digital Circuits

1. Improves circuit reliability.
2. Prevents damage to electronic components.
3. Saves time and maintenance costs.
4. Develops problem-solving skills.
5. Improves understanding of logic functions.
6. Helps identify errors in circuit construction.
7. Promotes responsible use of electronic equipment.

17.0 Digital and Analogue Systems in Practical Applications

Many modern electronic devices combine analogue and digital technologies.

For example, a digital thermometer uses a sensor to detect temperature. The sensor may produce an analogue electrical signal. An analogue-to-digital converter (ADC) changes the signal into a digital value that can be processed and displayed.

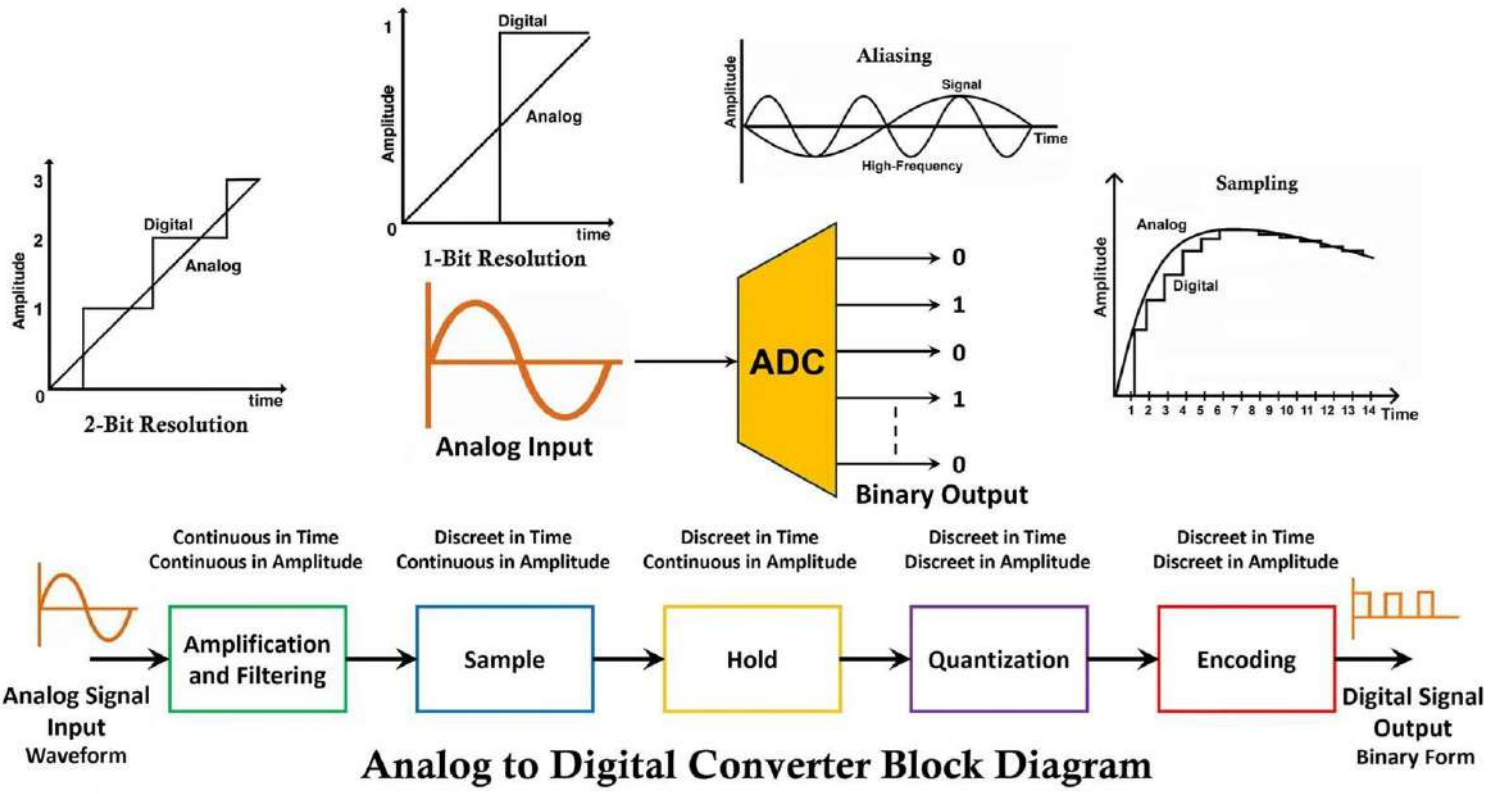
17.1 Analogue-to-Digital Converter (ADC)

An **analogue-to-digital converter** is an electronic circuit or device that changes an analogue signal into a digital representation.

Functions:

1. Receives an analogue input signal.

2. Samples the signal at selected time intervals.
3. Quantises the sampled values into discrete levels.
4. Encodes the levels as binary numbers.
5. Provides digital information for processing or storage.



Analog to Digital Converter Block Diagram

Applications:

- Digital thermometers.
- Digital audio recording.
- Electronic measuring instruments.
- Medical monitoring devices.
- Computer data acquisition systems.

17.2 Digital-to-Analogue Converter (DAC)

A **digital-to-analogue converter** is an electronic circuit or device that converts digital information into a corresponding analogue signal.

Functions:

1. Receives digital input data.
2. Converts the digital values into corresponding analogue levels.
3. Produces an analogue voltage or current.
4. Provides signals for analogue output devices.

Applications:

1. Audio playback systems.
2. Digital music equipment.

3. Electronic control systems.
4. Signal generation equipment.
5. Communication devices.

17.3 Comparison Between ADC and DAC

ADC	DAC
Converts analogue signals into digital data	Converts digital data into analogue signals
Used at the input of many digital systems	Used at the output of many digital systems
Samples and quantises an analogue signal	Reconstructs an analogue output from digital values
Example: digital thermometer input circuit	Example: digital audio output circuit

17.4 Example of a Combined Analogue and Digital System

Consider a digital temperature monitoring system.

Operation:

1. A temperature sensor detects the surrounding temperature.
2. The sensor produces an electrical signal related to temperature.
3. The ADC converts the analogue signal into digital information.
4. A microcontroller processes the digital information.
5. The result is displayed on a digital screen.
6. The system may activate an alarm if the temperature exceeds a set value.

This example shows how analogue and digital electronics work together in a modern electronic system.

18.0 CBE Learning Activities and Practical Investigations

Activity 1: Comparing Analogue and Digital Signals

Learning task: Learners investigate analogue and digital signals using print and digital resources.

Procedure:

1. Research the meaning of analogue and digital signals.
2. Identify examples of each type of signal.
3. Draw an analogue waveform.
4. Draw a digital waveform.
5. Compare their characteristics.
6. Discuss their advantages and disadvantages.
7. Present findings to classmates.

Expected learning outcome: Learners differentiate analogue and digital signals.

Activity 2: Binary-to-Decimal Conversion

Learning task: Learners convert binary numbers into decimal numbers.

Procedure:

1. Write the given binary number.
2. Identify the powers of 2.
3. Multiply each binary digit by its place value.
4. Add the products.
5. Write the decimal equivalent.
6. Verify the answer using a calculator where appropriate.

Expected learning outcome: Learners correctly convert binary numbers into decimal numbers.

Activity 3: Decimal-to-Binary Conversion

Learning task: Learners convert decimal numbers into binary numbers.

Procedure:

1. Select a decimal number.
2. Divide it repeatedly by 2.
3. Record each remainder.
4. Continue until the quotient is zero.
5. Read the remainders from bottom to top.
6. Verify the result by converting it back to decimal.

Activity 4: BCD Conversion

Learning task: Learners convert decimal numbers into BCD and BCD into decimal.

Procedure:

1. Obtain a BCD coding table.
2. Separate each decimal number into individual digits.
3. Find the four-bit code for each digit.
4. Combine the codes in their original order.
5. Convert given BCD values back into decimal.
6. Compare BCD and ordinary binary representations.

Activity 5: Binary Arithmetic

Learning task: Learners perform binary addition, subtraction, one's complement and two's complement.

Procedure:

1. Practise the basic rules of binary addition.
2. Add selected binary numbers.
3. Practise binary subtraction.
4. Invert bits to obtain one's complement.
5. Add 1 to obtain two's complement.

6. Use two's complement to perform selected subtraction operations.
7. Verify answers using decimal conversion.

Activity 6: Demonstrating Logic States

Learning task: Learners demonstrate logic 0 and logic 1 using a low-voltage electronic circuit.

Procedure:

1. Obtain an approved low-voltage supply.
2. Connect a suitable switching circuit.
3. Use an LED as an output indicator.
4. Observe the output when the switch is open.
5. Observe the output when the switch is closed.
6. Relate the two conditions to logic 0 and logic 1.
7. Record observations.

Activity 7: Constructing Basic Logic Gates

Learning task: Learners construct circuits to demonstrate AND, OR and NOT functions.

Procedure:

1. Obtain appropriate logic gate components.
2. Study the circuit diagrams.
3. Identify input and output terminals.
4. Assemble the AND gate circuit.
5. Test all input combinations.
6. Repeat the process for OR and NOT gates.
7. Prepare truth tables.
8. Compare practical observations with expected results.
9. Present findings.

Glossary of Key Terms

Term	Meaning
Digital electronics	Branch of electronics that processes information using discrete signal levels
Analogue signal	A continuously varying electrical signal
Digital signal	A signal represented by discrete levels
Binary	A number system with base 2
Decimal	A number system with base 10

Bit	A binary digit, either 0 or 1
Byte	A group of eight bits
Number system	A method of representing numbers using symbols and place values
BCD	Binary Coded Decimal
Logic gate	An electronic circuit that performs a logical operation
Logic 1	The HIGH logic state
Logic 0	The LOW logic state
Truth table	A table showing input combinations and corresponding outputs
AND gate	A gate that produces 1 only when all inputs are 1
OR gate	A gate that produces 1 when at least one input is 1
NOT gate	A gate that produces the opposite of its input
Boolean algebra	A mathematical system used to describe and analyse logic operations
One's complement	A binary representation obtained by inverting every bit
Two's complement	A binary representation obtained by inverting all bits and adding 1
Integrated circuit	An electronic circuit manufactured on a semiconductor chip
Microprocessor	An integrated circuit that performs processing operations
ADC	An electronic device that converts analogue signals into digital data
DAC	An electronic device that converts digital data into analogue signals
Quantisation	The process of assigning sampled signal values to discrete levels
Logic HIGH	A voltage level recognised as binary 1
Logic LOW	A voltage level recognised as binary 0
Inverter	A logic circuit that reverses the input state

TOPICAL REVISION ASSESSMENT

STRAND 4.0: ELECTRONICS

SUB-STRAND 4.3: INTRODUCTION TO DIGITAL ELECTRONICS

SECTION A: MULTIPLE-CHOICE QUESTIONS (30 MARKS)

Choose the correct answer from the alternatives A, B, C or D.

1. Which of the following best describes digital electronics?

A. The study of continuously varying electrical signals only.

B. The branch of electronics that processes information using discrete signal levels.

C. The study of mechanical systems.

D. The branch of electronics concerned only with electrical power transmission.

2. Which of the following is an example of an analogue signal?

A. A binary signal represented by 0 and 1.

B. A square wave with two defined logic states.

C. A continuously varying voltage produced by a suitable temperature sensor.

D. A digital code stored in computer memory.

3. The binary number system uses which of the following digits?

A. 0 and 1.

B. 0 to 7.

C. 0 to 9.

D. 0 to 15.

4. What is the base of the decimal number system?

A. 2.

B. 8.

C. 10.

D. 16.

5. What is the place value of the third digit from the right in a binary number?

A. 2.

B. 4.

C. 8.

D. 16.

6. Convert 1010210102 into decimal.

A. 8.

B. 9.

C. 10.

D. 12.

7. Convert 1101211012 into decimal.

A. 11.

B. 12.

C. 13.

D. 14.

8. Convert 13101310 into binary.

A. 1010.

B. 1011.

C. 1100.

D. 1101.

9. Convert 19101910 into binary.

A. 10001.

B. 10010.

C. 10011.

D. 10100.

10. What is the BCD representation of decimal digit 7?

A. 0101.

B. 0110.

C. 0111.

D. 1000.

11. What is the BCD representation of decimal number 25?

A. 11001.

B. 0010 0101.

C. 0001 1001.

D. 0011 0101.

12. Which of the following is the correct result of binary addition 1+11+1?

A. 1.

B. 10.

C. 11.

D. 100.

13. Calculate 1012+01021012+0102.

A. 100.

B. 110.

C. 111.

D. 101.

14. Calculate 11002−0101211002−01012.

A. 0101.

B. 0110.

C. 0111.

D. 1000.

15. What is the one's complement of 1010101010101010?

A. 10101010.

B. 01010101.

C. 11111111.

D. 00000000.

16. What is the two's complement of the 8-bit binary number 0000010100000101?

A. 11111010.

B. 11111011.

C. 00000110.

D. 11111100.

17. In a simple positive-logic digital circuit, logic 1 represents the:

A. LOW state.

B. HIGH state.

C. Open-circuit state only.

D. Ground state only.

18. In an illustrative 5 V digital logic system, logic 0 is commonly represented by a voltage close to:

A. 0 V.

B. 2.5 V.

C. 5 V.

D. 12 V.

19. A logic gate is an electronic circuit that:

A. Converts mechanical energy into electrical energy.

B. Performs logical operations on binary inputs.

C. Stores electrical energy in a capacitor only.

D. Increases the frequency of an AC supply.

20. Which logic gate produces an output of 1 only when all its inputs are 1?

A. OR.

B. NOT.

C. AND.

D. Inverter.

21. Which is the Boolean expression for a two-input AND gate?

A. Y=A+BY=A+B.

B. Y=A·BY=A·B.

C. Y=A¯Y=A.

D. Y=A−BY=A−B.

22. A two-input OR gate produces an output of 0 when:

A. Both inputs are 1.

B. The first input is 1.

C. The second input is 1.

D. Both inputs are 0.

23. Which logic gate reverses the input state?

A. AND.

B. OR.

C. NOT.

D. XOR.

24. How many possible input combinations are there for a two-input logic gate?

A. 2.

B. 3.

C. 4.

D. 8.

25. Which of the following is the correct output of a NOT gate when the input is 0?

A. 0.

B. 1.

C. 10.

D. 11.

26. Which instrument is suitable for observing digital signal waveforms?

A. Soldering iron.

B. Oscilloscope.

C. Wire stripper.

D. Electric drill.

27. A school alarm activates when either a door sensor or a window sensor detects intrusion. Which logic function best represents this arrangement?

A. AND.

B. OR.

C. NOT.

D. Inverter only.

28. Which device converts an analogue signal into digital information?

A. DAC.

B. ADC.

C. Transformer.

D. Rectifier.

29. Which of the following is a major advantage of digital systems?

A. They are always free from electrical interference.

B. They cannot experience faults.

C. They allow information to be processed and stored digitally.

D. They do not require electrical power.

30. Which of the following best explains why binary numbers are used in digital electronics?

A. Electronic circuits can easily distinguish two defined logic states.

B. Binary numbers contain ten different digits.

C. Binary numbers are always longer than decimal numbers.

D. Digital circuits operate only using mechanical switches.

SECTION B: STRUCTURED QUESTIONS (50 MARKS)

Answer all questions.

31. Analogue and Digital Signals (8 marks)

a) Define an analogue signal. (2 marks)

b) Define a digital signal. (2 marks)

c) State four differences between analogue and digital signals. (4 marks)

32. Number Systems and Conversion (8 marks)

a) State the base of the following number systems:

i. Binary. (1 mark)

ii. Decimal. (1 mark)

b) Convert 10110121011012 into decimal. (3 marks)

c) Convert 19101910 into binary. (3 marks)

33. Binary Coded Decimal and Binary Arithmetic (8 marks)

a) Explain the meaning of Binary Coded Decimal. (2 marks)

b) Express decimal number 36 in BCD. (2 marks)

c) Calculate the following binary addition:

10112+0110210112+01102

(2 marks)

d) Find the one's complement of 1100101011001010. (2 marks)

34. Two's Complement and Logic States (8 marks)

a) Explain the meaning of two's complement. (2 marks)

b) Determine the two's complement of the 8-bit binary number 0000011000000110. (3 marks)

c) Differentiate between logic 1 and logic 0 in a digital circuit. (3 marks)

35. Basic Logic Gates (9 marks)

a) Define a logic gate. (2 marks)

b) State the Boolean expression for each of the following:

i. AND gate. (1 mark)

ii. OR gate. (1 mark)

iii. NOT gate. (1 mark)

c) Complete the truth table for a two-input AND gate. (2 marks)

A	B	Output Y
0	0	
0	1	
1	0	
1	1	

d) State two applications of logic gates in digital electronic systems. (2 marks)

36. Construction and Applications of Logic Gates (9 marks)

a) Describe how a learner can demonstrate the operation of an OR gate using two switches and an LED in a suitable low-voltage circuit. (3 marks)

b) State three precautions to observe when constructing basic logic gate circuits. (3 marks)

c) Explain three applications of digital electronics in Kenya. (3 marks)

STRAND 4.0: ELECTRONICS

SUB-STRAND 4.3: INTRODUCTION TO DIGITAL ELECTRONICS

PART I: COMPREHENSIVE TEACHING AND LEARNING NOTES

1.0 INTRODUCTION TO DIGITAL ELECTRONICS

1.1 Meaning of Digital Electronics

Digital electronics is a branch of electronics that deals with the processing, storage, transmission and control of information using discrete electrical signal levels, commonly represented by binary digits 0 and 1.

Digital electronic systems use electronic components such as transistors, logic gates, integrated circuits, microprocessors and digital memory devices to perform various operations.

Unlike analogue electronics, which uses continuously varying signals, digital electronics represents information using distinct electrical states.

Examples of digital electronic devices

1. Digital clocks and watches.
2. Calculators.
3. Mobile phones.
4. Computers and laptops.
5. Digital television receivers.
6. Electronic voting equipment.
7. Digital thermometers.
8. Electronic weighing scales.
9. Programmable logic controllers (PLCs).
10. Digital electricity meters.
11. Electronic security systems.
12. Automated industrial control systems.

1.2 Importance of Studying Digital Electronics

Digital electronics is an important area of Electricity Technology because it provides the foundation for understanding modern electronic devices and control systems.

It enables learners to:

1. Understand how computers and other digital devices process information.
2. Interpret binary numbers used in electronic systems.
3. Convert numbers between binary and decimal systems.
4. Understand how electronic circuits make logical decisions.
5. Construct and test basic logic gate circuits.
6. Understand the operation of digital measuring instruments.
7. Develop skills in electronic circuit construction and troubleshooting.
8. Appreciate the application of digital technology in industries.
9. Develop practical skills relevant to careers in electronics and electrical engineering.
10. Understand automation and modern industrial control systems.

2.0 ANALOGUE AND DIGITAL SIGNALS

2.1 Meaning of an Analogue Signal

An analogue signal is an electrical signal whose magnitude changes continuously with time and can take any value within a specified range.

The information carried by an analogue signal is represented by changes in its voltage or current.

For example, when a microphone receives sound, it converts sound vibrations into a continuously varying electrical signal.

Examples of analogue signals

1. Electrical signals produced by microphones.
2. Voltage generated by some temperature sensors.
3. Signals from analogue pressure sensors.
4. Traditional radio signals.
5. Electrical signals from analogue audio equipment.
6. Signals produced by some light sensors.
7. Signals from analogue measuring instruments.

Characteristics of analogue signals

1. They vary continuously with time.
2. They can take many different values within their operating range.
3. They are suitable for representing naturally varying quantities.
4. They are generally more susceptible to electrical noise and interference.
5. Their quality may deteriorate during transmission.
6. They can be processed using analogue electronic circuits.
7. Their information is represented by the magnitude of voltage or current.

Example

A temperature sensor may produce an analogue voltage that increases as the surrounding temperature rises.

If the temperature changes gradually from 20°C to 30°C, the output voltage may also change continuously.

2.2 Meaning of a Digital Signal

A digital signal is an electrical signal that represents information using a limited number of distinct values or states.

In ordinary binary digital electronics, information is represented using two states:

- **Logic 1:** HIGH state.
- **Logic 0:** LOW state.

The two states are represented by different voltage ranges determined by the electronic device being used.

In a simple illustrative 5 V logic system:

- Logic 1 is represented by a voltage close to 5 V.
- Logic 0 is represented by a voltage close to 0 V.

The actual voltage limits depend on the integrated circuit and logic family.

Characteristics of digital signals

1. They use discrete signal levels.
2. Binary digital systems commonly use 0 and 1.
3. They are suitable for computer processing.
4. They can be stored in digital memory.
5. They can be transmitted using digital communication systems.
6. They are generally more resistant to small amounts of noise within valid logic limits.
7. They are processed using logic gates and digital circuits.
8. They are widely used in modern communication and control systems.

2.3 Differences Between Analogue and Digital Signals

Analogue signals	Digital signals
Vary continuously.	Use discrete signal levels.
Can take many values within a range.	Use a limited number of defined states.
Commonly represented by smooth waveforms.	Commonly represented by square waveforms.
More susceptible to noise accumulation.	Can tolerate some noise within valid logic limits.
Information is represented by signal magnitude.	Information is represented by coded values.
Common in traditional audio equipment.	Common in computers and digital devices.
Processed using analogue circuits.	Processed using digital circuits.
May deteriorate during repeated copying.	Digital copies can reproduce the same data accurately.

2.4 Advantages of Analogue Systems

1. **Continuous representation:** They represent naturally changing quantities such as temperature, pressure and sound.
2. **Simple circuit construction:** Some analogue functions can be implemented using relatively simple circuits.
3. **Direct response:** Analogue circuits can respond directly to changing input signals.
4. **High resolution in principle:** They are not restricted to fixed digital steps, although practical accuracy is affected by noise and component limitations.
5. **Sensor compatibility:** Many physical sensors naturally produce analogue signals.
6. **Real-time operation:** Some analogue circuits process signals without requiring conversion into digital form.

2.5 Disadvantages of Analogue Systems

1. They are susceptible to electrical noise and interference.
2. Signal quality may deteriorate during long-distance transmission.
3. Repeated copying may introduce additional noise.
4. Analogue information can be difficult to store accurately.
5. Precise processing may require careful component adjustment.
6. Component ageing and temperature changes can affect circuit performance.

2.6 Advantages of Digital Systems

1. **Noise resistance:** Digital circuits can tolerate certain levels of noise without changing the recognised logic state.
2. **Easy storage:** Digital information can be stored in electronic memory devices.
3. **Easy processing:** Information can be processed using logic gates and microprocessors.
4. **Reliable transmission:** Digital systems can use error detection and correction techniques.

5. **Reproducibility:** Digital information can be copied without the gradual quality deterioration associated with analogue copying.
6. **Programmability:** Digital systems can be programmed to perform different tasks.
7. **Compact design:** Integrated circuits allow many components to be manufactured on small semiconductor chips.
8. **Automation:** Digital systems can automatically control machines and electronic processes.
9. **Security:** Digital information can be encrypted to protect it from unauthorised access.
10. **Versatility:** The same hardware can perform different functions through software changes.

2.7 Disadvantages of Digital Systems

1. They may require analogue-to-digital conversion when receiving real-world analogue signals.
2. They require suitable digital processing hardware.
3. Quantisation during conversion can introduce errors.
4. Some digital circuits require stable clock signals.
5. They may experience timing errors and electromagnetic interference.
6. They require specialised knowledge for design and maintenance.
7. They depend on electrical power.
8. They may become obsolete as technology advances.

2.8 Applications of Digital Electronics in Kenya

Digital electronics is widely used in different sectors of the Kenyan economy.

Sector	Applications
Education	Computers, digital projectors and electronic learning systems.
Banking	ATMs, electronic payment terminals and mobile banking equipment.
Healthcare	Digital thermometers and patient monitoring equipment.
Agriculture	Automatic irrigation controllers and digital soil monitoring systems.
Transport	Electronic ticketing and traffic control systems.
Security	CCTV, electronic alarms and access control systems.
Industry	Programmable logic controllers and automated production systems.
Energy	Digital electricity meters and solar charge controllers.
Commerce	Barcode scanners and electronic weighing scales.
Communication	Smartphones, routers and digital television receivers.

3.0 NUMBER SYSTEMS IN DIGITAL ELECTRONICS

3.1 Meaning of a Number System

A number system is a method of representing numbers using a set of symbols or digits according to specific rules and a particular base.

Number systems are used in mathematics, computing and digital electronics to represent and process numerical information.

Common number systems

1. Binary number system.
2. Decimal number system.
3. Octal number system.
4. Hexadecimal number system.

3.2 Meaning of a Base

A base, also called a radix, is the number of different digits or symbols used in a number system, including zero.

For example:

- Binary has base 2.
- Decimal has base 10.
- Octal has base 8.
- Hexadecimal has base 16.

4.0 BINARY NUMBER SYSTEM

4.1 Meaning of the Binary Number System

The binary number system is a number system that uses only two digits, namely 0 and 1.

It has a base of 2 and is the fundamental number system used in digital electronic circuits and computers.

The individual digits in a binary number are called **bits (binary digits).**

Examples of binary numbers include:

- 0
- 1
- 10
- 11
- 101
- 1101
- 10110
- 110011

4.2 Why Digital Electronics Uses Binary Numbers

Digital electronic circuits use binary numbers because electronic components can easily be designed to operate in two distinguishable states.

For example:

1. A transistor can operate as an electronic switch.
2. A switch can be either ON or OFF.
3. A digital circuit can recognise a LOW voltage as logic 0.
4. The same circuit can recognise a HIGH voltage as logic 1.
5. These two conditions can represent binary information.
6. Large quantities of information can be represented by combining many bits.

Relationship between switching conditions and binary digits

Electronic condition	Binary representation
Switch OFF	0
Switch ON	1
Logic LOW	0
Logic HIGH	1

4.3 Binary Place Values

The binary number system uses powers of 2.

Starting from the right-hand side, the place values are:

$$2^0,\ 2^1,\ 2^2,\ 2^3,\ 2^4,\ 2^5, \ldots$$

The place values are shown below.

Position from right	Power	Place value
1st	2^0	1
2nd	2^1	2
3rd	2^2	4
4th	2^3	8
5th	2^4	16
6th	2^5	32
7th	2^6	64
8th	2^7	128
9th	2^8	256
10th	2^9	512

Important: The rightmost digit always has a place value of $2^0 = 1$.

4.4 Worked Example: Determining the Value of a Binary Number

Determine the decimal equivalent of 1011_2.

Step 1: Write the binary digits.

Binary digit	1	0	1	1
Place value	8	4	2	1
Product	8	0	2	1

Step 2: Add the products.

$$8 + 0 + 2 + 1 = 11$$

Therefore:

$$\boxed{1011_2 = 11_{10}}$$

5.0 DECIMAL NUMBER SYSTEM

5.1 Meaning of the Decimal Number System

The decimal number system is a number system that uses ten digits, namely 0, 1, 2, 3, 4, 5, 6, 7, 8 and 9.

It has a base of 10 and is commonly used in everyday counting, measurement and mathematical calculations.

5.2 Decimal Place Values

The decimal number system uses powers of 10.

Position from right	Power	Place value
1st	10^0	1
2nd	10^1	10
3rd	10^2	100
4th	10^3	1,000
5th	10^4	10,000
6th	10^5	100,000

5.3 Worked Example: Decimal Place Value

Express 3527 in expanded form.

$$3527 = (3 \times 1000) + (5 \times 100) + (2 \times 10) + (7 \times 1)$$

$$= 3000 + 500 + 20 + 7$$

$$\boxed{3527}$$

5.4 Comparison Between Binary and Decimal Number Systems

Feature	Binary	Decimal
Base	2	10
Number of digits	2	10
Digits used	0 and 1	0–9
Place values	Powers of 2	Powers of 10
Main application	Digital electronics	Everyday calculations
First place value	1	1

6.0 CONVERSION OF BINARY NUMBERS TO DECIMAL NUMBERS

6.1 Meaning of Binary-to-Decimal Conversion

Binary-to-decimal conversion is the process of changing a number expressed in base 2 into its equivalent value in base 10.

This is achieved by multiplying each binary digit by its corresponding power of 2 and adding the resulting products.

6.2 Procedure for Converting Binary to Decimal

1. Write the binary number.
2. Identify the place values starting from the right.
3. Assign 2^0 to the rightmost digit.
4. Continue assigning increasing powers of 2 towards the left.
5. Multiply each binary digit by its corresponding place value.
6. Add all the products.
7. Write the final answer in decimal notation.

6.3 Worked Example 1

Convert 1010_2 into decimal.

Step 1: Arrange the digits and place values.

Binary digit	1	0	1	0
Place value	8	4	2	1
Product	8	0	2	0

Step 2: Add the products.

$$8 + 0 + 2 + 0 = 10$$

Therefore:

$$\boxed{1010_2 = 10_{10}}$$

6.4 Worked Example 2

Convert 11001_2 into decimal.

Binary digit	1	1	0	0	1
Place value	16	8	4	2	1
Product	16	8	0	0	1

Adding the products:

$$16 + 8 + 0 + 0 + 1 = 25$$

Therefore:

$$\boxed{11001_2 = 25_{10}}$$

6.5 Worked Example 3

Convert 101101_2 into decimal.

$$\begin{aligned} &= (1 \times 32) + (0 \times 16) \\ &\quad +(1 \times 8) + (1 \times 4) \\ &\quad +(0 \times 2) + (1 \times 1) \end{aligned}$$

$$= 32 + 0 + 8 + 4 + 0 + 1$$

$$\boxed{101101_2 = 45_{10}}$$

6.6 Practice Exercises

Convert the following binary numbers into decimal numbers.

1. 101_2
2. 111_2
3. 1001_2
4. 1110_2
5. 10101_2
6. 11010_2
7. 100111_2
8. 111111_2

7.0 CONVERSION OF DECIMAL NUMBERS TO BINARY NUMBERS

7.1 Meaning of Decimal-to-Binary Conversion

Decimal-to-binary conversion is the process of changing a number from base 10 into its equivalent representation in base 2.

One common method is repeated division by 2.

7.2 Conversion Using Repeated Division by 2

The procedure involves the following steps:

1. Divide the decimal number by 2.
2. Record the remainder.
3. Divide the quotient by 2 again.
4. Record the new remainder.
5. Continue dividing until the quotient becomes zero.
6. Read the remainders from bottom to top.
7. The resulting digits give the binary equivalent.

7.3 Worked Example 1

Convert 13_{10} into binary.

Division	Quotient	Remainder
13 ÷ 2	6	1
6 ÷ 2	3	0
3 ÷ 2	1	1
1 ÷ 2	0	1

Read the remainders from bottom to top:

$$1101$$

Therefore:

$$\boxed{13_{10} = 1101_2}$$

7.4 Worked Example 2

Convert 25_{10} into binary.

Division	Quotient	Remainder

Division	Quotient	Remainder
25 ÷ 2	12	1
12 ÷ 2	6	0
6 ÷ 2	3	0
3 ÷ 2	1	1
1 ÷ 2	0	1

Reading the remainders from bottom to top:

$$11001$$

Therefore:

$$\boxed{25_{10} = 11001_2}$$

7.5 Worked Example 3

Convert 45_{10} into binary.

Division	Quotient	Remainder
45 ÷ 2	22	1
22 ÷ 2	11	0
11 ÷ 2	5	1
5 ÷ 2	2	1
2 ÷ 2	1	0
1 ÷ 2	0	1

Reading from bottom to top:

$$101101$$

Therefore:

$$\boxed{45_{10} = 101101_2}$$

7.6 Alternative Method: Conversion Using Powers of Two

A decimal number can also be converted into binary by expressing it as a sum of powers of 2.

Example: Convert 19 into binary.

The powers of 2 required are:

$$16,\ 8,\ 4,\ 2,\ 1$$

Express 19 as a sum:

$$19 = 16 + 2 + 1$$

Arrange the place values:

Place value	16	8	4	2	1
Binary digit	1	0	0	1	1

Therefore:

$$\boxed{19_{10} = 10011_2}$$

7.7 Practice Exercises

Convert the following decimal numbers into binary numbers.

1. 8
2. 12
3. 15
4. 18
5. 21
6. 27
7. 32
8. 50

8.0 BINARY CODED DECIMAL (BCD)

8.1 Meaning of Binary Coded Decimal

Binary Coded Decimal (BCD) is a coding system in which each decimal digit is represented separately using its four-bit binary equivalent.

The commonly used 8421 BCD system assigns the weights 8, 4, 2 and 1 to the four bits.

Unlike ordinary binary representation, BCD represents each decimal digit independently.

8.2 BCD Coding Table

Decimal digit	BCD code
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001

Important: The combinations 1010, 1011, 1100, 1101, 1110 and 1111 are not valid individual digit codes in standard 8421 BCD.

8.3 Conversion of Decimal Numbers into BCD

To convert decimal numbers into BCD:

1. Separate the decimal number into individual digits.
2. Find the four-bit BCD code for each digit.
3. Arrange the codes in their original order.
4. Separate each four-bit group clearly.

Worked Example 1: Convert 25 into BCD.

Separate the digits:

- 2 = 0010
- 5 = 0101

Therefore:

$$\boxed{25_{10} = 0010\ 0101_{BCD}}$$

Worked Example 2: Convert 347 into BCD.

Separate the digits:

- 3 = 0011
- 4 = 0100
- 7 = 0111

Therefore:

$$\boxed{347_{10} = 0011\ 0100\ 0111_{BCD}}$$

Worked Example 3: Convert 809 into BCD.

- 8 = 1000
- 0 = 0000
- 9 = 1001

Therefore:

$$\boxed{809_{10} = 1000\ 0000\ 1001_{BCD}}$$

8.4 Conversion of BCD into Decimal

To convert BCD into decimal:

1. Divide the BCD code into groups of four bits.
2. Convert each group into its decimal equivalent.
3. Combine the resulting decimal digits in their original order.

Worked Example: Convert 0101 1001 BCD into decimal.

Separate the groups:

- 0101 = 5
- 1001 = 9

Therefore:

$$\boxed{0101\ 1001_{BCD} = 59_{10}}$$

8.5 Difference Between Ordinary Binary and BCD

Consider the decimal number 25.

Ordinary binary:

$$25_{10} = 11001_2$$

BCD:

- 2 = 0010
- 5 = 0101

$$25_{10} = 0010\ 0101_{BCD}$$

Feature	Ordinary binary	BCD
Representation	Represents the whole number	Represents each decimal digit separately
Bits required	Depends on the number	Four bits per decimal digit
Example of 25	11001	0010 0101
Storage	Usually more compact	Requires more bits
Main application	General digital processing	Decimal displays and counters

8.6 Applications of BCD

1. Digital clocks.
2. Electronic calculators.
3. Digital weighing scales.
4. Digital measuring instruments.
5. Electronic counters.
6. Digital panel meters.
7. Some accounting and point-of-sale systems.
8. Electronic display systems.

9.0 BINARY ARITHMETIC

9.1 Meaning of Binary Arithmetic

Binary arithmetic refers to mathematical operations performed using binary numbers.

It is essential in digital electronics because computers, calculators and microprocessors use binary numbers to process information.

The main binary arithmetic operations covered in this sub-strand are:

1. Binary addition.
2. Binary subtraction.
3. One's complement.
4. Two's complement.

9.2 Binary Addition

Binary addition is the process of adding binary digits according to the rules of the base-2 number system.

Rules of binary addition

Operation	Result
0 + 0	0
0 + 1	1
1 + 0	1
1 + 1	10

The expression $1 + 1 = 10_2$ means that zero is written in the current column and one is carried to the next column.

Procedure for binary addition

1. Arrange the binary numbers vertically.
2. Align digits according to their place values.
3. Begin adding from the rightmost column.
4. Write the result in the current column.
5. Carry any extra value to the next column.
6. Continue until all columns are added.
7. Include the final carry where necessary.

Worked Example 1: Add 101_2 and 010_2.

```
  101
+ 010

---

  111
```

Therefore:

$$\boxed{101_2 + 010_2 = 111_2}$$

Verification:

$$5 + 2 = 7$$

Worked Example 2: Add 1011_2 and 0110_2.

```
   1 1 1
    1011
  + 0110

---

   10001
```

Explanation:

- First column: $1 + 0 = 1$.
- Second column: $1 + 1 = 10_2$. Write 0 and carry 1.
- Third column: $0 + 1 + 1 = 10_2$. Write 0 and carry 1.
- Fourth column: $1 + 0 + 1 = 10_2$. Write 0 and carry 1.
- Write the final carry.

Therefore:

$$\boxed{1011_2 + 0110_2 = 10001_2}$$

Verification:

$$11 + 6 = 17$$

Worked Example 3: Add 1101_2 and 1011_2.

```
   1101
 + 1011

---
```

```
  11000
```

Therefore:

$$\boxed{1101_2 + 1011_2 = 11000_2}$$

Verification:

$$13 + 11 = 24$$

9.3 Binary Subtraction

Binary subtraction is the process of finding the difference between two binary numbers.

Rules of binary subtraction

Operation	Result
0 – 0	0
1 – 0	1
1 – 1	0
0 – 1	1 after borrowing

When subtracting 1 from 0, borrowing is required from the next column on the left.

In binary, borrowing one from the next column gives 10_2 in the current column.

Worked Example 1: Subtract 0011_2 from 0111_2.

```
  0111
- 0011
---
  0100
```

Therefore:

$$\boxed{0111_2 - 0011_2 = 0100_2}$$

Verification:

$$7 - 3 = 4$$

Worked Example 2: Subtract 0101_2 from 1100_2.

```
  1100
- 0101
---
  0111
```

Therefore:

$$\boxed{1100_2 - 0101_2 = 0111_2}$$

Verification:

$$12 - 5 = 7$$

Worked Example 3: Subtract 0011_2 from 1000_2.

```
  1000
- 0011
---
  0101
```

Therefore:

$$\boxed{1000_2 - 0011_2 = 0101_2}$$

Verification:

$$8 - 3 = 5$$

9.4 One's Complement

One's complement is a method of representing a binary number by reversing every bit in the number.

It is obtained by changing:

- Every 0 into 1.
- Every 1 into 0.

Worked Example 1

Find the one's complement of:

$$10110010$$

Change every bit:

Original bit	1	0	1	1	0	0	1	0
Complement	0	1	0	0	1	1	0	1

Therefore:

$$\boxed{10110010 \rightarrow 01001101}$$

Worked Example 2

Find the one's complement of:

$$11001100$$

Changing each bit:

$$11001100 \rightarrow 00110011$$

Therefore:

$$\boxed{00110011}$$

9.5 Applications of One's Complement

1. Used in certain methods of representing signed binary numbers.

2. Helps explain binary subtraction techniques.
3. Supports the understanding of negative number representation.
4. Forms the basis for learning two's complement.
5. Helps learners understand binary arithmetic operations.

9.6 Two's Complement

Two's complement is a method of representing signed binary numbers and performing subtraction using binary addition.

It is obtained by finding the one's complement of a binary number and adding 1 to the result.

Procedure for finding two's complement

1. Write the binary number using a fixed number of bits.
2. Find its one's complement by reversing all the bits.
3. Add 1 to the one's complement.
4. Write the final result using the same number of bits.

Worked Example 1

Find the two's complement of the 8-bit binary number:

$$00000101$$

Step 1: Original number.

```
00000101
```

Step 2: Find the one's complement.

```
11111010
```

Step 3: Add 1.

```
  11111010
+ 00000001

---

  11111011
```

Therefore:

$$\boxed{00000101 \rightarrow 11111011}$$

Worked Example 2

Find the two's complement of:

$$00101100$$

Step 1: Find the one's complement.

$$00101100 \rightarrow 11010011$$

Step 2: Add 1.

```
  11010011
+ 00000001

---
```

```
 11010100
```

Therefore:

$$\boxed{11010100}$$

9.7 Using Two's Complement to Perform Binary Subtraction

Binary subtraction can be performed by adding the two's complement of the number being subtracted.

Procedure

1. Write both binary numbers using the same number of bits.
2. Find the two's complement of the number being subtracted.
3. Add the two's complement to the first number.
4. Discard the final carry if it occurs in a fixed-width calculation.
5. Interpret the result.

Worked Example: Calculate $9 - 5$ using two's complement.

Step 1: Convert the decimal numbers into 8-bit binary.

$$9 = 00001001$$

$$5 = 00000101$$

Step 2: Find the two's complement of 5.

One's complement:

```
11111010
```

Add 1:

```
  11111010
+ 00000001

---

  11111011
```

Step 3: Add the two's complement of 5 to 9.

```
   00001001
 + 11111011

---

  100000100
```

Step 4: Discard the final carry.

```
00000100
```

Therefore:

$$\boxed{9 - 5 = 00000100_2 = 4_{10}}$$

9.8 Comparison Between One's Complement and Two's Complement

One's complement	Two's complement

One's complement	Two's complement
Obtained by reversing all bits.	Obtained by reversing all bits and adding 1.
Changes 0 to 1 and 1 to 0.	Uses one's complement followed by addition of 1.
Has two representations of zero in conventional signed representation.	Has one representation of zero.
Less commonly used for general signed integer arithmetic.	Widely used in modern digital processors.
Can be used to explain negative binary numbers.	Supports efficient arithmetic operations.

9.9 Importance of Binary Arithmetic

1. Enables computers to perform calculations.
2. Supports arithmetic operations in microprocessors.
3. Helps in processing numerical information.
4. Supports digital data storage and manipulation.
5. Enables electronic calculators to perform mathematical operations.
6. Supports digital control systems.
7. Helps in understanding computer number representation.

10.0 LOGIC STATES IN DIGITAL ELECTRONICS

10.1 Meaning of a Logic State

A logic state is one of the two basic binary conditions used to represent information in a digital electronic circuit.

The two basic states are:

8. Logic 1 – HIGH state.
9. Logic 0 – LOW state.

A logic state is represented by a voltage level within the recognised input or output range of a digital electronic device.

10.2 Logic 1 (HIGH State)

Logic 1 represents the HIGH state in a digital circuit.

In an illustrative 5 V digital logic system, logic 1 may be represented by a voltage close to +5 V.

Characteristics of logic 1

1. Represents the binary digit 1.
2. Is commonly associated with a HIGH voltage level.
3. Can represent an ON condition in a simple switching demonstration.
4. May indicate an active condition in a digital circuit.
5. Represents TRUE in positive logic.

10.3 Logic 0 (LOW State)

Logic 0 represents the LOW state in a digital circuit.

In an illustrative 5 V digital logic system, logic 0 may be represented by a voltage close to 0 V.

Characteristics of logic 0

1. Represents the binary digit 0.
2. Is commonly associated with a LOW voltage level.

3. Can represent an OFF condition in a simple switching demonstration.
4. May indicate an inactive condition in a digital circuit.
5. Represents FALSE in positive logic.

10.4 Relationship Between Binary Digits and Logic States

Binary digit	Logic state	Illustrative voltage
0	LOW	Approximately 0 V
1	HIGH	Approximately 5 V

Important technical note: Logic 0 does not always mean exactly zero volts, and logic 1 does not always mean exactly 5 V. The recognised voltage ranges depend on the integrated circuit. Modern digital circuits may use 3.3 V, 1.8 V or other voltage levels.

10.5 Demonstrating Logic States Using a Switch and LED

A simple low-voltage DC circuit can be used to demonstrate the relationship between switching conditions and binary states.

Materials required

1. Suitable low-voltage DC supply.
2. LED.
3. Current-limiting resistor.
4. Switch.
5. Connecting wires.
6. Breadboard.

Procedure

1. Obtain the required electronic components.
2. Connect the LED and resistor appropriately.
3. Connect the switch to control the circuit.
4. Open the switch and observe the LED.
5. Close the switch and observe the LED.
6. Record the observations.
7. Relate the two conditions to binary states.

Expected observations

Switch condition	LED condition	Demonstration state
Open	OFF	0
Closed	ON	1

The demonstration represents two possible switching conditions. In a real logic circuit, voltage thresholds determine the recognised logic states.

11.0 LOGIC GATES

11.1 Meaning of a Logic Gate

A logic gate is an electronic circuit that performs a logical operation on one or more binary inputs to produce a single binary output.

Logic gates are the basic building blocks of digital electronic systems.

They are commonly constructed using transistors and other electronic components and are manufactured in integrated circuit form.

Examples of logic gates

1. AND gate.
2. OR gate.
3. NOT gate.
4. NAND gate.
5. NOR gate.
6. XOR gate.
7. XNOR gate.

The main focus of this sub-strand is on AND, OR and NOT gates.

11.2 Importance of Logic Gates

1. They perform logical operations in digital circuits.
2. They process binary information.
3. They control the operation of electronic devices.
4. They form the basic building blocks of computers.
5. They support decision-making in digital systems.
6. They enable the construction of arithmetic circuits.
7. They support digital memory and control circuits.
8. They help automate electronic systems.
9. They are used in communication equipment.
10. They support the operation of microprocessors and microcontrollers.

11.3 Meaning of a Truth Table

A truth table is a table that shows all possible combinations of input values and their corresponding outputs for a logic gate or digital circuit.

Truth tables are used to describe and analyse the operation of digital logic circuits.

For a circuit with one input, there are two possible combinations.

For a circuit with two inputs:

$$2^2 = 4 \text{ combinations}$$

For a circuit with three inputs:

$$2^3 = 8 \text{ combinations}$$

In general, the number of possible input combinations for a circuit with n independent binary inputs is:

$$\boxed{2^n}$$

12.0 AND GATE

12.1 Meaning of an AND Gate

An AND gate is a digital logic gate that produces an output of logic 1 only when all its inputs are logic 1.

If any input is logic 0, the output becomes logic 0.

A two-input AND gate has:

- Two inputs, labelled A and B.
- One output, labelled Y.

12.2 Boolean Expression for an AND Gate

The Boolean expression for an AND gate is:

$$\boxed{Y = A \cdot B}$$

It can also be written as:

$$Y = AB$$

Where:

- A = First input.
- B = Second input.
- Y = Output.
- The dot represents the AND operation.

12.3 Truth Table of a Two-Input AND Gate

Input A	Input B	Output Y
0	0	0
0	1	0
1	0	0
1	1	1

12.4 Explanation of AND Gate Operation

1. When both inputs are 0, the output is 0.
2. When A is 0 and B is 1, the output is 0.
3. When A is 1 and B is 0, the output is 0.
4. When both inputs are 1, the output is 1.

Therefore, an AND gate produces a HIGH output only when all its inputs are HIGH.

12.5 Demonstrating an AND Gate Using Two Switches

Two switches can be connected in series with a low-voltage LED indicator circuit to demonstrate the AND function.

Components required

1. Low-voltage DC power source.
2. Two switches.
3. LED.
4. Current-limiting resistor.
5. Connecting wires.

Operation

- Switch A represents input A.
- Switch B represents input B.
- LED represents the output.

When both switches are open, the LED remains OFF.

When only one switch is closed, the LED remains OFF.

When both switches are closed, the LED lights.

Truth table for the demonstration

Switch A	Switch B	LED
Open	Open	OFF
Open	Closed	OFF
Closed	Open	OFF
Closed	Closed	ON

12.6 Applications of AND Gates

1. Security systems requiring two conditions before activation.
2. Industrial control systems requiring multiple operating conditions.
3. Electronic interlocking circuits.
4. Computer processing circuits.
5. Digital control systems.
6. Alarm circuits.
7. Automatic lighting systems.

Practical Kenyan example

An automated water pumping system in a school may be programmed to operate only when:

- The water tank level is low.
- The power and safety conditions are satisfactory.

An AND function can be used in the control logic to ensure that the required conditions are satisfied before the pump receives an operating command. Actual pump safety requires suitable electrical protection and control equipment.

13.0 OR GATE

13.1 Meaning of an OR Gate

An OR gate is a digital logic gate that produces an output of logic 1 when at least one of its inputs is logic 1.

Its output is 0 only when all its inputs are 0.

A two-input OR gate has:

- Two inputs, A and B.
- One output, Y.

13.2 Boolean Expression for an OR Gate

The Boolean expression for an OR gate is:

$$\boxed{Y = A + B}$$

Where:

- A = First input.

- B = Second input.
- Y = Output.

Note: The plus sign represents the OR operation in Boolean algebra and not ordinary arithmetic addition.

13.3 Truth Table of a Two-Input OR Gate

Input A	Input B	Output Y
0	0	0
0	1	1
1	0	1
1	1	1

13.4 Explanation of OR Gate Operation

1. When both inputs are 0, the output is 0.
2. When A is 0 and B is 1, the output is 1.
3. When A is 1 and B is 0, the output is 1.
4. When both inputs are 1, the output is 1.

Therefore, an OR gate produces a HIGH output when one or more inputs are HIGH.

13.5 Demonstrating an OR Gate Using Two Switches

Two switches can be connected in parallel with a low-voltage LED indicator circuit to demonstrate the OR function.

Operation

- Switch A represents input A.
- Switch B represents input B.
- LED represents the output.

When both switches are open, the LED remains OFF.

When either switch is closed, the LED lights.

When both switches are closed, the LED remains ON.

Truth table

Switch A	Switch B	LED
Open	Open	OFF
Open	Closed	ON
Closed	Open	ON
Closed	Closed	ON

13.6 Applications of OR Gates

1. Security alarm systems.
2. Emergency warning systems.
3. Industrial monitoring systems.
4. Computer logic circuits.
5. Digital control systems.
6. Automatic lighting systems.
7. Fire detection systems.

Practical Kenyan example

A school security alarm can be activated when either the main entrance sensor or the window sensor detects unauthorised opening.

The OR function allows either sensor to activate the alarm.

14.0 NOT GATE

14.1 Meaning of a NOT Gate

A NOT gate is a digital logic gate that produces an output opposite to its input.

It is also called an inverter because it changes logic 1 into logic 0 and logic 0 into logic 1.

Unlike AND and OR gates, a NOT gate has only one input and one output.

14.2 Boolean Expression for a NOT Gate

The Boolean expression for a NOT gate is:

$$\boxed{Y = \overline{A}}$$

It can also be written as:

$$Y = \neg A$$

Where:

- A = Input.
- Y = Output.
- The bar or NOT symbol indicates inversion.

14.3 Truth Table of a NOT Gate

Input A	Output Y
0	1
1	0

14.4 Explanation of NOT Gate Operation

1. When the input is 0, the output becomes 1.
2. When the input is 1, the output becomes 0.
3. The output is always opposite to the input.

4. It is used to reverse or invert a logic condition.

14.5 Demonstrating a NOT Gate

A NOT gate can be demonstrated using a low-voltage inverter circuit.

Procedure

1. Obtain a suitable NOT gate integrated circuit.
2. Identify the input and output terminals.
3. Connect the circuit according to the manufacturer's datasheet.
4. Apply logic 0 to the input.
5. Observe the output.
6. Apply logic 1 to the input.
7. Observe the output.
8. Record the results in a truth table.

Expected observations

Input	Output
0	1
1	0

14.6 Applications of NOT Gates

1. Inverting digital signals.
2. Producing complementary signals.
3. Digital control circuits.
4. Computer logic circuits.
5. Alarm and warning systems.
6. Signal conditioning.
7. Construction of more complex logic circuits.

Practical example

A warning system may be designed so that an indicator switches ON when a particular input condition is absent. A NOT gate can reverse the input state to achieve the required output.

15.0 COMPARISON OF AND, OR AND NOT GATES

The AND, OR and NOT gates are basic logic gates used to perform fundamental logical operations in digital electronic systems.

15.1 Comparison Table

Feature	AND	OR	NOT
Number of inputs	Two or more	Two or more	One
Number of outputs	One	One	One
Main function	All inputs must be 1	At least one input must be 1	Reverses the input
Boolean expression	$Y = A \cdot B$	$Y = A + B$	$Y = \overline{A}$
Output when inputs are 0	0	0	1 when input is 0
Output when inputs are 1	1	1	0 when input is 1

15.2 Combined Truth Table

A	B	AND (AB)	OR (A+B)
0	0	0	0
0	1	0	1
1	0	0	1
1	1	1	1

NOT gate truth table

A	NOT A
0	1
1	0

15.3 Important Differences in Their Operations

1. An AND gate requires all inputs to be HIGH to produce a HIGH output.
2. An OR gate requires at least one input to be HIGH to produce a HIGH output.
3. A NOT gate reverses the state of its input.
4. AND and OR gates can have two or more inputs.
5. A NOT gate has only one input.
6. All three gates are used in designing complex digital electronic circuits.

16.0 CONSTRUCTION OF BASIC LOGIC GATE CIRCUITS

16.1 Meaning of Logic Gate Circuit Construction

Logic gate circuit construction is the process of assembling electronic components to form a digital circuit that performs a specified logical operation.

Learners can construct simple circuits to demonstrate AND, OR and NOT functions.

These activities develop practical skills in circuit assembly, testing, observation and interpretation of truth tables.

16.2 Materials and Equipment Required

1. Low-voltage regulated DC power supply.
2. Breadboard.
3. Connecting wires.
4. Push-button or toggle switches.
5. LEDs.
6. Current-limiting resistors.
7. Basic logic gate integrated circuits.
8. Digital multimeter.
9. Integrated circuit datasheets.
10. Circuit diagrams.

16.3 Construction of an AND Gate Circuit

Objective: To demonstrate the operation of a two-input AND gate.

Components

- Two switches representing inputs A and B.

- A two-input AND gate integrated circuit.
- An LED and suitable resistor.
- Regulated low-voltage supply.
- Breadboard and connecting wires.

Procedure

1. Study the AND gate circuit diagram.
2. Identify the input, output, supply and ground terminals.
3. Consult the manufacturer's datasheet.
4. Connect the integrated circuit to the appropriate regulated power supply.
5. Connect the two switches to the inputs using suitable logic-level connections.
6. Connect the output to an LED indicator through an appropriate resistor and driver arrangement where required.
7. Apply the approved supply voltage.
8. Set both inputs to LOW and observe the output.
9. Set A to LOW and B to HIGH.
10. Set A to HIGH and B to LOW.
11. Set both inputs to HIGH.
12. Record all observations in a truth table.

Expected result: The output becomes HIGH only when both inputs are HIGH.

16.4 Construction of an OR Gate Circuit

Objective: To demonstrate the operation of a two-input OR gate.

Procedure

1. Obtain a suitable OR gate integrated circuit.
2. Identify the input, output, supply and ground terminals.
3. Connect the circuit according to its datasheet.
4. Connect two switches to represent inputs A and B.
5. Connect an appropriate output indicator.
6. Set both inputs to LOW and observe the output.
7. Set A to LOW and B to HIGH.
8. Observe the output.
9. Set A to HIGH and B to LOW.
10. Observe the output.
11. Set both inputs to HIGH.
12. Record all observations.

Expected result: The output becomes HIGH when at least one input is HIGH.

16.5 Construction of a NOT Gate Circuit

Objective: To demonstrate the operation of a NOT gate.

Procedure

1. Obtain a suitable NOT gate integrated circuit.
2. Identify its input, output, supply and ground terminals.
3. Connect the circuit according to the manufacturer's datasheet.
4. Connect a switch to represent the input.
5. Connect an appropriate output indicator.

6. Apply logic 0 to the input.
7. Observe the output.
8. Apply logic 1 to the input.
9. Observe the output.
10. Record the results in a truth table.

Expected result: The output is always opposite to the input.

16.6 Comparison of Experimental Results

Gate	Input condition	Expected out-put
AND	Both inputs LOW	LOW
AND	Both inputs HIGH	HIGH
OR	Both inputs LOW	LOW
OR	At least one input HIGH	HIGH
NOT	Input LOW	HIGH
NOT	Input HIGH	LOW

16.7 Safety Precautions During Logic Gate Construction

1. Use a suitable regulated low-voltage DC supply.
2. Check the integrated circuit datasheet before connecting it.
3. Observe the correct polarity of the power supply.
4. Avoid short circuits between supply terminals.
5. Disconnect power before changing circuit connections.
6. Avoid applying voltages above the specified input limits.
7. Use current-limiting resistors with LEDs.
8. Avoid touching integrated circuit pins unnecessarily.
9. Use appropriate tools and equipment.
10. Work under the supervision of the teacher.

17.0 APPLICATIONS OF LOGIC GATES IN DIGITAL ELECTRONIC CIRCUITS

Logic gates are used in many electronic systems to process information and control operations.

17.1 Computers

Computers use logic gates to perform arithmetic and logical operations.

Applications include:

1. Processing binary information.
2. Performing addition and subtraction.
3. Making logical decisions.
4. Controlling data movement.
5. Supporting processor operations.

17.2 Digital Security Systems

Logic gates are used to control electronic security systems.

For example, a security alarm may be activated when either a door sensor or a window sensor detects unauthorised entry.

This demonstrates the OR function.

17.3 Industrial Automation

Logic gates are used in automated manufacturing and industrial control systems.

Applications include:

1. Controlling production processes.
2. Monitoring machine conditions.
3. Operating electronic interlocks.
4. Processing sensor signals.
5. Controlling automatic machinery.

17.4 Automatic Lighting Systems

Digital logic can control lighting according to sensor inputs.

For example, a lighting system may switch ON when:

- A darkness sensor detects low light.
- A movement sensor detects a person.

The control logic can use an AND function to ensure that both conditions are satisfied.

17.5 Electronic Alarm Systems

Logic gates help determine when an alarm should be activated.

For example:

- A fire sensor provides one input.
- A smoke sensor provides another input.
- An OR gate activates the alarm when either sensor detects a warning condition.

17.6 Digital Clocks and Counters

Logic gates form part of circuits used in digital clocks and electronic counters.

Functions include:

1. Counting electrical pulses.
2. Controlling display updates.
3. Detecting particular counting conditions.
4. Generating timing and control signals.

17.7 Communication Systems

Logic gates are used in digital communication equipment to process and control information.

Applications include:

1. Data processing.
2. Signal control.
3. Digital switching.
4. Error detection circuits.
5. Communication interface circuits.

17.8 Medical Electronic Equipment

Digital circuits are used in medical equipment such as:

1. Digital thermometers.
2. Patient monitoring equipment.
3. Electronic blood pressure monitors.
4. Digital diagnostic instruments.
5. Medical imaging control systems.

17.9 Applications in Kenyan Institutions

Institution or sector	Digital electronics application
Schools	Computer laboratories and digital projectors.
Hospitals	Patient monitoring and diagnostic equipment.
Banks	ATMs and electronic payment systems.
Industries	Automated production and control systems.
Farms	Digital irrigation and monitoring systems.
Security firms	Electronic alarms and surveillance equipment.
Businesses	Digital weighing machines and payment terminals.

18.0 TROUBLESHOOTING BASIC DIGITAL LOGIC CIRCUITS

18.1 Meaning of Troubleshooting

Troubleshooting is the systematic process of identifying, locating and correcting faults in an electronic circuit.

Digital logic circuits may fail to operate correctly because of incorrect connections, faulty components, unsuitable supply voltage or damaged integrated circuits.

18.2 Common Faults in Digital Logic Circuits

Fault	Possible cause	Corrective action
No output	Missing power supply	Check the power supply.
Output always HIGH	Incorrect input wiring	Inspect input connections.
Output always LOW	Missing logic HIGH input	Check the input signals.
Unstable output	Floating input	Ensure inputs have defined logic levels.
IC becomes hot	Incorrect supply polarity	Disconnect power and inspect connections.
LED does not light	Incorrect LED polarity	Check LED polarity and resistor.
Incorrect truth table	Wrong IC or wiring	Confirm the gate type and connections.
Intermittent operation	Loose wires	Secure all connections.

18.3 Systematic Troubleshooting Procedure

1. **Identify the problem:** Establish what the circuit should do and what it is actually doing.
2. **Inspect the circuit:** Check for loose wires, incorrect connections and damaged components.

3. **Check the power supply:** Confirm that the correct supply voltage is available.
4. **Check the integrated circuit:** Confirm the IC type and pin arrangement using its datasheet.
5. **Check the inputs:** Ensure that the input signals have defined logic levels.
6. **Test the output:** Measure or observe the output using a suitable instrument.
7. **Compare with the truth table:** Determine whether the output matches the expected operation.
8. **Correct the fault:** Repair incorrect connections or replace defective components.
9. **Retest the circuit:** Repeat the input combinations and confirm correct operation.
10. **Record the results:** Document the fault, cause and corrective action.

18.4 Importance of Troubleshooting Digital Circuits

1. Improves circuit reliability.
2. Prevents damage to electronic components.
3. Saves time and maintenance costs.
4. Develops problem-solving skills.
5. Improves understanding of logic functions.
6. Helps identify errors in circuit construction.
7. Promotes responsible use of electronic equipment.

19.0 DIGITAL AND ANALOGUE SYSTEMS IN PRACTICAL APPLICATIONS

Modern electronic devices often combine analogue and digital technologies.

For example, a digital thermometer uses a sensor to detect temperature. The sensor may produce an analogue electrical signal, which is converted into digital information for processing and display.

19.1 Analogue-to-Digital Converter (ADC)

An analogue-to-digital converter (ADC) is an electronic circuit or device that converts an analogue signal into a digital representation.

Functions of an ADC

1. Receives an analogue input signal.
2. Samples the signal at selected time intervals.
3. Quantises the sampled values into discrete levels.
4. Encodes the levels into binary numbers.
5. Provides digital information for processing or storage.

Applications of ADC

1. Digital thermometers.
2. Digital audio recording.
3. Electronic measuring instruments.
4. Medical monitoring equipment.
5. Computer data acquisition systems.
6. Digital weighing scales.

19.2 Digital-to-Analogue Converter (DAC)

A digital-to-analogue converter (DAC) is an electronic circuit or device that converts digital information into a corresponding analogue signal.

Functions of a DAC

1. Receives digital input data.
2. Converts digital values into corresponding analogue levels.
3. Produces an analogue voltage or current.

4. Provides signals for analogue output devices.

Applications of DAC

1. Audio playback systems.
2. Digital music equipment.
3. Electronic control systems.
4. Signal generation equipment.
5. Communication devices.

19.3 Comparison Between ADC and DAC

ADC	DAC
Converts analogue signals into digital data.	Converts digital data into analogue signals.
Used at the input of many digital systems.	Used at the output of many digital systems.
Samples and quantises analogue signals.	Produces analogue levels corresponding to digital values.
Example: thermometer input circuit.	Example: digital audio output circuit.

19.4 Example of a Combined Analogue and Digital System

Consider a digital temperature monitoring system.

Operation

1. A temperature sensor detects the surrounding temperature.
2. The sensor produces an electrical signal related to temperature.
3. The ADC converts the analogue signal into digital information.
4. A microcontroller processes the digital information.
5. The result is displayed on a digital screen.
6. The system may activate an alarm if the temperature exceeds a set value.

This demonstrates how analogue and digital electronics work together in modern electronic systems.

20.0 CBE LEARNING ACTIVITIES AND PRACTICAL INVESTIGATIONS

The following activities enable learners to develop practical skills, critical thinking, creativity, collaboration and problem-solving abilities.

Activity 1: Comparing Analogue and Digital Signals

Learning task: Investigate the differences between analogue and digital signals.

Procedure

1. Use print or digital media to research analogue and digital signals.
2. Identify examples of each type.
3. Draw an analogue waveform.
4. Draw a digital waveform.
5. Compare their characteristics.
6. Discuss their advantages and disadvantages.
7. Present findings to classmates.

Expected learning outcome: The learner differentiates analogue and digital signals.

Activity 2: Binary-to-Decimal Conversion

Learning task: Convert binary numbers into decimal numbers.

Procedure

1. Write the given binary number.
2. Identify the powers of 2.
3. Multiply each binary digit by its place value.
4. Add the products.
5. Write the decimal equivalent.
6. Verify the answer.

Expected learning outcome: The learner correctly converts binary numbers into decimal numbers.

Activity 3: Decimal-to-Binary Conversion

Learning task: Convert decimal numbers into binary numbers.

Procedure

1. Select a decimal number.
2. Divide it repeatedly by 2.
3. Record each remainder.
4. Continue until the quotient is zero.
5. Read the remainders from bottom to top.
6. Verify the result by converting it back to decimal.

Activity 4: BCD Conversion

Learning task: Convert decimal numbers into BCD and BCD into decimal.

Procedure

1. Obtain a BCD coding table.
2. Separate each decimal number into individual digits.
3. Find the four-bit code for each digit.
4. Combine the codes in their original order.
5. Convert given BCD values back into decimal.
6. Compare BCD and ordinary binary representations.

Activity 5: Binary Arithmetic

Learning task: Perform binary addition, subtraction, one's complement and two's complement.

Procedure

1. Practise the rules of binary addition.
2. Add selected binary numbers.
3. Practise binary subtraction.
4. Invert bits to obtain one's complement.
5. Add 1 to obtain two's complement.
6. Use two's complement to perform selected subtraction operations.
7. Verify answers using decimal conversion.

Activity 6: Demonstrating Logic States

Learning task: Demonstrate logic 0 and logic 1 using a low-voltage electronic circuit.

Procedure

1. Obtain an approved low-voltage supply.
2. Connect a suitable switching circuit.

3. Use an LED as an output indicator.
4. Observe the output when the switch is open.
5. Observe the output when the switch is closed.
6. Relate the conditions to logic 0 and logic 1.
7. Record observations.

Activity 7: Constructing Basic Logic Gates

Learning task: Construct circuits to demonstrate AND, OR and NOT functions.

Procedure

1. Obtain appropriate logic gate components.
2. Study the circuit diagrams.
3. Identify input and output terminals.
4. Assemble the AND gate circuit.
5. Test all input combinations.
6. Repeat the process for OR and NOT gates.
7. Prepare truth tables.
8. Compare practical observations with expected results.
9. Present findings to classmates.

22.0 GLOSSARY OF KEY TERMS

Term	Meaning
Digital electronics	Branch of electronics that processes information using discrete signal levels.
Analogue signal	A continuously varying electrical signal.
Digital signal	A signal represented by discrete levels.
Binary	A number system with base 2.
Decimal	A number system with base 10.
Bit	A binary digit, either 0 or 1.
Byte	A group of eight bits.
Number system	A method of representing numbers using symbols and place values.
BCD	Binary Coded Decimal.
Logic gate	An electronic circuit that performs a logical operation.
Logic 1	The HIGH logic state.
Logic 0	The LOW logic state.
Truth table	A table showing input combinations and corresponding outputs.
AND gate	A gate that produces 1 only when all inputs are 1.
OR gate	A gate that produces 1 when at least one input is 1.
NOT gate	A gate that produces the opposite of its input.
Boolean algebra	A mathematical system used to describe and analyse logic operations.
One's complement	A binary representation obtained by inverting eve-

Term	Meaning
	ry bit.
Two's complement	A binary representation obtained by inverting all bits and adding 1.
Integrated circuit	An electronic circuit manufactured on a semiconductor chip.
Microprocessor	An integrated circuit that performs processing operations.
ADC	An electronic device that converts analogue signals into digital data.
DAC	An electronic device that converts digital data into analogue signals.
Quantisation	The process of assigning sampled signal values to discrete levels.
Logic HIGH	A voltage level recognised as binary 1.
Logic LOW	A voltage level recognised as binary 0.
Inverter	A logic circuit that reverses the input state.

PART II: GRADE 11 TOPICAL REVISION ASSESSMENT

80 MARKS

STRAND 4.0: ELECTRONICS

SUB-STRAND 4.3: INTRODUCTION TO DIGITAL ELECTRONICS

COMPETENCY-BASED EDUCATION (CBE) – LEARNER'S PROGRESS ASSESSMENT

LEARNER'S DETAILS

Learner's Name: ……..

Assessment Number: ……

School: ……..

Date: ……

ASSESSMENT INSTRUCTIONS

1. Answer all questions in Section A.
2. Answer all questions in Section B.
3. Choose the correct answer from alternatives A, B, C and D.
4. Show all working in number conversion and binary arithmetic questions.
5. Use appropriate electronic symbols and diagrams where necessary.
6. All questions carry the marks indicated.

SECTION A: MULTIPLE-CHOICE QUESTIONS (30 MARKS)

Choose the correct answer from the alternatives given.

1. Which of the following best describes digital electronics?

A. The study of continuously varying electrical signals only.

B. The branch of electronics that processes information using discrete signal levels.

C. The study of mechanical systems.

D. The branch of electronics concerned only with electrical power transmission.

2. Which of the following is an example of an analogue signal?

A. A binary signal represented by 0 and 1.

B. A square wave with two defined logic states.

C. A continuously varying voltage produced by a temperature sensor.

D. A digital code stored in computer memory.

3. The binary number system uses which of the following digits?

A. 0 and 1.

B. 0 to 7.

C. 0 to 9.

D. 0 to 15.

4. What is the base of the decimal number system?

A. 2.

B. 8.

C. 10.

D. 16.

5. What is the place value of the third digit from the right in a binary number?

A. 2.

B. 4.

C. 8.

D. 16.

6. Convert 1010_2 into decimal.

A. 8.

B. 9.

C. 10.

D. 12.

7. Convert 1101_2 into decimal.

A. 11.

B. 12.

C. 13.

D. 14.

8. Convert 13_{10} into binary.

A. 1010.

B. 1011.

C. 1100.

D. 1101.

9. Convert 19_{10} into binary.

A. 10001.

B. 10010.

C. 10011.

D. 10100.

10. What is the BCD representation of decimal digit 7?

A. 0101.

B. 0110.

C. 0111.

D. 1000.

11. What is the BCD representation of decimal number 25?

A. 11001.

B. 0010 0101.

C. 0001 1001.

D. 0011 0101.

12. Which of the following is the correct result of binary addition $1 + 1$?

A. 1.

B. 10.

C. 11.

D. 100.

13. Calculate $101_2 + 010_2$.

A. 100.

B. 110.

C. 111.

D. 101.

14. Calculate $1100_2 - 0101_2$.

A. 0101.

B. 0110.

C. 0111.

D. 1000.

15. What is the one's complement of 10101010?

A. 10101010.

B. 01010101.

C. 11111111.

D. 00000000.

16. What is the two's complement of the 8-bit binary number 00000101?

A. 11111010.

B. 11111011.

C. 00000110.

D. 11111100.

17. In a simple positive-logic digital circuit, logic 1 represents the:

A. LOW state.

B. HIGH state.

C. Open-circuit state only.

D. Ground state only.

18. In an illustrative 5 V digital logic system, logic 0 is commonly represented by a voltage close to:

A. 0 V.

B. 2.5 V.

C. 5 V.

D. 12 V.

19. A logic gate is an electronic circuit that:

A. Converts mechanical energy into electrical energy.

B. Performs logical operations on binary inputs.

C. Stores electrical energy in a capacitor only.

D. Increases the frequency of an AC supply.

20. Which logic gate produces an output of 1 only when all its inputs are 1?

A. OR.

B. NOT.

C. AND.

D. Inverter.

21. Which is the Boolean expression for a two-input AND gate?

A. $Y = A + B$.

B. $Y = A \cdot B$.

C. $Y = \overline{A}$.

D. $Y = A - B$.

22. A two-input OR gate produces an output of 0 when:

A. Both inputs are 1.

B. The first input is 1.

C. The second input is 1.

D. Both inputs are 0.

23. Which logic gate reverses the input state?

A. AND.

B. OR.

C. NOT.

D. XOR.

24. How many possible input combinations are there for a two-input logic gate?

A. 2.

B. 3.

C. 4.

D. 8.

25. What is the correct output of a NOT gate when the input is 0?

A. 0.

B. 1.

C. 10.

D. 11.

26. Which instrument is suitable for observing digital signal waveforms?

A. Soldering iron.

B. Oscilloscope.

C. Wire stripper.

D. Electric drill.

27. A school alarm activates when either a door sensor or a window sensor detects intrusion. Which logic function best represents this arrangement?

A. AND.

B. OR.

C. NOT.

D. Inverter only.

28. Which device converts an analogue signal into digital information?

A. DAC.

B. ADC.

C. Transformer.

D. Rectifier.

29. Which of the following is a major advantage of digital systems?

A. They are always free from electrical interference.

B. They cannot experience faults.

C. They allow information to be processed and stored digitally.

D. They do not require electrical power.

30. Which of the following best explains why binary numbers are used in digital electronics?

A. Electronic circuits can easily distinguish two defined logic states.

B. Binary numbers contain ten different digits.

C. Binary numbers are always longer than decimal numbers.

D. Digital circuits operate only using mechanical switches.

SECTION B: STRUCTURED QUESTIONS (50 MARKS)

Answer ALL questions. Show your working where necessary.

31. Analogue and Digital Signals (8 marks)

a) Define an analogue signal. (2 marks)

b) Define a digital signal. (2 marks)

c) State four differences between analogue and digital signals. (4 marks)

32. Number Systems and Conversion (8 marks)

a) State the base of the following number systems:

i. Binary. (1 mark)

ii. Decimal. (1 mark)

b) Convert 101101_2 into decimal. (3 marks)

c) Convert 19_{10} into binary. (3 marks)

33. Binary Coded Decimal and Binary Arithmetic (8 marks)

a) Explain the meaning of Binary Coded Decimal (BCD). (2 marks)

b) Express decimal number 36 in BCD. (2 marks)

c) Calculate the following binary addition:

$$1011_2 + 0110_2$$

(2 marks)

d) Find the one's complement of 11001010. (2 marks)

34. Two's Complement and Logic States (8 marks)

a) Explain the meaning of two's complement. (2 marks)

b) Determine the two's complement of the 8-bit binary number 00000110. Show all working. (3 marks)

c) Differentiate between logic 1 and logic 0 in a digital circuit. (3 marks)

35. Basic Logic Gates (9 marks)

a) Define a logic gate. (2 marks)

b) State the Boolean expression for each of the following:

i. AND gate. (1 mark)

ii. OR gate. (1 mark)

iii. NOT gate. (1 mark)

c) Complete the truth table for a two-input AND gate. (2 marks)

A	B	Output Y

A	B	Output Y
0	0	……..
0	1	……..
1	0	……..
1	1	……..

e) State two applications of logic gates in digital electronic systems. (2 marks)

36. Construction and Applications of Logic Gates (9 marks)

a) Describe how a learner can demonstrate the operation of an OR gate using two switches and an LED in a suitable low-voltage circuit. (3 marks)

b) State three precautions to observe when constructing basic logic gate circuits. (3 marks)

c) Explain three applications of digital electronics in Kenya. (3 marks)

STRAND 4.0: ELECTRONICS

SUB-STRAND 4.4: PROJECT IDENTIFICATION

1.0 Introduction to Project Identification

Project identification is the process of recognising problems, needs or opportunities in the community and proposing suitable projects to address them.

In Electricity Technology, project identification involves observing challenges in homes, schools, work-places and the wider community that can be solved through the application of electrical and electronic principles.

An electrical project may involve designing, constructing, installing, repairing or improving an electrical device or system to meet a particular need.

Examples of electrical projects include:

1. Designing a solar-powered lighting system for a classroom.
2. Developing an automatic water-level controller for a water tank.
3. Constructing an automatic security lighting system.
4. Designing a simple fire or smoke alarm.
5. Developing a battery-charging system using solar energy.
6. Constructing an automatic hand-washing water dispenser.
7. Designing a low-cost electric fence warning system.
8. Developing a battery-powered emergency lighting system.
9. Constructing an automatic poultry lighting system.
10. Designing a simple electronic irrigation controller.

Project identification is an important stage in project development because it helps learners select projects that are relevant, achievable, safe and beneficial to society.

1.1 Meaning of Key Terms

a) Project

A project is a planned activity undertaken to achieve a specific objective within a given period using available resources.

In Electricity Technology, a project may involve developing an electrical device, system or solution to address an identified problem.

b) Project identification

Project identification is the process of recognising a need or problem and determining a suitable project that can address it.

c) Community

A community refers to a group of people living, working or interacting within a particular geographical area or social setting.

Examples include:

- A school community.
- A village community.
- An urban residential community.

- A farming community.
- A trading centre.

d) Electrical principles

Electrical principles are the basic scientific concepts and laws that explain how electricity behaves and how electrical devices and systems operate.

Examples include:

- Electric current.
- Voltage.
- Resistance.
- Electrical power.
- Electrical energy.
- Series and parallel circuits.
- Electromagnetism.
- Electronic control.
- Renewable energy systems.

e) Feasibility

Feasibility refers to the possibility of successfully carrying out a proposed project using available resources, skills, time and suitable working conditions.

f) Project portfolio

A project portfolio is an organised collection of documents and evidence showing the development of a project from the identification of a problem to the proposal of a possible solution.

1.2 Importance of Project Identification

Project identification is important because it:

1. Helps learners recognise problems affecting their communities.
2. Encourages creativity and innovation in solving practical problems.
3. Promotes the application of electrical knowledge to real-life situations.
4. Helps learners identify opportunities for technological improvement.
5. Encourages the responsible use of available resources.
6. Promotes teamwork and cooperation among learners.
7. Helps learners develop problem-solving and critical-thinking skills.
8. Prevents wastage of time and resources on unsuitable projects.
9. Encourages the development of affordable and sustainable solutions.
10. Creates opportunities for self-employment and entrepreneurship.
11. Promotes environmental conservation through appropriate technologies.
12. Encourages learners to develop products that improve people's quality of life.

2.0 Identification of Community Needs and Problems

A community need is something required by people to improve their living conditions, safety, productivity or general well-being.

A community problem is a situation that causes difficulty, inconvenience, danger or reduced efficiency among members of a community.

In Electricity Technology, learners identify community problems that can be addressed through electrical devices, electronic systems or the application of electrical principles.

2.1 Sources of Community Problems and Project Opportunities

Learners can identify project opportunities by observing different areas of community life.

a) Homes and residential areas

Common problems include:

- Frequent power interruptions.
- Poor security lighting.
- High electricity consumption.
- Lack of emergency lighting.
- Water tanks overflowing.
- Lack of efficient systems for controlling electrical appliances.

Possible electrical projects:

- Solar-powered security lighting.
- Automatic water-level controller.
- Battery-powered emergency lamp.
- Automatic room-light controller.
- Energy-saving lighting system.

b) Schools and learning institutions

Common problems include:

- Poor lighting in classrooms.
- Lack of security lighting.
- Power interruptions affecting learning.
- Wastage of electricity.
- Inadequate electronic learning facilities.
- Lack of automatic control systems.

Possible electrical projects:

- Solar-powered classroom lighting.
- Automatic corridor lighting.
- School bell control system.

- Energy-monitoring system.
- Electronic security alarm.
- Emergency lighting system.

c) Agriculture and livestock farming

Common problems include:

- Irregular watering of crops.
- Water wastage during irrigation.
- Poor lighting in poultry houses.
- Difficulty monitoring water levels in storage tanks.
- High labour requirements in farm operations.

Possible electrical projects:

- Automatic irrigation controller.
- Solar-powered water pumping system.
- Automatic poultry lighting system.
- Water-level indicator.
- Automatic livestock watering system.

d) Health facilities

Common problems include:

- Lack of emergency lighting.
- Power interruptions.
- Difficulty monitoring certain environmental conditions.
- Need for reliable low-voltage electronic equipment.

Possible electrical projects:

- Solar-powered emergency lighting.
- Battery backup system for selected essential equipment.
- Temperature monitoring device.
- Electronic alert system.

e) Small businesses and trading centres

Common problems include:

- High electricity bills.
- Poor security lighting.
- Loss of power during business operations.
- Manual control of electrical equipment.
- Lack of reliable lighting in shops.

Possible electrical projects:

- Solar-powered shop lighting.
- Automatic security lighting.
- Energy-saving lighting controller.
- Backup lighting system.
- Electronic customer alert system.

2.2 Examples of Community Problems and Proposed Electrical Solutions

Community problem	Proposed electrical project	Electrical principle involved
Water tanks overflow	Automatic water-level controller	Sensors and switching circuits
Dark school pathways	Solar-powered security lighting	Solar energy and electrical circuits
Poultry houses lack adequate lighting	Automatic poultry lighting system	Electronic control and switching
Frequent power interruptions	Emergency lighting system	Battery storage and DC circuits
Water wastage during irrigation	Automatic irrigation controller	Sensors and control circuits
Poor home security	Intruder alarm system	Sensors and electronic circuits
High electricity consumption	Automatic lighting controller	Switching and energy management
Shops lack security lighting	Motion-activated lighting	Motion sensors and control circuits

Note: A proposed solution should address a real need. It should also be appropriate to the local environment and the resources available.

3.0 Methods of Identifying Project Opportunities

There are several methods that learners can use to identify electrical project opportunities in their communities.

3.1 Observation

Observation involves carefully examining the environment to identify problems that may be solved using electrical technology.

Learners observe homes, schools, farms, workshops, health facilities and business premises.

Examples:

- Observing that school pathways are dark at night may lead to a solar security lighting project.
- Observing that a water tank frequently overflows may lead to an automatic water-level controller project.
- Observing that poultry farmers manually switch lights on and off may lead to an automatic poultry lighting project.

Advantages of observation

1. Helps identify actual problems.
2. Provides first-hand information.
3. Encourages learners to understand their environment.
4. Helps identify practical opportunities for innovation.

3.2 Interviews

An interview involves asking individuals questions to obtain information about problems, needs and possible solutions.

Learners may interview:

- Teachers.
- Farmers.
- Electricians.
- Parents.
- Shopkeepers.
- Community leaders.
- Technicians.
- School administrators.

Example interview questions:

1. What electrical problems do you experience in your home or workplace?
2. Which electrical tasks are difficult to perform manually?
3. Do you experience frequent power interruptions?
4. What electrical device would make your work easier?
5. What challenges do you experience when using electrical appliances?
6. What affordable electrical solution would be useful to you?

Importance of interviews

- Provide detailed information about community needs.

- Allow learners to understand the experiences of different people.
- Help establish whether a proposed project will be useful.
- Encourage communication between learners and community members.

3.3 Questionnaires

A questionnaire is a set of written questions used to collect information from a group of people.

Learners can prepare questionnaires to establish the electrical needs of a community.

Example questionnaire

Question	Response
Do you experience power interruptions?	Yes / No
Does your water tank sometimes overflow?	Yes / No
Do you have security lighting?	Yes / No
Would you benefit from solar lighting?	Yes / No
Which electrical problem would you like solved?	_____

Advantages of questionnaires

1. Collect information from many people.
2. Save time when gathering information.
3. Provide responses that can be compared.
4. Help identify common problems in a community.

3.4 Brainstorming

Brainstorming is a group activity in which members freely suggest ideas for solving an identified problem.

During brainstorming, learners share ideas without immediately rejecting suggestions.

Procedure for brainstorming

1. Identify a problem affecting the community.
2. Form a group of learners.
3. Allow each member to suggest possible solutions.
4. Record all relevant suggestions.

5. Discuss the advantages and limitations of each suggestion.
6. Select the most appropriate project idea.

Example:

Problem: Frequent water wastage in a school garden.

Possible ideas:

- Automatic irrigation system.
- Soil-moisture monitoring device.
- Automatic water pump controller.
- Timed irrigation system.

The group evaluates the ideas and selects the most suitable project.

3.5 Research

Research involves collecting information from books, journals, textbooks, manuals, digital media and other reliable sources.

Learners may research:

- How electrical devices operate.
- Materials required for constructing a device.
- Different designs of an electrical system.
- Safety requirements.
- Estimated project costs.
- Possible improvements to existing devices.

Research helps learners make informed decisions before selecting a project.

3.6 Community Discussions and Consultations

Learners may discuss community problems with local leaders, technical experts and other stakeholders.

Such discussions help learners understand:

- The seriousness of the problem.
- The people affected.
- Existing solutions.
- Available resources.
- Possible environmental and safety concerns.

4.0 Proposing Electrical Projects to Solve Identified Problems

After identifying a community problem, learners propose a suitable electrical project that can address the problem.

A project proposal is a brief description of a planned project, explaining the problem to be solved, the proposed solution, how the solution will work and whether it can be implemented.

4.1 Characteristics of a Good Electrical Project

A good electrical project should have the following characteristics:

1. **Relevant:** It should address a real problem in the community.
2. **Achievable:** It should be possible to complete using available resources.
3. **Affordable:** The estimated cost should be reasonable.
4. **Safe:** It should minimise electrical, mechanical and environmental hazards.
5. **Practical:** It should have a clear application in everyday life.
6. **Sustainable:** It should be possible to maintain and operate it over time.
7. **Innovative:** It should introduce a useful idea or improve an existing solution.
8. **Environmentally friendly:** It should minimise pollution and unnecessary waste.
9. **Reliable:** It should perform its intended function consistently.
10. **Time-conscious:** It should be completed within the available time.

4.2 Steps in Proposing an Electrical Project

Step 1: Identify the community problem

Identify a specific problem that requires an electrical solution.

Example: A school water tank frequently overflows, resulting in water wastage.

Step 2: Establish the cause of the problem

Investigate why the problem occurs.

Example:

- The tank is filled manually.
- The person responsible may forget to switch off the pump.
- There is no automatic water-level monitoring system.

Step 3: Identify the people affected

Determine who experiences the problem.

Example:

- Learners.
- Teachers.
- School management.
- Support staff.

Step 4: Generate possible solutions

Brainstorm different electrical solutions.

Examples:

- Automatic water-level controller.
- Water-level indicator with an alarm.
- Automatic pump switching system.

Step 5: Select the most suitable solution

Compare the proposed solutions based on cost, safety, materials, available skills and usefulness.

Step 6: Describe how the proposed device will work

Explain the basic operating principle of the proposed device.

Example:

An automatic water-level controller uses a water-level sensor to detect when the tank is full. The control circuit then switches off the water pump to prevent overflow.

Step 7: Assess feasibility

Determine whether the project can be completed using available materials, tools, skills, time and financial resources.

Step 8: Prepare the project proposal

Document the project title, problem, objectives, proposed solution, materials, operating principle and feasibility analysis.

4.3 Examples of Proposed Electrical Projects

Project 1: Automatic Water-Level Controller

Problem addressed

- Water tanks may overflow when water pumps are left running.
- Overflow results in water wastage.
- Manual monitoring requires constant attention.

Proposed device/system

An automatic water-level controller that switches a water pump on or off depending on the water level.

Basic concept of how it works

1. A sensor or float switch detects the water level.
2. When the water reaches the predetermined upper level, the control circuit switches off the pump.
3. When the water level falls to the lower set level, the circuit can switch the pump on again.
4. The system automatically regulates the filling process.

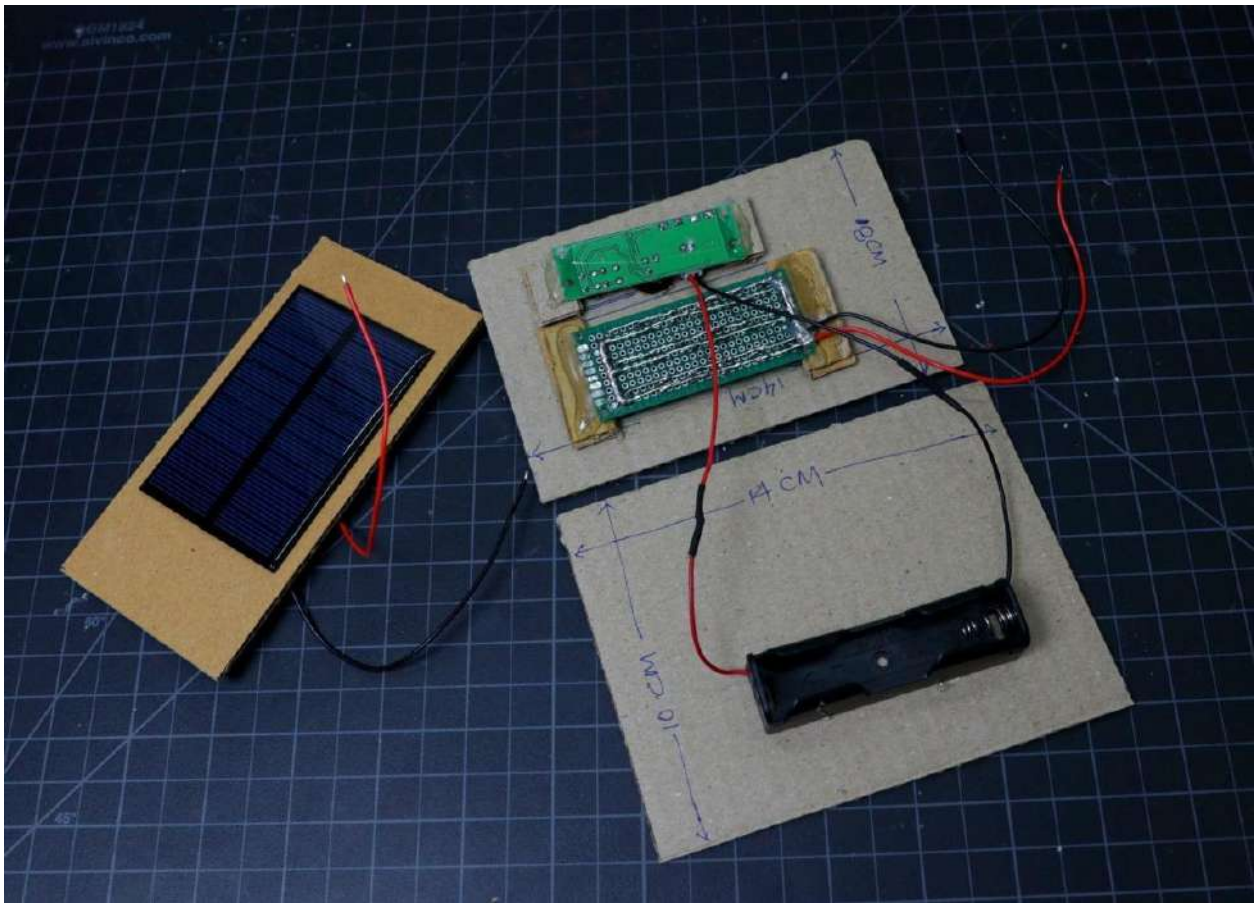
Materials and components

- Float switches or suitable water-level sensors.
- Low-voltage control circuit.
- Relay or suitable switching device.
- Connecting wires.
- Indicator lamps.
- Power supply.
- Demonstration tank or container.

Benefits

- Reduces water wastage.
- Minimises manual monitoring.
- Improves water management.
- Saves time and labour.

Project 2: Solar-Powered Security Lighting System



Problem addressed

- Poor lighting around schools, homes and community pathways.
- Security risks in dark areas.
- Electricity interruptions.

Proposed device/system

A solar-powered lighting system that stores electrical energy in a battery during the day and supplies power to an LED lamp when required.

Basic concept of how it works

1. A solar panel receives sunlight.
2. The solar panel converts light energy into electrical energy.
3. A charge controller regulates charging of the battery.
4. The battery stores electrical energy.
5. The LED lamp uses the stored energy to provide lighting.

6. A light sensor or controller may automatically switch the lamp on when darkness falls.

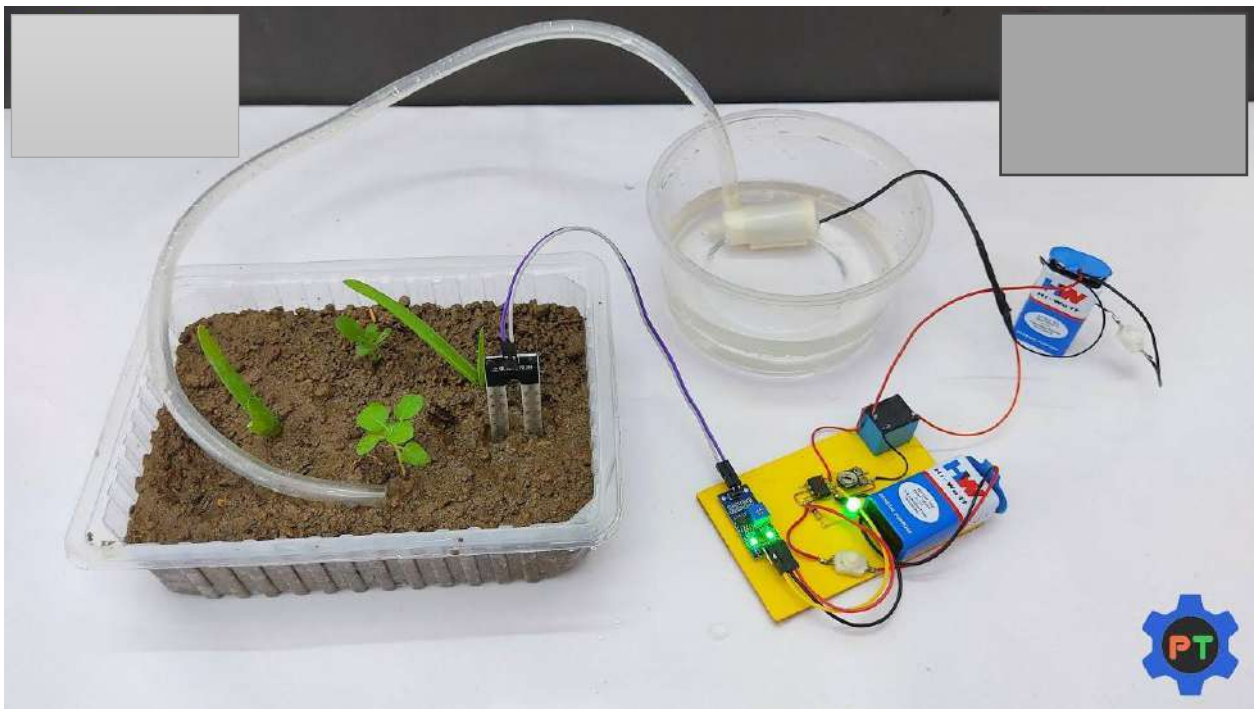
Materials and components

- Solar panel.
- Rechargeable battery.
- Charge controller.
- LED lamp.
- Connecting wires.
- Switch.
- Mounting materials.
- Suitable protective enclosure.

Benefits

- Provides lighting during power interruptions.
- Reduces dependence on grid electricity.
- Uses renewable energy.
- Improves security and visibility.

Project 3: Automatic Irrigation Controller



Problem addressed

- Water wastage during irrigation.
- Irregular watering of crops.
- High labour requirements in small-scale farming.

Proposed device/system

An automatic irrigation controller that uses a soil-moisture sensor to regulate water supply to plants.

Basic concept of how it works

1. A soil-moisture sensor measures the moisture condition of the soil.
2. The sensor sends a signal to the control circuit.
3. When the soil becomes too dry, the controller activates a pump or valve.
4. Water flows to the plants.
5. When the required moisture level is reached, the controller switches off the pump or closes the valve.

Materials and components

- Soil-moisture sensor.
- Control circuit or microcontroller.
- Low-voltage water pump or solenoid valve.
- Water container.
- Connecting wires.
- Power supply.
- Irrigation pipes or tubes.

Benefits

- Reduces water wastage.
- Improves water management.
- Saves labour.
- Supports efficient crop production.

Project 4: Automatic Security Alarm System



Problem addressed

- Unauthorised entry into homes, classrooms and business premises.
- Delayed detection of intruders.
- Inadequate security alert systems.

Proposed device/system

An electronic alarm system that detects unauthorised opening of a door or window and activates a warning sound.

Basic concept of how it works

1. A magnetic switch or suitable sensor is fitted to a door or window.
2. When the door or window is opened, the sensor changes its electrical state.
3. The control circuit detects the change.
4. The circuit activates a buzzer or warning light.
5. The alarm alerts people to possible unauthorised entry.

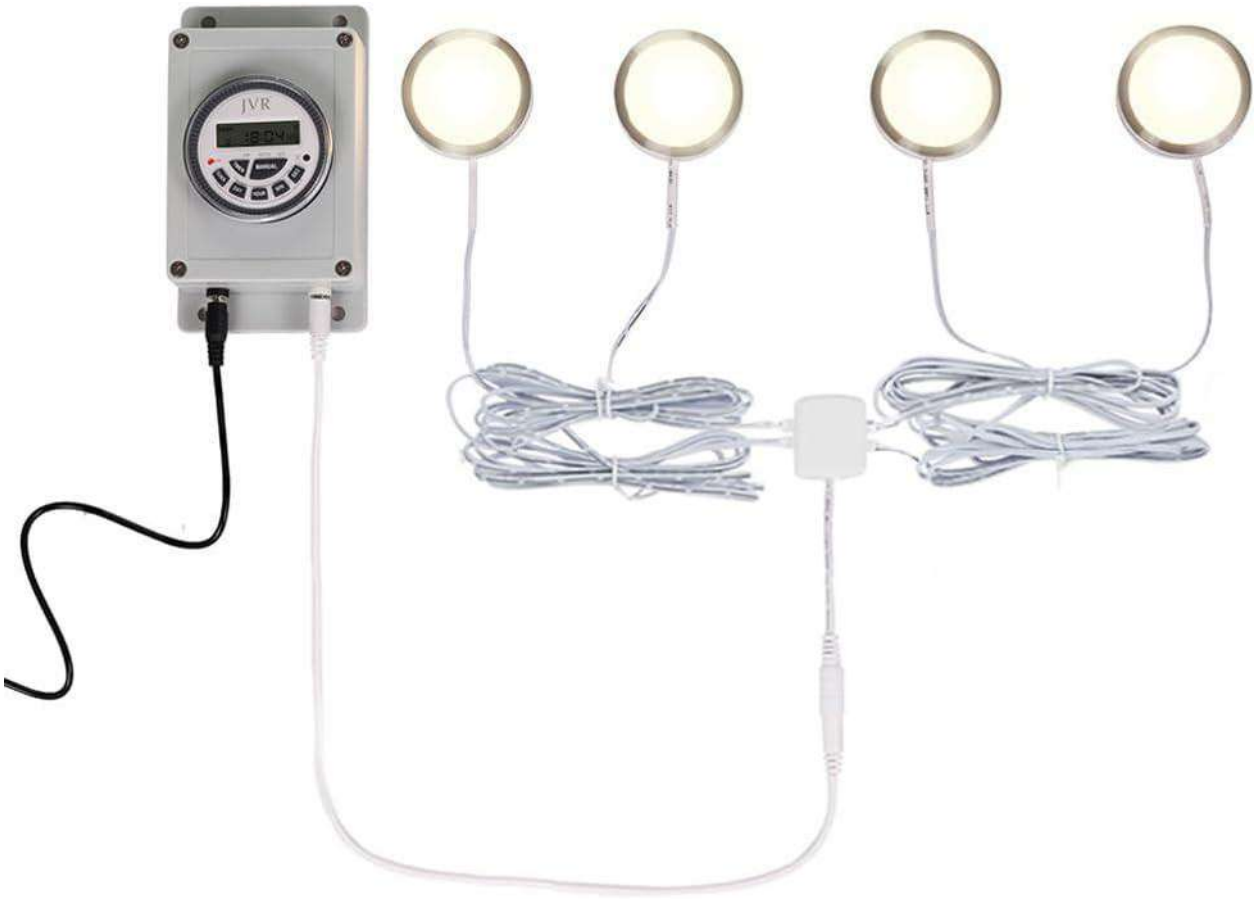
Materials and components

- Magnetic reed switch or other suitable sensor.
- Buzzer.
- LED indicator.
- Resistors.
- Transistor or logic control circuit.
- Connecting wires.
- Low-voltage battery.

Benefits

- Improves security awareness.
- Provides an early warning.
- Can be constructed using relatively simple electronic components.

Project 5: Automatic Poultry Lighting System



Problem addressed

- Manual switching of poultry-house lighting.
- Inconsistent lighting schedules.
- Time spent controlling lighting manually.

Proposed device/system

An automatic lighting controller that switches poultry-house lights according to a preset schedule or light level.

Basic concept of how it works

1. A timer or light sensor monitors the set operating condition.
2. The controller determines when lighting is required.
3. A relay or suitable switching device controls the lamp.
4. The lamp switches on or off according to the programmed setting.

Materials and components

- Timer module or light sensor.
- Control circuit.
- Relay.
- LED lamp.
- Power supply.
- Connecting wires.

- Protective enclosure.

Benefits

- Reduces manual work.
- Provides consistent lighting control.
- Helps farmers manage lighting schedules.

Important: The lighting schedule should be appropriate for the type and age of poultry. Automatic control should not replace proper animal-care practices.

5.0 Justification and Feasibility of an Identified Project

5.1 Meaning of Project Justification

Project justification is the explanation of why a proposed project is necessary, useful and appropriate for solving an identified problem.

It provides reasons why the project should be undertaken.

A project is justified when it addresses a genuine need and offers benefits that make the use of resources worthwhile.

5.2 Importance of Justifying a Project

Project justification helps to:

1. Explain the need for the proposed project.
2. Show how the project will benefit the community.
3. Establish whether the project is worth undertaking.
4. Support decision-making during project selection.
5. Identify the expected results.
6. Encourage responsible use of resources.
7. Convince stakeholders to support the project.
8. Demonstrate the relevance of the project to community needs.

5.3 Factors to Consider When Justifying an Electrical Project

a) The seriousness of the problem

The project should address a problem that significantly affects the community.

For example, a school that frequently experiences water wastage may benefit from an automatic water-level controller.

b) Benefits to the community

The project should provide clear benefits to the intended users.

Examples:

- Improved safety.
- Reduced energy consumption.
- Reduced water wastage.

- Improved productivity.
- Increased convenience.

c) Cost-effectiveness

The expected benefits should justify the money and resources spent on the project.

d) Availability of resources

The project should be supported by accessible materials, components, tools and equipment.

e) Technical suitability

The proposed technology should be appropriate for solving the identified problem.

f) Environmental impact

The project should minimise environmental damage and encourage responsible use of resources.

g) Sustainability

The proposed solution should be maintainable and affordable to operate over time.

h) Safety

The project should be designed and implemented with appropriate safety precautions.

5.4 Meaning of Project Feasibility

Project feasibility is the assessment of whether a proposed project can be successfully implemented using the available resources and within the required conditions.

A feasibility analysis is carried out before committing resources to a project.

It helps learners determine whether the proposed project is practical, affordable, safe and achievable.

5.5 Types of Project Feasibility

1. Technical feasibility

Technical feasibility determines whether the required technology, components, tools and technical knowledge are available to complete the project.

Factors to consider:

- Availability of electrical and electronic components.
- Availability of suitable tools and equipment.
- Availability of technical knowledge.
- Complexity of the proposed design.
- Ability to test and maintain the system.

Example:

A simple solar lighting project may be technically feasible if the learner can access a solar panel, rechargeable battery, charge controller and LED lamp.

2. Economic feasibility

Economic feasibility determines whether the project is affordable and whether its expected benefits justify its costs.

Factors to consider:

- Cost of materials.
- Cost of tools and equipment.
- Cost of installation.
- Cost of operation.
- Maintenance expenses.
- Expected savings or benefits.

Example:

A solar lighting project may require an initial investment but reduce dependence on grid electricity in the long term.

3. Operational feasibility

Operational feasibility determines whether the proposed system can be used effectively by the intended users.

Factors to consider:

- Ease of operation.
- Reliability of the system.
- Availability of users with the required knowledge.
- Maintenance requirements.
- Suitability to the users' daily activities.

Example:

An automatic water-level controller should be easy for school support staff to operate and maintain.

4. Time feasibility

Time feasibility determines whether the project can be completed within the available period.

Factors to consider:

- Time needed to obtain materials.
- Time required for construction.
- Time required for testing.
- Time required for corrections and improvements.
- Project submission deadline.

5. Safety feasibility

Safety feasibility determines whether the project can be implemented and operated without exposing users to unacceptable risks.

Factors to consider:

- Risk of electric shock.
- Risk of short circuits.

- Risk of overheating.
- Risk of fire.
- Exposure to water and moisture.
- Proper insulation and enclosure.
- Availability of protective devices.

6. Environmental feasibility

Environmental feasibility determines whether the project is environmentally acceptable.

Factors to consider:

- Energy efficiency.
- Waste generation.
- Disposal of batteries and electronic components.
- Use of renewable energy.
- Environmental effects of materials used.

5.6 Feasibility Checklist

A feasibility checklist is a list of questions used to assess whether a proposed project can be implemented successfully.

The checklist helps learners evaluate materials, tools, skills, cost, time, safety and other requirements.

Sample feasibility checklist

No.	Feasibility factor	Guiding question	Yes/No
1	Materials	Are the required materials available?	
2	Tools	Are the necessary tools accessible?	
3	Skills	Do we have the skills needed to complete the project?	
4	Cost	Can the project be completed within the available budget?	
5	Time	Can the project be completed within the given time?	
6	Safety	Can the project be constructed and operated safely?	

7	Technical require-ments	Is the technology suitable for the project?	
8	Maintenance	Can the project be maintained after completion?	
9	Environmental im-pact	Will the project minimise environmental harm?	
10	Community benefit	Will the project solve the identified problem?	

A project with several negative responses may require redesigning, additional resources or selection of an alternative project.

5.7 Example of a Feasibility Analysis

Proposed project: Solar-Powered Classroom Lighting System

Factor	**Analysis**	**Assessment**
Materials	Solar panel, battery, LED lamps and wires can be obtained locally.	Feasible
Tools	Basic electrical tools and measuring instruments are avail-able.	Feasible
Skills	Learners can assemble a low-voltage demonstration circuit under supervision.	Feasible
Cost	The project can be constructed using a small demonstra-tion budget.	Feasible, subject to costing
Time	The system can be assembled and tested within the pro-ject period.	Feasible
Safety	A low-voltage demonstration system can be used with suit-able protection.	Feasible
Maintenance	Components can be inspected and replaced when neces-sary.	Feasible

Environmental impact	Solar energy reduces dependence on grid electricity.	Feasible

Conclusion: The solar-powered classroom lighting system is a suitable project because it addresses poor lighting and power interruptions. Its implementation is possible if the required components, budget and supervision are available.

5.8 Project Selection Matrix

A project selection matrix helps learners compare several project ideas using agreed criteria.

For example, learners may score each project from 1 to 5, where:

- 1 = Very poor.
- 2 = Poor.
- 3 = Fair.
- 4 = Good.
- 5 = Excellent.

Example: Comparing three project ideas

Selection criterion	Solar lighting	Water-level controller	Security alarm
Community need	5	5	4
Availability of materials	4	4	5
Affordability	3	4	5
Technical skills available	4	4	4
Safety and manageability	4	4	4
Ease of maintenance	4	4	5
Total score	24	25	27

The security alarm has the highest score in this example. However, the final choice should also consider the seriousness of the community problem and whether the proposed system can meet the intended need.

Note: The scores above are illustrative. Learners should conduct their own assessment using information collected from their communities.

6.0 Documentation of a Project Portfolio

6.1 Meaning of a Project Portfolio

A project portfolio is an organised collection of documents, records, drawings and other evidence that describe an identified project and show how it is planned and developed.

In Electricity Technology, a project portfolio provides information about the community problem, the proposed electrical solution, the operating principle and the feasibility of implementing the project.

A portfolio helps learners organise their ideas and communicate their proposals clearly.

6.2 Importance of a Project Portfolio

A project portfolio is important because it:

1. Provides a permanent record of the identified project.
2. Organises information about the project.
3. Explains the problem the project intends to solve.
4. Shows the proposed electrical device or system.
5. Provides evidence of research and investigations.
6. Helps learners plan the use of resources.
7. Supports communication between learners and teachers.
8. Helps assess learners' understanding and progress.
9. Provides a reference during project implementation.
10. Helps identify areas that require improvement.
11. Encourages responsibility and proper record keeping.
12. Provides evidence of the learner's creativity and problem-solving ability.

6.3 Contents of an Electrical Project Portfolio

A project portfolio should contain relevant information about the proposed project.

1. Project title

The project title is the name given to the proposed project.

It should be brief, clear and directly related to the intended solution.

Examples:

- Design of an Automatic Water-Level Controller.
- Development of a Solar-Powered Security Lighting System.
- Construction of an Electronic Intruder Alarm.
- Design of an Automatic Irrigation Controller.

2. Background information

This section provides a brief explanation of the situation that led to the identification of the project.

It describes the environment in which the problem occurs and gives relevant background information.

Example:

The school uses a water pump to fill a storage tank. Sometimes the pump continues operating after the tank is full, resulting in water overflow. This causes water wastage and requires staff to monitor the filling process.

3. Problem statement

A problem statement is a clear description of the specific problem that the project intends to solve.

It should explain:

- What the problem is.
- Where the problem occurs.
- Who is affected.
- Why the problem needs to be addressed.

Example:

The school experiences water wastage because the water storage tank is filled manually without an automatic control system. This causes overflow when the pump is not switched off in time.

4. Proposed electrical device or system

This section describes the device or system that will be developed to solve the identified problem.

Example:

An automatic water-level controller that detects the water level and switches the water pump off when the tank is full.

5. Project objectives

Project objectives are the specific results that the project intends to achieve.

Objectives should be clear, realistic and related to the problem.

Example objectives for an automatic water-level controller:

- To design a simple water-level monitoring system.
- To construct a control circuit that responds to changes in water level.
- To demonstrate automatic switching of a water pump.
- To reduce water wastage caused by tank overflow.
- To test the performance of the proposed system.

6. Basic concept of how the project works

This section explains the scientific and electrical principles used in the proposed device.

It may include:

- A description of the operating principle.

- A block diagram.
- A simple circuit diagram.
- The function of important components.
- The sequence of operation.

Example:

The water-level sensor detects the water level and sends a signal to the control circuit. When the tank reaches the set upper level, the circuit operates a switching device to disconnect the pump.

7. Materials and components required

This section lists the materials and electrical components required for the project.

Example:

No.	Material/component	Purpose
1	Water-level sensor	Detects the water level
2	Relay or suitable switching device	Controls the pump circuit
3	Connecting wires	Provide electrical connections
4	Indicator LED	Shows the operating condition
5	Low-voltage power supply	Supplies power to the control circuit
6	Demonstration container	Represents the water tank
7	Mounting board	Supports the components

8. Tools and equipment required

This section lists the tools and equipment needed to construct and test the project.

Examples:

- Screwdrivers.
- Wire strippers.
- Combination pliers.
- Digital multimeter.

- Soldering iron, where appropriate.
- Measuring tape.
- Small spanners.
- Breadboard or suitable mounting board.

9. Feasibility analysis

This section explains whether the proposed project can be successfully completed.

It should consider:

- Availability of materials.
- Availability of tools.
- Technical skills.
- Estimated cost.
- Time available.
- Safety requirements.
- Maintenance.
- Environmental impact.

10. Estimated project budget

The budget provides an estimate of the money required to obtain materials and complete the project.

Example:

No.	Item	Quantity	Estimated cost (KSh)
1	Water-level sensor	1	300
2	Relay module	1	250
3	LED indicator	2	40
4	Connecting wires	1 set	150
5	Low-voltage power supply	1	400
6	Mounting board	1	200

	Total		1,340

The figures are illustrative estimates for learning purposes. Actual prices should be established through local quotations.

11. Project work plan

A work plan shows the activities to be completed and the time allocated to each activity.

Example:

Activity	**Estimated duration**
Identification of the community problem	1 day
Research and information gathering	2 days
Generation of possible solutions	1 day
Selection of the project	1 day
Feasibility analysis	1 day
Preparation of the project proposal	2 days
Presentation of the proposal	1 day

12. Safety precautions

This section describes the precautions that should be observed during the construction, testing and use of the proposed device.

Examples:

- Use an appropriate low-voltage supply for classroom demonstrations.
- Disconnect the power supply before changing circuit connections.
- Avoid touching exposed conductors.
- Use insulated tools where appropriate.
- Ensure that electrical connections are secure.

- Keep electrical components away from water unless they are specifically designed and protected for such conditions.
- Use appropriate fuses and protective devices.
- Obtain teacher supervision when working with electrical equipment.

13. Expected benefits

This section describes the positive results expected after implementing the project.

Examples:

- Reduced water wastage.
- Improved safety.
- Reduced manual labour.
- Improved energy efficiency.
- Increased convenience.
- Better management of available resources.

14. References

This section lists the sources of information used when developing the project proposal.

Sources may include:

- Electricity Technology textbooks.
- Electrical installation manuals.
- Electronic component datasheets.
- Technical journals.
- Reliable educational websites.
- Information obtained from interviews.

6.4 Sample Project Portfolio

PROJECT PORTFOLIO

Design of an Automatic Water-Level Controller

1. Project title

Design of an Automatic Water-Level Controller.

2. Problem addressed

Water is wasted when storage tanks overflow because pumps are not switched off at the appropriate time.

3. Proposed device/system

An automatic water-level controller that detects water levels and controls the operation of a pump.

4. Basic concept of how it works

A water-level sensor detects the water level and sends a signal to a control circuit. The control circuit operates a relay or suitable switching device to switch the pump off when the tank is full. It can also switch the pump on when the water level falls to a predetermined lower level.

5. Main materials and components

- Water-level sensors or float switches.
- Relay or suitable switching device.
- Low-voltage power supply.
- Indicator LEDs.
- Connecting wires.
- Demonstration water container.
- Mounting board.

6. Tools required

- Digital multimeter.
- Screwdrivers.
- Pliers.
- Wire strippers.
- Measuring instruments.

7. Feasibility analysis

- Materials: Components can be sourced from electrical and electronic suppliers.
- Tools: Basic electronic tools are sufficient for a demonstration model.
- Skills: Learners can assemble the low-voltage circuit under teacher supervision.
- Cost: A simple prototype can be developed using a manageable budget.
- Time: The project can be completed within the allocated project period.
- Safety: A low-voltage prototype can be used with appropriate precautions.

8. Expected benefits

- Reduces water wastage.
- Reduces manual monitoring.
- Improves water management.
- Saves time and labour.

9. Conclusion

The proposed automatic water-level controller is a practical solution to water wastage caused by over-flowing storage tanks. It applies electrical and electronic principles to solve a problem affecting the community.

6.5 Qualities of a Good Project Portfolio

A good project portfolio should be:

1. Well organised.
2. Clearly written.
3. Accurate and relevant.
4. Complete.
5. Neatly presented.
6. Easy to understand.
7. Supported by appropriate diagrams and illustrations.
8. Based on reliable information.
9. Realistic in terms of cost and available resources.
10. Properly dated and referenced.

7.0 Systematic Process of Project Identification

7.1 Meaning of a Systematic Process

A systematic process is an organised sequence of steps followed to achieve a particular objective.

In project identification, a systematic process ensures that learners identify community problems, investigate them, propose solutions and evaluate the feasibility of their ideas in an orderly manner.

Following a systematic process reduces errors and helps learners select suitable projects.

7.2 Stages in the Project Identification Process

Stage 1: Community observation

Learners examine their surroundings to identify challenges that can be solved using electrical principles.

Stage 2: Problem identification

Learners identify a specific problem that requires attention.

Stage 3: Information gathering

Learners collect information through interviews, questionnaires, observation, research and community discussions.

Stage 4: Problem analysis

Learners investigate the causes, effects and people affected by the problem.

Stage 5: Brainstorming possible solutions

Learners generate different electrical project ideas that could solve the problem.

Stage 6: Evaluation of project ideas

Learners compare the proposed solutions using criteria such as cost, materials, tools, skills, safety and usefulness.

Stage 7: Selection of the most suitable project

Learners select the project that best addresses the identified problem and can be implemented with available resources.

Stage 8: Feasibility analysis

Learners determine whether the project is technically, economically, operationally, environmentally and safely achievable.

Stage 9: Project proposal development

Learners prepare a proposal explaining the project title, problem, proposed device, operating principle and feasibility.

Stage 10: Portfolio documentation

Learners organise all relevant information and evidence into a project portfolio.

Stage 11: Presentation of the project proposal

Learners present their proposals to the teacher, classmates or relevant community stakeholders for discussion and feedback.

7.3 Flowchart of the Project Identification Process

A flowchart is a diagram that uses symbols and arrows to represent the sequence of activities in a process.

In project identification, a flowchart shows the steps followed from recognising a community problem to preparing a project proposal.

START

Observe the community

Identify possible needs and opportunities

Identify a problem

Define the challenge to be addressed

Gather information

Observe, interview, research and consult

Brainstorm possible solutions

Evaluate project ideas

Compare cost, materials, tools, skills and safety

Select the most suitable project

Conduct feasibility analysis

Prepare project proposal

Compile project portfolio

END: Present the project proposal

Importance of using a flowchart

1. Shows the order of activities clearly.

2. Makes the project identification process easier to understand.
3. Helps learners follow the correct sequence.
4. Reduces omission of important stages.
5. Makes it easier to communicate project ideas.
6. Helps identify stages where decisions must be made.

7.4 Common Flowchart Symbols

Symbol	Name	Function
Oval	Terminal	Represents the start or end of a process
Rectangle	Process	Represents an activity or operation
Diamond	Decision	Represents a question or decision
Parallelogram	Input/Output	Represents information entering or leaving a process
Arrow	Flow line	Shows the direction of the process

8.0 Roles of Teamwork and Collaboration in Project Identification

Teamwork is the process of working together as a group to achieve a common goal.

Collaboration involves sharing ideas, knowledge, skills and responsibilities to complete a task.

Project identification often requires learners to work together because different members may have different experiences, ideas and technical abilities.

8.1 Importance of Teamwork

Teamwork is important because it:

1. Encourages sharing of ideas.
2. Promotes creativity and innovation.
3. Helps learners identify more community problems.
4. Encourages respect for different opinions.
5. Makes it easier to gather information.
6. Promotes responsibility and accountability.
7. Helps learners share tasks according to their abilities.

8. Improves decision-making.
9. Encourages effective communication.
10. Develops leadership and interpersonal skills.

8.2 Roles of Group Members

Group member	Responsibility
Group leader	Coordinates activities and guides discussions
Secretary	Records ideas, decisions and meeting proceedings
Researcher	Collects information about the identified problem
Technical member	Investigates possible electrical solutions
Resource coordinator	Identifies materials, tools and estimated costs
Safety coordinator	Identifies possible hazards and safety precautions
Presenter	Communicates the project proposal to others

In a small group, one learner may perform more than one responsibility.

8.3 Qualities of Effective Team Members

Effective team members should:

- Be responsible.
- Listen to others.
- Respect different opinions.
- Communicate clearly.
- Share information honestly.
- Complete assigned tasks.
- Cooperate with other members.
- Accept constructive criticism.

- Resolve disagreements peacefully.

9.0 Safety and Environmental Considerations During Project Identification

Safety and environmental considerations should be included when identifying and proposing electrical projects.

A project should not only solve a community problem but also protect users, property and the environment.

9.1 Electrical Safety Considerations

1. Use appropriate voltage levels for the intended application.
2. Avoid exposed live conductors.
3. Use correctly rated cables and components.
4. Include suitable fuses and circuit protection.
5. Ensure proper insulation of electrical connections.
6. Avoid working with electrical equipment in wet conditions unless the equipment is designed and protected for such use.
7. Disconnect power before making circuit adjustments.
8. Use appropriate personal protective equipment.
9. Follow manufacturers' instructions and component datasheets.
10. Ensure that mains-voltage work is carried out only by qualified persons under applicable electrical safety requirements.

9.2 Environmental Considerations

1. Use energy-efficient electrical components.
2. Consider renewable energy sources where appropriate.
3. Avoid unnecessary material wastage.
4. Reuse suitable materials where safe and practical.
5. Dispose of damaged batteries responsibly.
6. Avoid releasing electronic waste into the environment.
7. Select durable materials to reduce frequent replacement.
8. Consider the environmental effects of the proposed project throughout its life cycle.

9.3 Challenges Encountered During Project Identification

Learners may experience several challenges when identifying electrical projects.

Challenge	Possible solution
Limited information about community needs	Conduct interviews, observation and research

Limited funds	Select affordable projects or seek support
Lack of technical skills	Consult teachers and qualified technicians
Unavailability of materials	Identify suitable alternative components
Poor teamwork	Assign responsibilities and encourage communication
Unrealistic project ideas	Conduct feasibility analysis
Safety concerns	Consult technical experts and follow safety procedures
Limited time	Prepare a realistic work plan
Community resistance	Explain the benefits and consult stakeholders

10.0 Application of Project Identification in the Kenyan Community

Electrical project identification can help address challenges experienced in different sectors of the Kenyan economy.

10.1 Application in Education

Electrical projects can improve learning environments through:

- Solar-powered classroom lighting.
- Automatic school bell systems.
- Electronic security alarms.
- Energy-saving lighting systems.
- Emergency lighting systems.

10.2 Application in Agriculture

Electrical projects can support agricultural production through:

- Solar-powered water pumps.
- Automatic irrigation systems.
- Soil-moisture monitoring devices.
- Automatic poultry lighting.
- Electronic water-level controllers.

10.3 Application in Health Services

Electrical projects can support health facilities through:

- Solar-powered lighting.
- Backup power systems for essential equipment.
- Temperature monitoring devices.
- Electronic warning and alert systems.

10.4 Application in Small-Scale Industries

Electrical projects can improve productivity through:

- Automatic machine control systems.
- Electronic counting devices.
- Energy-monitoring systems.
- Automatic lighting controllers.
- Simple electronic testing equipment.

10.5 Application in Homes

Electrical projects can improve household convenience and safety through:

- Automatic security lights.
- Electronic door alarms.
- Automatic water-pump controllers.
- Battery-powered emergency lamps.
- Energy-saving lighting systems.

14.0 Practical Learning Activities

Activity 1: Identifying Community Problems

Objective: To identify problems in the community that can be solved using electrical principles.

Requirements:

- Exercise books.
- Pens.
- Observation checklist.
- Access to the school or local community.

Procedure:

1. Form groups of four to five learners.
2. Observe the school or surrounding community.
3. Identify at least five problems that may require electrical solutions.
4. Record the problems in an exercise book.
5. Identify the people affected by each problem.

6. Suggest an electrical solution for each problem.
7. Present the findings to the class.

Expected outcome: Learners should be able to identify community needs and suggest relevant electrical projects.

Activity 2: Brainstorming Electrical Project Ideas

Objective: To generate possible electrical projects that address community problems.

Procedure:

1. Select one problem identified in Activity 1.
2. Form groups and discuss possible solutions.
3. Record all proposed solutions.
4. Compare the solutions according to cost, usefulness, materials and safety.
5. Select the most suitable project.
6. Explain why the project was selected.

Expected outcome: Learners should be able to propose practical electrical projects.

Activity 3: Conducting a Feasibility Analysis

Objective: To evaluate whether a proposed electrical project can be implemented.

Procedure:

1. Select an electrical project.
2. List the materials and components required.
3. Identify the necessary tools and equipment.
4. Determine the skills needed.
5. Estimate the cost of the project.
6. Identify possible safety hazards.
7. Determine whether the project can be completed within the available time.
8. Complete a feasibility checklist.
9. Present the findings.

Expected outcome: Learners should be able to justify the feasibility of a proposed electrical project.

Activity 4: Compiling a Project Portfolio

Objective: To document an identified electrical project.

Procedure:

1. Select a project idea.
2. Write the project title.
3. Describe the problem it addresses.
4. State the objectives.

5. Describe the proposed electrical device or system.
6. Explain the basic operating principle.
7. List materials, components, tools and equipment.
8. Prepare a feasibility analysis.
9. Estimate the project cost.
10. State the expected benefits.
11. Organise the information into a project portfolio.

Expected outcome: Learners should be able to prepare a clear and organised project portfolio.

Activity 5: Drawing a Project Identification Flowchart

Objective: To illustrate the systematic process of identifying an electrical project.

Procedure:

1. Identify a community problem.
2. List the stages involved in identifying a suitable project.
3. Arrange the stages in the correct order.
4. Select appropriate flowchart symbols.
5. Draw the flowchart using arrows to show the direction of the process.
6. Present the flowchart to the class.

Expected outcome: Learners should be able to demonstrate the systematic process of project identification using a flowchart.

15.0 Assessment Activities

Learners can be assessed through:

1. Oral questions on the meaning of project identification.
2. Written explanations of community problems.
3. Group discussions and brainstorming activities.
4. Observation reports.
5. Interviews and questionnaires.
6. Project selection matrices.
7. Completed feasibility checklists.
8. Project proposals.
9. Project portfolios.
10. Flowcharts showing the project identification process.
11. Group presentations.
12. Peer assessment and self-assessment.

16.0 Summary of the Sub-Strand

Project identification is an important stage in the development of electrical projects. It involves recognising problems and opportunities in the community that can be addressed using electrical and electronic principles.

The main stages include:

1. Observing the community.
2. Identifying a specific problem.
3. Gathering relevant information.
4. Analysing the problem.
5. Brainstorming possible solutions.
6. Evaluating proposed project ideas.
7. Selecting the most appropriate project.
8. Conducting feasibility analysis.
9. Preparing a project proposal.
10. Documenting the project in a portfolio.
11. Presenting the project proposal.

A suitable electrical project should be relevant, affordable, achievable, safe, sustainable and beneficial to the community.

Project identification encourages creativity, innovation, teamwork, critical thinking and the practical application of electrical knowledge to solve real-life problems.

17.0 Glossary of Key Terms

Term	**Meaning**
Project	A planned activity undertaken to achieve a specific objective.
Project identification	The process of recognising a problem and proposing a suitable project to address it.
Community	A group of people living or interacting within a particular area or social setting.
Electrical principles	Basic concepts and laws governing the behaviour and application of electricity.
Project proposal	A document describing a planned project and how it will address a particular problem.

Feasibility	The possibility of successfully implementing a proposed project.
Project justification	Reasons explaining why a project is necessary and worth undertaking.
Project portfolio	An organised collection of documents and evidence relating to a project.
Brainstorming	A group process of generating ideas to solve a problem.
Observation	Careful examination of the environment to identify problems or opportunities.
Questionnaire	A set of written questions used to collect information.
Interview	A conversation in which questions are asked to obtain information.
Flowchart	A diagram showing the sequence of steps in a process.
Sustainability	The ability of a project or system to continue providing benefits over time.
Project budget	An estimate of the money required to complete a project.
Project objectives	Specific results that a project intends to achieve.
Technical feasibility	The possibility of completing a project using available technology, tools and skills.
Economic feasibility	The affordability and financial suitability of a project.
Operational feasibility	The ability of intended users to operate and maintain a proposed system.

Revision Questions

Section A: Short Answer Questions

1. Define the term project identification.
2. State five sources of community problems that can be solved using electrical principles.
3. Explain four methods of identifying project opportunities.
4. State five characteristics of a good electrical project.
5. Give five examples of electrical projects that can benefit a school.
6. Explain the meaning of project justification.
7. State six factors considered when justifying an electrical project.
8. Define project feasibility.
9. Explain five types of project feasibility.
10. State six items that should be included in a feasibility checklist.
11. Explain five reasons for preparing a project portfolio.
12. List eight components of an electrical project portfolio.
13. Explain the importance of teamwork during project identification.
14. State five safety considerations when proposing an electrical project.
15. Explain the importance of using a flowchart during project identification.

Section B: Structured Questions

1. Project Identification (8 marks)

a) Define project identification. (2 marks)

b) State three methods of identifying community problems that can be solved using electrical principles. (3 marks)

c) Give three examples of electrical projects that can address problems in a Kenyan school. (3 marks)

2. Community Needs and Electrical Solutions (8 marks)

A school experiences frequent water wastage because its water storage tank overflows when the pump is left running.

a) Identify the main problem in the school. (1 mark)

b) Propose a suitable electrical project to solve the problem. (2 marks)

c) Explain how the proposed device or system would operate. (3 marks)

d) State two benefits of the proposed project. (2 marks)

3. Project Feasibility (8 marks)

a) Define project feasibility. (2 marks)

b) State four factors considered when evaluating the feasibility of an electrical project. (4 marks)

c) Explain two reasons why safety feasibility is important. (2 marks)

4. Project Portfolio (8 marks)

a) Define a project portfolio. (2 marks)

b) List four items that should be included in an electrical project portfolio. (4 marks)

c) State two benefits of documenting an identified project. (2 marks)

5. Systematic Project Identification (9 marks)

a) Explain the meaning of a systematic process. (2 marks)

b) Outline five stages followed when identifying an electrical project. (5 marks)

c) State two advantages of using a flowchart in project identification. (2 marks)

6. Project Proposal and Justification (9 marks)

A farming community experiences water shortages during dry seasons.

a) Identify one electrical project that could help address this problem. (2 marks)

b) State three materials or components required for the proposed project. (3 marks)

c) Give two reasons why the proposed project would benefit the community. (2 marks)

d) State two safety precautions to observe when developing the project. (2 marks)

End of Sub-strand 4.4

Editorial note: The curriculum heading supplied is written as *4.2 Electronics, 4.4 Project Identification*. For consistency with the earlier Electronics content, the notes use **Strand 4.0: Electronics, Sub-strand 4.4: Project Identification**. Verify the strand numbering against the official Grade 11 curriculum design before publication.