

Subject Name & Code:

## BASIC ELECTRICAL ENGINEERING- BE01R00051

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### Experiment – 1

#### Answers: Experiment Quiz – Kirchhoff's Laws

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##### 1. State Kirchhoff's laws in the context of DC circuits.

Kirchhoff's laws are fundamental principles used for the analysis of electrical circuits under steady-state DC conditions. They are formulated as follows:

##### **Kirchhoff's Current Law (KCL):**

At any junction (node) in an electrical circuit, the algebraic sum of currents entering and leaving the node is zero. Mathematically,

$$\sum I_{\text{in}} = \sum I_{\text{out}} \text{ or } \sum I = 0.$$

This law is based on the principle of conservation of charge, implying that charge cannot accumulate at a node.

##### **Kirchhoff's Voltage Law (KVL):**

Around any closed loop (mesh) in a circuit, the algebraic sum of all voltage drops and electromotive forces (emfs) is zero. Mathematically,

$$\sum V = 0.$$

This law arises from the conservation of energy, ensuring that the net energy gained per unit charge around a closed path is zero.

In DC circuit analysis, these laws are applied to determine unknown currents, voltages, and resistances by setting up systems of linear equations based on circuit topology.

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##### 2. Any closed path formed by the branches in a network is called a \_\_\_\_\_.

**Answer: Loop**

A loop is any closed conducting path in a network formed by branches, where the starting and ending nodes are the same. Loops can be of any shape or size and may contain other loops within them. In contrast, a *mesh* is a special type of loop that does not enclose any other loops within it (i.e., a minimal loop in a planar circuit).

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##### 3. In a network having N nodes, the number of independent equations required to solve the network, with ground as the reference node, is \_\_\_\_\_.

**Answer:  $N - 1$** 

For a network with  $N$  nodes, one node is typically designated as the reference (ground) node. Applying KCL at each of the remaining  $(N - 1)$  nodes yields a set of independent equations sufficient to describe the currents in the circuit. These equations, together with those obtained from KVL for independent loops, form a complete system for solving all branch currents and node voltages.

**4. Differentiate loop and Mesh.**

Aspect	Loop	Mesh
<b>Definition</b>	Any closed path in a circuit, regardless of whether it contains other loops.	A loop that does not contain any other loops within it (a minimal loop in a planar circuit).
<b>Enclosed area</b>	May enclose other loops or branches.	Does not enclose any other loops; it is the simplest possible closed path.
<b>Independence</b>	Not all loops are independent for KVL equations.	Meshes are inherently independent loops in planar circuits.
<b>Use in analysis</b>	Used in KVL generally, but care must be taken to select independent loops.	Preferred in <b>Mesh Analysis</b> because each mesh provides an independent KVL equation.
<b>Example in a circuit</b>	In a circuit with multiple components, several overlapping loops can exist.	In a planar circuit, meshes correspond to the “windows” of the circuit diagram.

## Experiment – 2

### Answers: Experiment Quiz – Superposition Theorem

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#### 1. State superposition theorem.

The **Superposition Theorem** states that in a **linear electrical network** containing multiple independent sources (voltage or current sources), the response (current through or voltage across any element) can be determined by considering the effect of each independent source acting alone, while all other independent sources are turned off. The total response is then the **algebraic sum** of the individual responses.

#### Procedure for applying the theorem:

- **Voltage sources** are turned off by replacing them with a short circuit.
- **Current sources** are turned off by replacing them with an open circuit.
- Dependent sources are left unchanged.

Mathematically, if a circuit has  $n$  independent sources, the total response  $Y$  is:

$$Y = Y_1 + Y_2 + \dots + Y_n$$

where  $Y_k$  is the response due to the  $k$ -th source alone.

The theorem is a direct consequence of the **linearity** of Ohm's law and Kirchhoff's laws, and it simplifies the analysis of multi-source circuits.

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#### 2. What is Node and super Node?

##### Node:

A **node** is a point in a circuit where two or more circuit elements (resistors, sources, etc.) are connected together. In circuit analysis, a node represents a distinct voltage point. Nodes are used in **Nodal Analysis** to write KCL equations.

##### Super Node:

A **super node** is a conceptual construct used in nodal analysis when a voltage source (independent or dependent) is connected **between two non-reference nodes** without any resistance in series. To handle such a case:

- The two nodes connected by the voltage source are grouped together into a **super node**.
- A single KCL equation is written for the entire super node (considering currents entering/leaving the combined region).
- An additional constraint equation is provided by the voltage source itself, relating the voltages of the two nodes.

**Example:** If a voltage source  $V_s$  is connected between Node A and Node B, then:

$$V_A - V_B = V_s$$

This equation is used together with the KCL for the super node to solve for the node voltages.

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### 3. What are limitations of superposition theorem?

The superposition theorem is powerful but has specific limitations:

1. **Applicable only to linear circuits:**

The circuit must consist of linear elements (resistors, inductors, capacitors with constant values) and linear dependent sources. Nonlinear components (diodes, transistors in nonlinear regions) invalidate the theorem.

2. **Not applicable to power calculations:**

Power in a resistor is proportional to the square of current or voltage ( $P = I^2R$  or  $P = V^2/R$ ), which is a nonlinear relationship. Superposition cannot be used to find total power by summing individual powers; instead, total current or voltage must be found first, then power calculated.

3. **Only for independent sources:**

The theorem considers each independent source separately. Dependent sources must remain active during each step of superposition.

4. **Does not simplify all circuits:**

For circuits with many sources, the method can become lengthy because it requires solving the circuit repeatedly for each source.

5. **Assumes bilateral elements:**

The circuit elements must be bilateral (current-voltage relationship is symmetric). Unilateral elements (like ideal diodes) break the linearity required.

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### 4. Superposition theorem is applicable for linear network or nonlinear network?

**Justify your answer.**

**Answer: The superposition theorem is applicable only to linear networks.**

**Justification:**

1. **Mathematical foundation:**

Superposition relies on the **principle of linearity**, which states that if an input  $x_1$  produces output  $y_1$  and input  $x_2$  produces output  $y_2$ , then the input  $ax_1 + bx_2$  will produce output  $ay_1 + by_2$ . This property holds only for linear systems described by linear differential or algebraic equations.

2. **Circuit context:**

In electrical networks, linearity requires that all components obey linear relationships:

- Resistors:  $V = IR$  (Ohm's law)
  - Inductors:  $V = L \frac{di}{dt}$
  - Capacitors:  $I = C \frac{dv}{dt}$
- These relationships are linear if  $R, L, C$  are constants.

### 3. **Nonlinear elements break superposition:**

In a nonlinear element (e.g., a diode, transistor in saturation), the response to combined sources is **not** the sum of responses to individual sources. For example, if a diode is forward-biased by one source, adding another source may not produce a proportional change in current.

### 4. **Experimental verification:**

Laboratory experiments (like the one in this assignment) confirm that measured currents in linear resistor networks satisfy  $I = I'_1 + I'_2$  when sources are applied individually and together. This result consistently fails in networks containing nonlinear components.

Therefore, superposition is a tool exclusively for **linear network analysis**, and its use in nonlinear circuits leads to incorrect results.

## Experiment – 3

### Answers: Experiment Quiz – Thevenin's Theorem

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#### 1. State Thevenin's Theorem.

**Thevenin's Theorem** states that any **linear two-terminal electrical network** composed of independent and dependent sources, and linear resistances (or impedances in AC), can be replaced at the two terminals by an equivalent circuit consisting of:

- A **single voltage source**  $V_{th}$  (Thevenin voltage), which is the open-circuit voltage measured across the terminals.
- A **single series resistance**  $R_{th}$  (Thevenin resistance), which is the equivalent resistance seen from the terminals when all independent sources are turned off (voltage sources shorted, current sources opened).

The resulting **Thevenin equivalent circuit** has exactly the same terminal voltage–current ( $V - I$ ) characteristics as the original network. This theorem simplifies the analysis of complex circuits, especially when evaluating the effect of different loads connected to the same two terminals.

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#### 2. Draw the equivalent circuit for Thevenin's theorem.

**Diagram:**

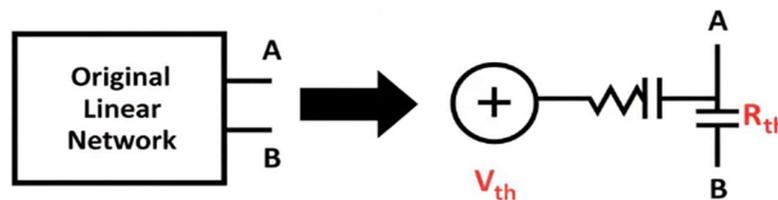


Fig: Thevenin equivalent circuit of a linear two-terminal network.

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#### 3. What is the other name of Thevenin's theorem?

Thevenin's theorem is also known as the **Helmholtz–Thevenin theorem** or simply the **equivalent generator theorem**. This acknowledges the independent work of Hermann von Helmholtz and Léon Charles Thévenin in developing the concept of representing a complex network by an equivalent voltage source and series resistance.

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#### 4. Thevenin's theorem can be applied to networks containing active elements only.

True/false?

**False.**

##### **Justification:**

Thevenin's theorem applies to **linear networks** that may contain **both active and passive elements**, under specific conditions:

- **Active elements:** Independent voltage/current sources and **linear dependent sources** are permitted. However, dependent sources must remain in the circuit when calculating  $R_{th}$  (they are not turned off).
- **Passive elements:** Linear resistors, inductors, capacitors (in AC) are required.
- **Nonlinear elements:** The theorem **does not apply** if the network contains nonlinear components (e.g., diodes, transistors in nonlinear region) because the principle of superposition (on which Thevenin's theorem relies) fails.

Thus, the statement is false because Thevenin's theorem is **not** restricted to networks with active elements only; it applies to linear networks containing a mix of linear active and passive components.

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## Experiment – 4

### Answers: Experiment Quiz – B-H Curve and Hysteresis

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1. The unit of magnetic field intensity is \_\_\_\_\_

**Answer: Ampere per meter (A/m)**

Magnetic field intensity  $H$  is defined as the magnetomotive force (MMF) per unit length of the magnetic path.

$$H = \frac{NI}{\ell}$$

where  $N$  is number of turns,  $I$  is current in amperes, and  $\ell$  is length in meters. Hence, the SI unit is **A/m**.

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2. Magnetic circuit obeys

a) Kirchhoff's Law   b) Thevenin's theorem   c) Norton's theorem   d) None of these

**Answer: a) Kirchhoff's Law**

Magnetic circuits obey **analogues** of Kirchhoff's laws:

- **Kirchhoff's Flux Law (KFL):** The total magnetic flux entering a junction equals the total flux leaving it (conservation of magnetic flux).
- **Kirchhoff's MMF Law (KML):** Around any closed magnetic loop, the algebraic sum of magnetomotive forces (MMF) equals the algebraic sum of magnetic potential drops ( $\phi R$ , where  $R$  is reluctance).

Thevenin's and Norton's theorems are network theorems primarily used for linear *electric* circuits; they are not directly stated as fundamental laws for magnetic circuits, although analogous concepts can sometimes be constructed for linear magnetic systems.

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3. The word "Hysteresis" means \_\_\_\_\_

**Answer: Lagging behind**

The term **hysteresis** (from Greek *hysteros*, meaning "later" or "lagging") refers to the phenomenon in which the response (magnetization  $B$  or  $I$ ) of a material **lags behind** the applied forcing field ( $H$ ). In ferromagnetic materials, this lag occurs because the magnetic domains do not align instantaneously with the changing external field, leading to energy loss and the characteristic **hysteresis loop** when  $B$  is plotted against  $H$ .

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4. The unit of  $H \times B$  is \_\_\_\_\_

**Answer: Joule per cubic meter ( $\text{J}/\text{m}^3$ ) or equivalently, Tesla·Ampere/meter ( $\text{T}\cdot\text{A}/\text{m}$ )**

The product  $H \times B$  has units:

- $H$ : A/m
- $B$ : Tesla (T) =  $\text{Wb}/\text{m}^2 = \text{kg}\cdot\text{s}^{-2}\cdot\text{A}^{-1}$

Thus,

$$[H \times B] = \frac{\text{A}}{\text{m}} \times \frac{\text{Wb}}{\text{m}^2} = \frac{\text{A} \cdot \text{Wb}}{\text{m}^3}.$$

Since  $1 \text{ Wb} = 1 \text{ V} \cdot \text{s}$  and  $1 \text{ V} \cdot \text{A} \cdot \text{s} = 1 \text{ J}$ ,

$$\frac{\text{A} \cdot \text{Wb}}{\text{m}^3} = \frac{\text{A} \cdot \text{V} \cdot \text{s}}{\text{m}^3} = \frac{\text{J}}{\text{m}^3}.$$

This represents **energy density**—specifically, the magnetic energy stored per unit volume in a magnetic field. In the context of a hysteresis loop, the area enclosed by the loop equals the **hysteresis energy loss per cycle per unit volume** of the material, measured in  $\text{J}/\text{m}^3$ .

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## Experiment – 5

### Answers: Experiment Quiz – Series R-L Circuit

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#### 1. Define RMS value.

The **Root Mean Square (RMS) value** of an alternating current (AC) or voltage is defined as the equivalent steady (DC) value that delivers the **same average power** to a resistive load.

For a time-varying quantity  $x(t)$  with period  $T$ , the RMS value is calculated as:

$$X_{\text{rms}} = \sqrt{\frac{1}{T} \int_0^T [x(t)]^2 dt}$$

For a sinusoidal current  $i(t) = I_m \sin(\omega t + \phi)$ , the RMS value is:

$$I_{\text{rms}} = \frac{I_m}{\sqrt{2}} \approx 0.707 I_m$$

Similarly, for sinusoidal voltage  $v(t) = V_m \sin(\omega t + \phi)$ :

$$V_{\text{rms}} = \frac{V_m}{\sqrt{2}} \approx 0.707 V_m$$

The RMS value is the standard measure for AC quantities because it correctly represents the heating effect (power) in resistive components and is used universally in AC power systems.

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#### 2. What is phasor?

A **phasor** is a complex number used to represent a sinusoidal function whose amplitude, frequency, and phase are time-invariant. It simplifies the analysis of linear AC circuits by converting differential equations into algebraic equations.

- A sinusoidal voltage  $v(t) = V_m \cos(\omega t + \phi)$  can be represented by a phasor:

$$\mathbf{V} = V_m \angle \phi \text{ or } \mathbf{V} = V_m e^{j\phi}$$

where  $V_m$  is the peak amplitude (or RMS magnitude, if scaled accordingly) and  $\phi$  is the phase angle.

- Phasors assume a common frequency  $\omega$ , so the time-dependent factor  $e^{j\omega t}$  is suppressed.

- Operations like addition, subtraction, and application of Kirchoff's laws become simpler in the phasor domain because sinusoidal functions are transformed into complex arithmetic.

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### 3. What is impedance triangle?

The **impedance triangle** is a right-angle triangle used to graphically represent the relationship between resistance  $R$ , reactance  $X$ , and impedance  $Z$  in an AC circuit.

- **Horizontal side:** Resistance  $R$  (in ohms), representing the component of impedance in phase with the current.
- **Vertical side:** Reactance  $X$  (in ohms), representing the component of impedance  $90^\circ$  out of phase with the current.
  - For inductive circuits,  $X = X_L = \omega L$  (positive).
  - For capacitive circuits,  $X = X_C = -\frac{1}{\omega C}$  (negative).
- **Hypotenuse:** Impedance magnitude  $Z = \sqrt{R^2 + X^2}$  (in ohms).
- **Angle  $\phi$ :** Phase angle between voltage and current, given by:

$$\phi = \tan^{-1}\left(\frac{X}{R}\right)$$

The triangle visually illustrates:

- Power factor:  $\cos \phi = R/Z$
- Reactive factor:  $\sin \phi = X/Z$
- Apparent power  $S$ , real power  $P$ , and reactive power  $Q$  form a similar **power triangle**.

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### 4. State advantages of sinusoidal alternating quantity.

Sinusoidal AC quantities are predominant in electrical power systems and signal processing due to the following advantages:

1. **Ease of generation and transformation:**  
Alternators (AC generators) naturally produce sinusoidal waveforms due to rotational motion in a uniform magnetic field. Transformers operate efficiently only with AC, and sinusoidal voltage minimizes core losses (hysteresis and eddy currents).
2. **Mathematical tractability:**  
Sinusoids are solutions to linear differential equations with constant coefficients. They allow the use of **phasor analysis**, which simplifies circuit analysis to algebraic complex arithmetic.

3. **Efficient power transmission:**

AC voltages can be easily stepped up to high levels using transformers, reducing  $I^2R$  losses during long-distance transmission, and then stepped down for safe consumption.

4. **Minimal harmonic distortion:**

A pure sinusoid contains a single frequency. In power systems, this minimizes harmonic pollution, which can cause overheating, interference, and equipment malfunction.

5. **Compatibility with motors and devices:**

Induction motors, synchronous motors, and many electronic devices are designed to operate optimally with sinusoidal supplies.

6. **Ease of measurement:**

Standard AC meters (ammeters, voltmeters, wattmeters) are calibrated for sinusoidal waveforms, and RMS values are straightforward to compute.

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## Experiment – 6

### Answers: Experiment Quiz – Three-Phase Star and Delta Connections

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#### 1. What are advantages of 3-Ø supply over 1-Ø supply?

Three-phase (3-Ø) AC power systems offer several significant advantages over single-phase (1-Ø) systems, especially in industrial and high-power applications:

1. **Higher power capacity:**

For the same conductor size and voltage level, a three-phase system can deliver about  $\sqrt{3}$  ( $\approx 1.732$ ) times more power than a single-phase system. This makes it more economical for transmission and distribution.

2. **Constant power delivery:**

The total instantaneous power in a balanced three-phase system is constant (non-pulsating), whereas in a single-phase system it pulsates at twice the supply frequency. This results in smoother operation of motors and reduces torque ripple, vibration, and noise.

3. **Efficient motor design:**

Three-phase induction and synchronous motors are inherently self-starting, have higher efficiency, better power factor, and more uniform torque compared to single-phase motors, which often require auxiliary starting mechanisms.

4. **Reduced conductor material:**

For the same power transmission at the same line voltage and same losses, a three-phase system requires about 75% of the conductor material needed for a single-phase system. This lowers cost and weight.

5. **Flexibility in voltage levels:**

Three-phase systems allow easy transformation between line-to-line (line voltage) and line-to-neutral (phase voltage) using star connections, providing two voltage levels (e.g., 400 V line and 230 V phase) from the same supply.

6. **Better voltage regulation:**

Due to balanced loading and lower voltage drop, three-phase systems generally exhibit better voltage regulation over long distances.

7. **Compatibility with industrial loads:**

Most heavy industrial machinery (pumps, compressors, fans, CNC machines) are designed for three-phase operation because of the above benefits.

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#### 2. What do you mean by balanced system?

A **balanced three-phase system** is one in which:

- The **three phase voltages** are equal in magnitude and displaced from each other by exactly  $120^\circ$  (electrical degrees).

- The **three phase currents** are also equal in magnitude and each lags (or leads) its respective phase voltage by the **same angle** (i.e., identical power factor in each phase).
- The **load impedances** in all three phases are identical in magnitude and phase angle.

#### Consequences of balance:

- Line voltages are equal and  $120^\circ$  apart.
- Neutral current in a star-connected system is zero ( $I_N = 0$ ).
- Total instantaneous power is constant.
- Analysis simplifies greatly because one phase can be solved and the results extended to the other two by symmetry.

If any of these conditions is not met, the system is **unbalanced**, which can cause unequal heating, reduced efficiency, neutral currents, and undesirable voltage fluctuations.

### 3. Write the formula of Active power for 3-Ø delta connected load.

For a **balanced three-phase delta-connected load**:

- Let  $V_L =$  line voltage (V)  
 $I_L =$  line current (A)  
 $\phi =$  phase angle between phase voltage and phase current (same for each phase)

In a delta connection:

- Phase voltage  $V_{PH} = V_L$
- Phase current  $I_{PH} = I_L/\sqrt{3}$

Active (real) power per phase:

$$P_{\text{phase}} = V_{PH} I_{PH} \cos \phi$$

Total active power for three phases:

$$P_{\text{total}} = 3 V_{PH} I_{PH} \cos \phi$$

Substituting delta relations:

$$P_{\text{total}} = 3 \times V_L \times \frac{I_L}{\sqrt{3}} \times \cos \phi$$

$$\boxed{P = \sqrt{3} V_L I_L \cos \phi}$$

This formula ( $\sqrt{3}V_L I_L \cos \phi$ ) is valid for **any balanced three-phase load** (star or delta) when using line quantities.

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#### 4. Phase angle between line voltage and phase voltage in star connected load is

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**Answer:**  $30^\circ$

In a **balanced star connection**, each line voltage leads the corresponding phase voltage by  $30^\circ$ .

**Explanation:**

Consider a star connection with phase voltages:

$$V_{RN} = V_{PH}\angle 0^\circ, V_{YN} = V_{PH}\angle -120^\circ, V_{BN} = V_{PH}\angle -240^\circ$$

Line voltage  $V_{RY} = V_{RN} - V_{YN}$ :

$$V_{RY} = V_{PH}\angle 0^\circ - V_{PH}\angle -120^\circ = \sqrt{3} V_{PH}\angle 30^\circ$$

Thus,  $V_{RY}$  (line voltage) leads  $V_{RN}$  (phase voltage) by  $30^\circ$ . Similarly, other line voltages lead their respective phase voltages by  $30^\circ$ .

This  $30^\circ$  shift is important in phasor diagrams, power calculations, and when synchronizing measurements.

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## Experiment – 7

### Answers: Experiment Quiz – Two-Wattmeter Method

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#### 1. Define power factor.

**Power factor (PF)** is defined as the ratio of the **real (active) power**  $P$  consumed by an AC circuit to the **apparent power**  $S$  supplied to the circuit.

$$\text{Power Factor} = \frac{P}{S} = \cos \phi$$

where:

- $P$  = Real power (in watts, W), representing the useful work performed.
- $S$  = Apparent power (in volt-amperes, VA), the product of RMS voltage and RMS current.
- $\phi$  = Phase angle between the voltage and current waveforms.

#### Interpretation:

- **PF = 1** ( $\phi = 0^\circ$ ): Purely resistive load, voltage and current in phase.
- **$0 < \text{PF} < 1$**  ( $0^\circ < \phi < 90^\circ$ ): Load has reactive (inductive or capacitive) component.
- **Leading PF**: Current leads voltage (capacitive load).
- **Lagging PF**: Current lags voltage (inductive load, common in motors).

A low power factor increases line losses, reduces system capacity, and may incur penalties in industrial power tariffs.

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#### 2. Two wattmeter method is applicable for star connected system or delta connected system or both? Justify your answer.

**Answer:** The two-wattmeter method is applicable to **both star-connected and delta-connected three-phase systems**, whether the load is balanced or unbalanced.

#### Justification:

##### 1. Theoretical basis:

The method relies only on Kirchhoff's laws and the definition of instantaneous power. The derivation (as shown in the experiment theory) does not assume any specific load connection; it only requires that the system is three-wire (i.e., no neutral connection). The sum of the two wattmeter readings gives the total real power:

$$P_{\text{total}} = W_1 + W_2$$

This holds for any three-phase, three-wire system.

**2. Star connection:**

In a star-connected load **without a neutral wire** (three-wire star), the two-wattmeter method is directly applicable. If a neutral wire is present (four-wire star), the method still works but is not necessary because a neutral allows single-phase measurements.

**3. Delta connection:**

A delta-connected load is inherently a three-wire system; hence the two-wattmeter method is perfectly suitable.

**4. Practical verification:**

Laboratory experiments confirm that identical power readings are obtained for the same load whether connected in star or delta, provided the line voltages and currents are the same.

Thus, the two-wattmeter method is a **universal method for three-phase three-wire systems**, independent of the load connection (star or delta) and load balance.

**3. Total number of phase sequence in 3-Ø AC system is \_\_\_\_\_**

**Answer: Two**

**Explanation:**

Phase sequence refers to the order in which the three phase voltages reach their maximum positive values. For a three-phase system, there are only two possible sequences:

**1. Positive (abc) sequence:**

Phases reach maxima in the order  $A \rightarrow B \rightarrow C$  (or  $R \rightarrow Y \rightarrow B$ ). This is the standard sequence for normal motor operation (forward rotation).

**2. Negative (acb) sequence:**

Phases reach maxima in the order  $A \rightarrow C \rightarrow B$  (or  $R \rightarrow B \rightarrow Y$ ). This reverses the direction of rotation of three-phase motors.

Any other apparent “sequence” is merely a renaming of the phases; fundamentally, only two distinct sequences exist.

**4. In the two wattmeter method of measuring power in 3-Ø circuit, the two wattmeter will show equal readings when the power factor angle is equal to \_\_\_\_\_**

**Answer:  $0^\circ$  (i.e., unity power factor)**

**Derivation:**

For a balanced three-phase load, the readings of the two wattmeters are:

$$W_1 = V_L I_L \cos(30^\circ - \phi), W_2 = V_L I_L \cos(30^\circ + \phi)$$

where  $V_L$  and  $I_L$  are line quantities and  $\phi$  is the load power factor angle.

For  $W_1 = W_2$ :

$$\cos(30^\circ - \phi) = \cos(30^\circ + \phi)$$

This equality holds when:

- $30^\circ - \phi = 30^\circ + \phi \Rightarrow \phi = 0^\circ$ , or
- $30^\circ - \phi = -(30^\circ + \phi) \Rightarrow 60^\circ = 0$  (invalid).

Hence, the only solution is  $\phi = 0^\circ$ , corresponding to **unity power factor** ( $\cos \phi = 1$ ).

At  $\phi = 0^\circ$ :

$$W_1 = W_2 = V_L I_L \cos 30^\circ = \frac{\sqrt{3}}{2} V_L I_L$$

and total power  $P = W_1 + W_2 = \sqrt{3} V_L I_L$ , which matches the formula for balanced three-phase power at unity PF.

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## Experiment – 8

### Answers: Experiment Quiz – Brushless DC Motor (BLDC)

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#### 1. What is the main difference between a BLDC motor and a brushed DC motor?

**Answer: c) BLDC motors use electronic commutation instead of mechanical brushes.**

*Explanation:*

Brushed DC motors employ a mechanical commutator and brushes to switch current in the rotor windings, while BLDC motors eliminate these wearing parts by using an electronic controller that switches current in the stator windings based on rotor position feedback (from sensors or back-EMF). This leads to higher efficiency, longer life, lower maintenance, and better performance in BLDC motors.

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#### 2. Which material is commonly used for the windings in a BLDC motor?

**Answer: b) Copper**

*Explanation:*

Copper is the preferred material for stator windings due to its high electrical conductivity, which minimizes resistive ( $I^2R$ ) losses and ensures efficient generation of the magnetic field. Aluminium is sometimes used for cost reduction in low-performance applications, but copper remains the standard for performance-oriented BLDC motors.

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#### 3. What is the role of position sensors in a BLDC motor?

**Answer: b) To detect the position of the rotor for electronic commutation.**

*Explanation:*

Position sensors (e.g., Hall-effect sensors, optical encoders) provide real-time feedback on the rotor's angular position relative to the stator. This information is used by the electronic controller to precisely sequence the energization of stator phases, ensuring that the stator's rotating magnetic field remains synchronized with the rotor's permanent magnets. This synchronization is essential for smooth torque production, high efficiency, and stable operation.

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#### 4. Describe the principle of operation of a BLDC motor.

A Brushless DC motor operates on the principle of **synchronized magnetic interaction** between a **rotating magnetic field** produced by the stator and a **permanent-magnet rotor**.

**Key steps:**

1. **Stator excitation:**

The stator consists of three-phase windings (typically). An electronic controller sequentially energizes pairs of windings (e.g., A-B, B-C, C-A) with DC current pulses, creating a **rotating magnetic field**.

2. **Rotor alignment:**

The rotor carries permanent magnets (N-S poles). Due to magnetic attraction and repulsion, the rotor's magnets align with the stator's magnetic field.

3. **Commutation:**

As the rotor turns, position sensors (or back-EMF sensing in sensorless designs) detect its orientation. The controller uses this information to switch the current to the next pair of windings at the exact moment, causing the stator field to rotate further. This **electronic commutation** replaces the mechanical brushes and commutator used in traditional DC motors.

4. **Continuous rotation:**

By repeating the switching sequence in synchrony with rotor movement, a continuous torque is produced, resulting in smooth, efficient rotation.

Thus, the BLDC motor converts electrical energy into mechanical motion through electronically controlled, timed excitation of stator windings that “drag” the permanent-magnet rotor.

## 5. What are the common rotor configurations in a BLDC motor?

The rotor of a BLDC motor carries permanent magnets. Common configurations are classified based on how the magnets are mounted:

1. **Surface-Mounted Permanent Magnet (SPM):**

Magnets are glued or bonded onto the outer surface of the rotor core. This configuration is simple to manufacture, provides a relatively large air-gap, and is suitable for high-speed applications. However, it may have mechanical integrity limitations at very high speeds due to centrifugal forces.

2. **Interior (or Buried) Permanent Magnet (IPM):**

Magnets are embedded (buried) inside slots within the rotor core. This arrangement offers better mechanical robustness, allows for higher speeds, and can utilize **reluctance torque** in addition to magnetic torque, improving overall torque density and efficiency. IPM designs are common in high-performance applications like electric vehicles.

3. **Spoke-type or Radial-type:**

Magnets are arranged radially like spokes of a wheel, often with alternating polarity. This can enhance flux concentration and torque.

4. **Ring-type (Magnet-in-Ring):**

A ring-shaped magnet is mounted around the rotor, providing a uniform magnetic field.

The choice depends on required torque profile, speed range, mechanical strength, and cost.

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## 6. Explain the importance of electronic commutation in a BLDC motor.

Electronic commutation is fundamental to BLDC motor operation and offers several critical advantages over mechanical commutation:

- 1. Elimination of brushes and commutator:**  
Brushes and commutators in traditional DC motors cause friction, sparking, electrical noise, and wear. Electronic commutation removes these parts, leading to **higher reliability, longer lifespan, and reduced maintenance.**
- 2. Higher efficiency:**  
Without brush-contact voltage drops and friction losses, BLDC motors achieve efficiencies of 85-90% (compared to 75-80% for brushed motors). Reduced  $I^2R$  losses and precise timing of current switching also contribute.
- 3. Precise control:**  
The electronic controller can adjust the timing and magnitude of phase currents dynamically, enabling **accurate speed regulation, torque control,** and smooth operation over a wide speed range.
- 4. Reduced electromagnetic interference (EMI):**  
Sparking at brushes generates significant EMI. Electronic commutation with solid-state switches (MOSFETs/IGBTs) minimizes such interference.
- 5. Better heat dissipation:**  
Windings are on the stator (stationary part), allowing easier cooling, whereas in brushed motors rotor windings are harder to cool.
- 6. High-speed capability:**  
Absence of mechanical brushes eliminates speed limitations imposed by brush wear and commutation sparking, enabling BLDC motors to operate at very high speeds.
- 7. Quiet operation:**  
Elimination of brush friction and arcing reduces acoustic noise.

Thus, electronic commutation transforms the DC motor into a robust, efficient, and controllable device suitable for modern applications like electric vehicles, drones, industrial automation, and precision instruments.

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## Experiment – 9

### Answers: Experiment Quiz – Miniature Circuit Breaker (MCB)

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#### 1. What is the function of MCB?

The **Miniature Circuit Breaker (MCB)** is a protective electrical device designed to **automatically interrupt an electrical circuit** under abnormal conditions, primarily **overcurrents** (overloads) and **short circuits**. Its key functions are:

##### 1. **Overload Protection:**

When the current exceeds the rated value for a prolonged period (typically 1.13 to 1.45 times the rated current), the **thermal tripping mechanism** (bimetallic strip) heats up, bends, and trips the latch, disconnecting the circuit. This protects cables and equipment from overheating and potential fire hazards.

##### 2. **Short-Circuit Protection:**

Under very high fault currents (typically 3 to 10 times the rated current), the **magnetic tripping mechanism** (solenoid) instantaneously activates the trip mechanism, rapidly opening the contacts to prevent damage from high-energy faults.

##### 3. **Manual Switching:**

MCBs also serve as a manual ON/OFF switch for the circuit, allowing convenient isolation for maintenance or emergency shutdown.

##### 4. **Arc Suppression:**

During interruption, the **arc chute** (arc splitter plates) extinguishes the arc safely, preventing damage to contacts and surrounding components.

Thus, the MCB ensures **safety, equipment protection, and operational reliability** in low-voltage electrical installations (domestic, commercial, and light industrial).

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#### 2. State difference between MCB and MCCB.

Aspect	MCB (Miniature Circuit Breaker)	MCCB (Moulded Case Circuit Breaker)
Current Rating	Low (up to about 100 A)	Higher (typically 10 A to 2500 A)
Breaking Capacity	Lower (up to about 10 kA)	Higher (up to 100 kA or more)

Aspect	MCB (Miniature Circuit Breaker)	MCCB (Moulded Case Circuit Breaker)
<b>Trip Characteristics</b>	Fixed; usually thermal-magnetic with limited adjustability	Adjustable (thermal and magnetic settings can be tailored)
<b>Size &amp; Construction</b>	Compact, moulded insulation, designed for DIN-rail mounting	Larger, robust moulded case, often with additional features
<b>Applications</b>	Domestic, commercial lighting, socket circuits	Industrial distribution boards, motor feeders, large loads
<b>Cost</b>	Lower	Higher
<b>Arc-Chute Design</b>	Simpler	More robust, designed for higher fault currents
<b>Remote Control</b>	Usually not available	Often available with shunt trip, under-voltage release, etc.

### 3. What is the difference between fuse and MCB?

Aspect	Fuse	MCB
<b>Operating Principle</b>	Destructive; a fuse element melts due to overcurrent, breaking the circuit.	Non-destructive; uses thermal-magnetic mechanisms to open contacts.
<b>Reusability</b>	Single-use; must be replaced after operation.	Reusable; can be reset manually after tripping.
<b>Response Time</b>	Generally slower for overloads; faster for high short-circuit currents.	Precise time-current characteristics; separate delays

<b>Aspect</b>	<b>Fuse</b>	<b>MCB</b>
		for overload and instantaneous trip for short-circuit.
<b>Accuracy &amp; Consistency</b>	Characteristics may vary with ageing, temperature, and manufacturing tolerances.	More consistent tripping characteristics over time.
<b>Cost per Operation</b>	Low initial cost, but recurring replacement cost.	Higher initial cost, but no replacement cost after tripping.
<b>Visual Indication</b>	No obvious indication of operation; must be checked physically.	Clear indication: handle moves to OFF (or trip) position.
<b>Switching Function</b>	Cannot be used as a switch.	Can be used as a manual ON/OFF switch.
<b>Selectivity</b>	Poor selectivity (discrimination) between fuses in series.	Better selectivity due to adjustable time-current curves (in MCCBs) and coordinated designs.
<b>Maintenance</b>	Requires stock of replacement fuses.	Virtually maintenance-free; periodic testing recommended.
<b>Safety</b>	Risk of incorrect replacement (wrong rating, makeshift repairs).	Safer; correct rating is fixed; no user-replaceable parts.
<b>Arc Energy</b>	Arc energy is contained within the fuse body.	Arc is extinguished in the arc chute; may produce some external sparking in severe faults.

## Experiment – 10

### Answers: Experiment Quiz – Batteries

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#### 1. What is primary cell and secondary cell?

##### Primary Cell:

A primary cell is a **non-rechargeable** electrochemical cell. Once its chemical reactants are exhausted through discharge, the cell cannot be practically restored to its original state by electrical means. The electrochemical reaction is **irreversible**. Primary cells are designed for single-use applications where recharging is inconvenient or impossible.

**Examples:** Alkaline (AA, AAA), Zinc-carbon, Lithium primary cells (e.g., CR2032 coin cells), Mercury cells.

**Typical applications:** Remote controls, watches, pacemakers, military equipment, toys, and other low-drain portable devices.

##### Secondary Cell:

A secondary cell is a **rechargeable** electrochemical cell. The chemical reactions that occur during discharge can be reversed by applying an external electrical voltage (charging), restoring the cell to its original charged state. This allows the cell to be used repeatedly over many charge-discharge cycles.

**Examples:** Lead-acid, Nickel-cadmium (NiCd), Nickel-metal hydride (NiMH), Lithium-ion (Li-ion).

**Typical applications:** Mobile phones, laptops, electric vehicles, uninterruptible power supplies (UPS), solar energy storage, power tools.

##### Key distinction:

- **Primary cells:** High specific energy, longer shelf life, lower self-discharge, but disposable.
  - **Secondary cells:** Lower specific energy, higher self-discharge, but reusable and more cost-effective over many cycles.
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#### 2. Do temperature have effect on battery?

**Yes, temperature significantly affects battery performance, life, and safety.**

##### Effects of temperature on batteries:

##### 1. Capacity & Energy Delivery:

- **Low temperatures:** Increase internal resistance, reduce ionic mobility and chemical reaction rates. This decreases available capacity and peak power output. In extreme cold, batteries may fail to deliver usable power.
- **High temperatures:** Accelerate chemical reactions, temporarily increasing capacity and power. However, prolonged high temperatures degrade materials, increase self-discharge, and permanently reduce capacity over time.

## 2. Cycle Life:

- Elevated temperatures (above  $\sim 25\text{ }^{\circ}\text{C}$ ) accelerate side reactions (e.g., electrolyte decomposition, electrode corrosion), leading to faster capacity fade and shorter cycle life.
- Very low temperatures can cause mechanical stress (e.g., lithium plating in Li-ion batteries) that also reduces cycle life.

## 3. Self-Discharge:

Self-discharge rate increases exponentially with temperature. A battery stored at  $30\text{ }^{\circ}\text{C}$  may lose charge several times faster than at  $10\text{ }^{\circ}\text{C}$ .

## 4. Safety Risks:

- High temperatures can trigger thermal runaway in rechargeable batteries (especially Li-ion), leading to overheating, venting, or fire.
- Low temperatures may cause electrolyte freezing, physical damage, and increased risk of short circuits.

## 5. Charging Efficiency:

Charging at low temperatures is inefficient and can be dangerous (e.g., lithium plating in Li-ion). Most battery management systems (BMS) restrict or modify charging below certain temperatures.

### Optimal temperature range:

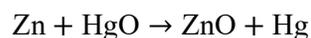
Most batteries perform best between  $15\text{ }^{\circ}\text{C}$  and  $25\text{ }^{\circ}\text{C}$ . Operating or storing batteries outside this range requires thermal management or design adjustments.

## 3. Mercury cell is primary cell. True/False? Justify your answer.

**True.** Mercury cells are primary (non-rechargeable) cells.

### Justification:

1. **Chemistry:** A mercury cell uses a zinc anode, mercury(II) oxide cathode, and potassium hydroxide or sodium hydroxide electrolyte. The discharge reaction is:



This reaction is **not reversible** by applying an external voltage; attempting to recharge a mercury cell would cause different reactions (e.g., hydrogen evolution) that do not restore the original reactants.

2. **Design intent:** Mercury cells were engineered for stable voltage, long shelf life, and high energy density in miniature formats (e.g., button cells). They were never designed for recharging.
3. **Historical use:** Mercury cells were widely used in watches, calculators, hearing aids, and military equipment where constant voltage and long life were critical. Their

production has been largely phased out due to environmental concerns about mercury toxicity, but they remain a classic example of a primary cell.

4. **Rechargeable alternatives:** Rechargeable button cells (e.g., NiMH, Li-ion) use different chemistries and are explicitly designed for cyclic use.

Therefore, mercury cells are **primary cells** by definition and practical use.

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