Fundamentals of Electrical Engineering

DI01000101 – Winter 2024

Semester 1 Study Material

Detailed Solutions and Explanations

Question 1(a) [3 marks]

Explain Ohm's law with its limitation and application.

Solution

Ohm's Law Summary:

Aspect	Description
Statement	Current through a conductor is directly proportional to voltage across it, provided physical conditions remain constant.
Formula	$V = I \times R$
Units	V (Volts), I (Amperes), R (Ohms)

Limitations:

- **Temperature dependency**: Resistance changes with temperature.
- **Non-linear materials**: Does not apply to semiconductors, diodes, etc.
- **AC circuits**: Modified form needed for reactive components (Impedance Z).

Applications:

- **Circuit analysis**: Calculate unknown voltage, current, or resistance.
- **Power calculations**: $P = V^2/R$ or $P = I^2 R$.

Mnemonic

"Voltage Is Really Important" ($V = I \times R$)

Question 1(b) [4 marks]

Explain Faraday's law of electromagnetic induction with necessary figure.
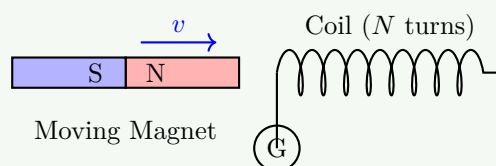

Solution

Faraday's Laws:

- **First Law**: An EMF is induced in a conductor whenever the magnetic flux linking with it changes.
- **Second Law**: The magnitude of the induced EMF is equal to the rate of change of flux linkages.

Key Formula

$$e = -N \frac{d\Phi}{dt}$$

Diagram:

Applications:

- **Transformers**: Mutual induction principle.
- **Generators**: Mechanical to electrical energy conversion.
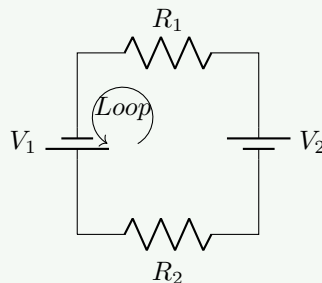
Question 1(c) [7 marks]

Explain Kirchhoff's Voltage Law (KVL) and Kirchhoff's Current Law (KCL) with necessary diagram.
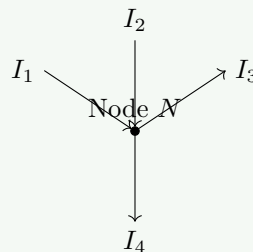
Solution

Comparison:

Law	Statement	Formula	Application
KVL	Sum of voltages in closed loop is zero	$\sum V = 0$	Series circuits
KCL	Sum of currents at a node is zero	$\sum I = 0$	Parallel circuits

KVL Diagram:

KCL Diagram:

Key Points:
- **KVL**: Algebraic sum considers voltage polarities.
- **KCL**: Considers current directions (incoming = positive, outgoing = negative).

Question 1(c OR) [7 marks]

Differentiate statically induced EMF and dynamically induced EMF.

> **Solution**
>
> | Parameter | Statically Induced EMF | Dynamically Induced EMF |
> |---|---|---|
> | Cause | Changing magnetic field | Relative motion between conductor and field |
> | Field | Time-varying, conductor stationary | Steady field, conductor moving |
> | Examples | Transformer, Inductor | Generator, Motor |
> | Formula | $e = -N\frac{d\Phi}{dt}$ | $e = Blv\sin\theta$ |
> | Applications | AC circuits, power supplies | Power generation, motors |
>
> **Static EMF Types:**
> - **Self-induced**: EMF in the same coil due to its own flux change.
> - **Mutually induced**: EMF in a coil due to flux change in a neighboring coil.

> **Mnemonic**
>
> "Static Stays, Dynamic Dances"

Question 2(a) [3 marks]

Explain various types of losses in transformer.

> **Solution**
>
> | Loss Type | Cause | Location | Characteristics |
> |---|---|---|---|
> | **Iron Loss** | Hysteresis + Eddy currents | Core | Constant, frequency dependent |
> | **Copper Loss** | I^2R heating | Windings | Variable with load (I^2) |
> | **Stray Loss** | Leakage flux | Overall | Minimal |
>
> **Details:**
> - **Hysteresis loss**: Due to magnetic domain reversal energy.
> - **Eddy current loss**: Due to circulating currents in the core (reduced by lamination).
> - **Copper loss**: Depends on current, proportional to square of load current.
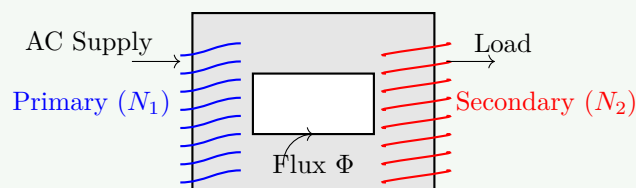
> **Mnemonic**
>
> "Iron Core, Copper Coil"

Question 2(b) [4 marks]

Explain working principle of transformer.

> **Solution**
>
> **Working Principle:** Mutual electromagnetic induction between primary and secondary windings linked by a common magnetic core.
> **Diagram:**
>
>
>
> **Operation Steps:**
> 1. AC current in primary creates alternating flux.
> 2. Flux circulates through the magnetic core.
> 3. Flux links with secondary winding.

4. Changing flux induces EMF in secondary (Faraday's Law).

> **Key Formula**
>
> $$\frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2} = K$$

> **Mnemonic**
>
> "Primary Produces, Secondary Supplies"

Question 2(c) [7 marks]

Derive EMF equation of transformer.

> **Solution**
>
> **Given:**
> - N_1, N_2: Number of turns
> - Φ_m: Maximum flux in core
> - f: Frequency of supply
>
> **Derivation:**
> 1. **Flux Equation**: $\Phi = \Phi_m \sin(2\pi f t)$
> 2. **Induced EMF**: $e = -N\frac{d\Phi}{dt}$
> 3. **Differentiation**:
> $$e = -N\frac{d}{dt}(\Phi_m \sin(2\pi f t)) = -N\Phi_m(2\pi f)\cos(2\pi f t)$$
> $$e = 2\pi f N\Phi_m \sin(2\pi f t - 90°)$$
> 4. **Maximum EMF**: $E_m = 2\pi f N\Phi_m$
> 5. **RMS EMF**: $E_{rms} = \frac{E_m}{\sqrt{2}} = \frac{2\pi f N\Phi_m}{\sqrt{2}} = 4.44 f N\Phi_m$
>
> > **Key Formula**
> >
> > $$E_1 = 4.44 f N_1 \Phi_m \quad \text{and} \quad E_2 = 4.44 f N_2 \Phi_m$$
>
> **Transformation Ratio:** $K = \frac{E_2}{E_1} = \frac{N_2}{N_1}$

> **Mnemonic**
>
> "4.44 Flux Formula"

Question 2(a OR) [3 marks]

Write application of transformer.

> **Solution**
>
> | Application | Purpose | Voltage Level |
> |---|---|---|
> | Power Transmission | Reduce transmission losses (I^2R) | Step-up (e.g., 400 kV) |
> | Distribution | Safe voltage for consumers | Step-down (e.g., 230 V) |
> | Isolation | Electrical safety/isolation | 1:1 Ratio |
> | Electronics | DC power supplies | Step-down |
>
> **Industrial Uses:** Welding transformers (High Current), Instrument transformers (CT/PT).

Question 2(b OR) [4 marks]

Write equation for back EMF and torque of D.C motor.

Solution

1. Back EMF Equation:

$$E_b = \frac{\phi ZNP}{60A}$$

Simplified: $E_b = K\phi N$

2. Torque Equation:

$$T = \frac{\phi ZI_a P}{2\pi A}$$

Simplified: $T = K\phi I_a$

Where:

- ϕ: Flux per pole (Weber)
- Z: Total armature conductors
- N: Speed (RPM)
- P: Number of poles
- A: Parallel paths
- I_a: Armature current

Mnemonic

"Back EMF opposes, Torque proposes"

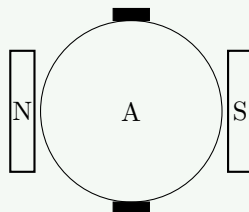# Question 2(c OR) [7 marks]

Explain construction and working of D.C. motor with necessary figure.

Solution

Construction:

- **Stator**: Yoke, Poles, Field windings (Produces magnetic field).
- **Rotor (Armature)**: Stacked laminations with slots for conductors.
- **Commutator**: Split rings to reverse current direction.
- **Brushes**: Carbon brushes to collect/supply current.

Diagram:

Working Principle:

1. Current flows through armature conductors placed in a magnetic field.
2. A mechanical force is experienced (Lorentz Force $F = BIl$).
3. Forces on opposite sides produce a torque.
4. Commutator reverses current direction every half rotation to maintain unidirectional torque.

Mnemonic

"Current Creates Circular Motion"

Question 3(a) [3 marks]

Explain construction of transformer.

> **Solution**
>
> **Core Components:**
>
> | Component | Material | Function |
> |---|---|---|
> | Core | Silicon Steel | Provides low reluctance magnetic path. Laminated to reduce eddy currents. |
> | Windings | Copper/Aluminium | Primary carries input, Secondary carries output current. |
> | Insulation | Paper/Varnish | Prevents short circuits. |
> | Tank | Steel | Protection and cooling (oil filled). |
>
> **Types:** Core Type (Windings surround core), Shell Type (Core surrounds windings).

> **Mnemonic**
>
> "Core Carries Current Carefully"

Question 3(b) [4 marks]

Explain application of DC motor.

> **Solution**
>
> | Motor Type | Characteristics | Applications |
> |---|---|---|
> | Shunt Motor | Constant Speed | Lathes, Fans, Centrifugal Pumps, Machine Tools |
> | Series Motor | High Starting Torque | Traction (Trains), Cranes, Hoists |
> | Compound Motor | Stable Speed & Torque | Elevators, Compressors, Rolling Mills |

> **Mnemonic**
>
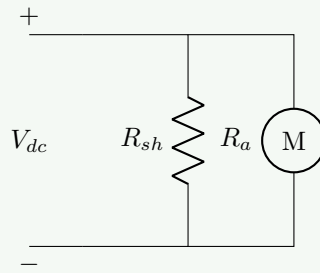> "Shunt Stays, Series Speeds"

Question 3(c) [7 marks]

Explain different types of DC motor.

> **Solution**
>
> **Classification based on Field Connection:**
>   1. **DC Shunt Motor**:
>   - Field winding connected in parallel with armature.
>   - Constant speed motor.

2. **DC Series Motor**:
   - Field winding connected in series with armature.
   - Application: High starting torque loads.
3. **DC Compound Motor**:
   - Contains both series and shunt field windings.

Key Formula

Shunt: $N \propto \frac{V - I_a R_a}{\phi}$ Series: $N \propto \frac{V}{\sqrt{T}}$

Mnemonic

"Shunt Steady, Series Strong, Compound Combined"

Question 3(a OR) [3 marks]

Explain transformation ratio of transformer.

Solution

Definition: The ratio of secondary voltage (or turns) to primary voltage (or turns).

Key Formula

$$K = \frac{N_2}{N_1} = \frac{E_2}{E_1} = \frac{V_2}{V_1} = \frac{I_1}{I_2}$$

- If $K > 1$: Step-up transformer.
- If $K < 1$: Step-down transformer.
- If $K = 1$: Isolation transformer.

Mnemonic

"Turns Tell Transformation"

Question 3(b OR) [4 marks]

Write application of autotransformer.

Solution

Applications:
1. **Motor Starting**: Used as a starter to reduce starting voltage/current for induction motors.
2. **Voltage Regulation**: Used in labs (Variac) to provide continuously variable voltage.
3. **Power Systems**: Interconnecting systems operating at different voltages (e.g., 132kV to 220kV).
4. **Testing**: Checking equipment performance at different voltage levels.

Advantages: Smaller size, lower cost, higher efficiency compared to two-winding transformer.

Question 3(c OR) [7 marks]

Explain speed control of DC shunt motor.
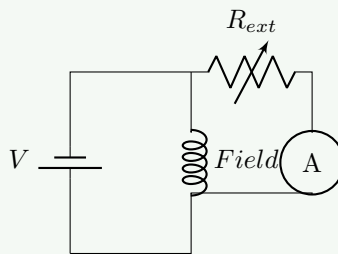
Solution

Methods:
1. **Armature Control (Rheostatic Control):**
   - Logic: $N \propto V - I_a(R_a + R_{ext})$.
   - Adding resistance reduces back EMF and speed.
   - **Effect**: Speed decreases below rated speed.
2. **Field Control (Flux Control):**
   - Logic: $N \propto 1/\phi$.
   - Decreasing flux increases speed.
   - **Effect**: Speed increases above rated speed.

Armature Control Diagram:

Mnemonic

"Armature Accurate, Field Fast"
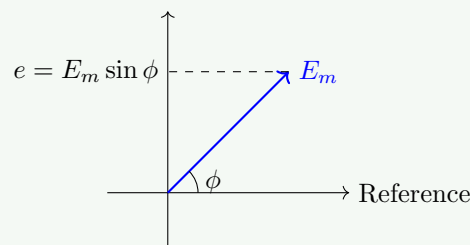
Question 4(a) [3 marks]

Explain vector representation of alternating EMF.

Solution

Concept: An alternating quantity is represented as a rotating vector (phasor) rotating at angular velocity ω rad/s.

Equation: $e = E_m \sin(\omega t + \phi)$

Diagram:

Mnemonic

"Vectors Visualize Voltage Variation"

Question 4(b) [4 marks]

Define: RMS value, Average value, Frequency, Time period.

Solution

Term	Definition
RMS Value	Review Mean Square. The effective DC value that produces the same heat. $I_{rms} = I_m/\sqrt{2}$.
Average Value	Mean of all instantaneous values over half cycle. $I_{avg} = 2I_m/\pi$.
Frequency	Number of cycles per second. $f = 1/T$ (Unit: Hz).
Time Period	Time taken to complete one full cycle. $T = 1/f$ (Unit: seconds).

Mnemonic

"Really Mean Square, Average Frequency Time"
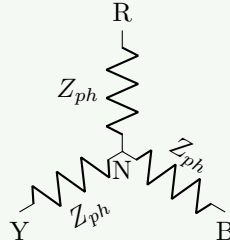
Question 4(c) [7 marks]

Derive equation for relation between line and phase voltage and current in star connection.

Solution

Star Connection:
- **Line Current**: $I_L = I_{ph}$ (Series connection between line and phase impedance).
- **Line Voltage**: Vector difference, $V_L = \sqrt{3}V_{ph}$.

Diagram:

Key Formula

$$V_L = \sqrt{3}V_{ph} \quad \text{and} \quad I_L = I_{ph}$$

Mnemonic

"Star Scales Voltage" ($\sqrt{3}$ factor)

Question 4(a OR) [3 marks]

Explain vector representation of alternating current.

Solution

Concept: Similar to voltage, AC current is represented as a phasor.

$$i = I_m \sin(\omega t \pm \phi)$$

Table:

Quantity	Symbol
Magnitude	I_m (Peak)
RMS	$I = I_m/\sqrt{2}$
Phase Angle	ϕ (Lag/Lead)

Mnemonic

"Current Circles Continuously"

Question 4(b OR) [4 marks]

Define: Form factor, Peak factor, Angular velocity, Amplitude.

Solution

Term	Definition	value (Sine)
Form Factor	$K_f = I_{rms}/I_{avg}$	1.11
Peak Factor	$K_p = I_{max}/I_{rms}$	1.414
Angular Velocity	Rate of phase change ($\omega = 2\pi f$).	314 rad/s
Amplitude	Maximum value (I_m).	-

Mnemonic

"Form Peak Angular Amplitude"
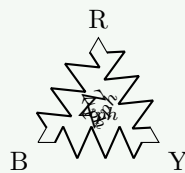
Question 4(c OR) [7 marks]

Derive equation for relation between line and phase voltage and current in delta connection.

Solution

Delta Connection:
- **Line Voltage**: $V_L = V_{ph}$ (Connected directly).
- **Line Current**: Vector difference of two phase currents. $I_L = \sqrt{3}I_{ph}$.

Diagram:

Key Formula

$$V_L = V_{ph} \quad \text{and} \quad I_L = \sqrt{3}I_{ph}$$

Mnemonic

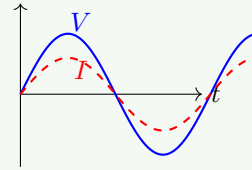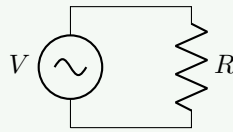"Delta Doubles Current" ($\sqrt{3}$ factor)

Question 5(a) [3 marks]

Explain AC through pure resistor with necessary circuit and waveform.

> **Solution**
>
> **Analysis:**
> - Voltage and Current are in phase ($\phi = 0°$).
> - Impedance equals Resistance ($Z = R$).
>
> **Diagrams:**

> **Mnemonic**
>
> "Resistor Refuses Phase Shift"

Question 5(b) [4 marks]

Define: Impedance, Phase angle, Power factor, Reactive power.

> **Solution**
>
> | Term | Definition | Formula |
> |------|-----------|---------|
> | Impedance | Total opposition to current flow (Z). | $Z = \sqrt{R^2 + X^2}$ |
> | Phase Angle | Angle difference between V and I. | $\phi = \tan^{-1}(X/R)$ |
> | Power Factor | Cosine of phase angle causing active power. | $PF = \cos\phi = R/Z$ |
> | Reactive Power | Power oscillating between source and load. | $Q = VI \sin\phi$ |

> **Mnemonic**
>
> "Impedance Phase Power Quadrature"

Question 5(c) [7 marks]

Enlist different protective device and explain construction and working of any one (MCB).

> **Solution**
>
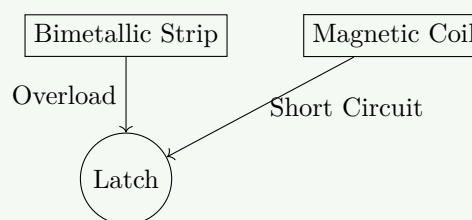> **Devices**: Fuse, MCB, MCCB, ELCB, Relay.
> **MCB (Miniature Circuit Breaker):**
> - **Construction**: Contacts, Arc chute, Bimetallic strip (Thermal), Magnetic coil (Magnetic).
>
> **Working Principle:**
> 1. **Overload**: Bimetallic strip heats up and bends, unlatching the mechanism (Slow).
> 2. **Short Circuit**: High current in magnetic coil creates strong field, tripping instantly (Fast).
>
> **Block Diagram:**

> **Mnemonic**
>
> "MCB Magnetically Controls Both"

Question 5(a OR) [3 marks]

Derive equation of AC current passing through pure inductor.

Solution

Given: $v = V_m \sin(\omega t)$, $v = L\frac{di}{dt}$
Derivation:

$$di = \frac{v}{L}dt = \frac{V_m}{L}\sin(\omega t)dt$$

$$i = \int \frac{V_m}{L}\sin(\omega t)dt = -\frac{V_m}{\omega L}\cos(\omega t)$$

$$i = \frac{V_m}{\omega L}\sin(\omega t - 90°)$$

Conclusion: Current lags voltage by 90°. $X_L = \omega L$.

Mnemonic

"Inductor Impedes, Current Lags"
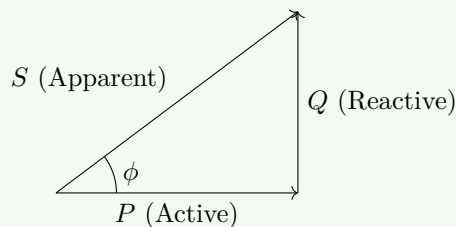
Question 5(b OR) [4 marks]

Explain concept of power and power triangle in AC circuit.

Solution

Power Types:
- **Active** (P): $VI\cos\phi$ (Watts) - Useful work.
- **Reactive** (Q): $VI\sin\phi$ (VAR) - Field maintenance.
- **Apparent** (S): VI (VA) - Total rating.

Power Triangle:

$S^2 = P^2 + Q^2$. Power Factor $\cos\phi = P/S$.

Mnemonic

"Power Triangle: Please Qualify Students"

Question 5(c OR) [7 marks]

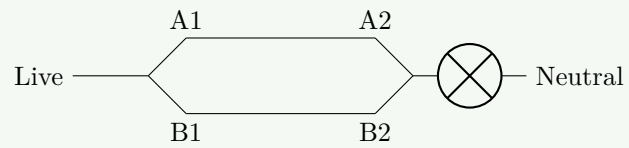**Explain wiring of lamp control from one place and staircase type.**

Solution

1. One Place Control: Simple series circuit with Switch (S) and Lamp (L).
Diagram: Live → Switch → Lamp → Neutral.
2. Staircase Wiring (Two way control): Uses two SPDT (Single Pole Double Throw) switches.
Diagram:

Working: The lamp can be switched ON/OFF from either switch independent of the other's position.

Mnemonic

"Two-way Toggles, Two Places"