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.

Answer

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 $P = I^2R$.

Mnemonic

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

Question 1(b) [4 marks]

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

Answer

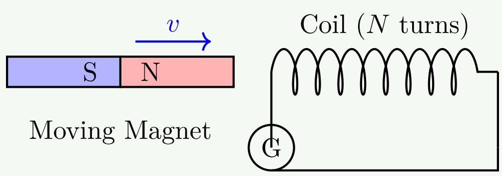
Faraday's Laws:

- **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.

Mnemonic

"Flux Change Generates EMF" ($d\Phi/dt = \text{EMF}$)

Question 1(c) [7 marks]

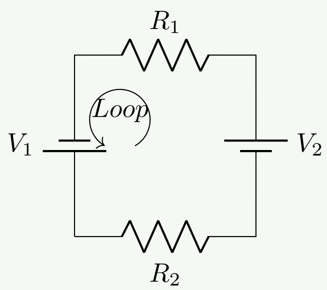
Explain Kirchhoff's Voltage Law (KVL) and Kirchhoff's Current Law (KCL) with necessary diagram.

Answer

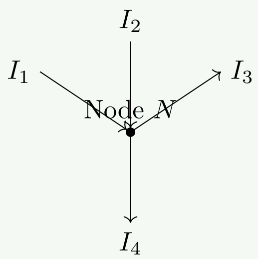
Comparison:

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).

Mnemonic

"Voltage Loops, Current Nodes"

Question 1(c OR) [7 marks]

Differentiate statically induced EMF and dynamically induced EMF.

Answer

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.

Answer

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"

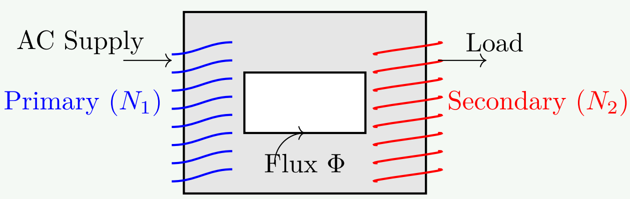
Question 2(b) [4 marks]

Explain working principle of transformer.

Answer

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.

Answer

Given:

- N_1, N_2: Number of turns
- Φ_m: Maximum flux in core
- f: Frequency of supply

Derivation:

1. **Flux Equation**: $\Phi = \Phi_m \sin(2\pi ft)$
2. **Induced EMF**: $e = -N\frac{d\Phi}{dt}$
3. **Differentiation**:

$$e = -N\frac{d}{dt}(\Phi_m \sin(2\pi ft)) = -N\Phi_m(2\pi f)\cos(2\pi ft)$$

$$e = 2\pi fN\Phi_m \sin(2\pi ft - 90°)$$

4. **Maximum EMF**: $E_m = 2\pi fN\Phi_m$
5. **RMS EMF**: $E_{rms} = \frac{E_m}{\sqrt{2}} = \frac{2\pi fN\Phi_m}{\sqrt{2}} = 4.44fN\Phi_m$

Key Formula

$$E_1 = 4.44fN_1\Phi_m \quad \text{and} \quad E_2 = 4.44fN_2\Phi_m$$

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.

Answer

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).

Mnemonic

"Power Distribution Isolation Electronics"

Question 2(b OR) [4 marks]

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

Answer

1. Back EMF Equation:

$$E_b = \frac{\phi Z N P}{60A}$$

Simplified: $E_b = K\phi N$

2. Torque Equation:

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

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]

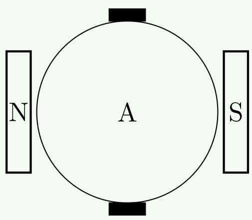
Explain construction and working of D.C. motor with necessary figure.

Answer

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.

Answer

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.

Answer

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"

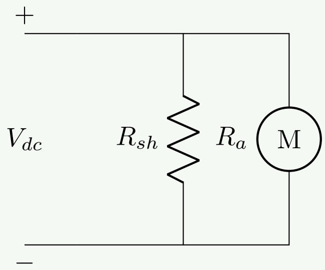
Question 3(c) [7 marks]

Explain different types of DC motor.

Answer

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.

Answer

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.

Answer

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.

Mnemonic

"Auto Adjusts Advantageously"

Question 3(c OR) [7 marks]

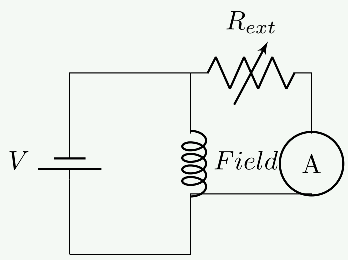
Explain speed control of DC shunt motor.

Answer

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]

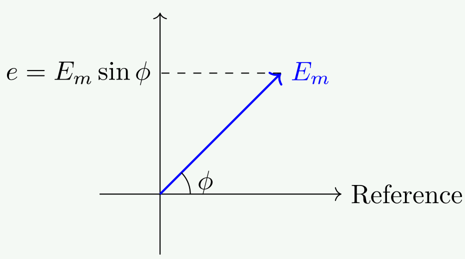
Explain vector representation of alternating EMF.

Answer

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.

Answer

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]

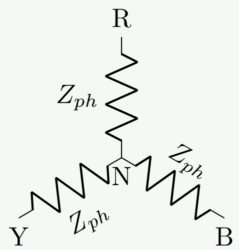
Derive equation for relation between line and phase voltage and current in star connection.

Answer

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.

Answer

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.

Answer

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]

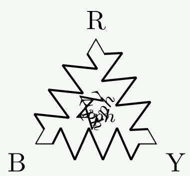
Derive equation for relation between line and phase voltage and current in delta connection.

Answer

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]

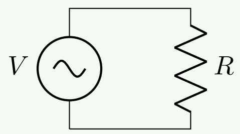
Explain AC through pure resistor with necessary circuit and waveform.

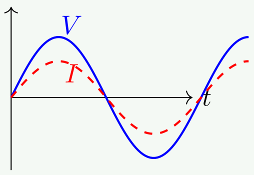
Answer

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.

Answer

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).

Answer

Devices: Fuse, MCB, MCCB, ELCB, Relay.

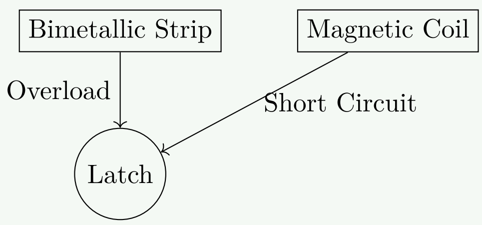
MCB (Miniature Circuit Breaker):

- **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.

Answer

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

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

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

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

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

Mnemonic

"Inductor Impedes, Current Lags"

Question 5(b OR) [4 marks]

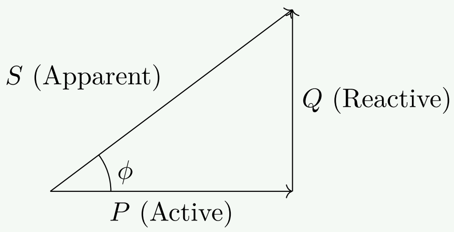
Explain concept of power and power triangle in AC circuit.

Answer

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

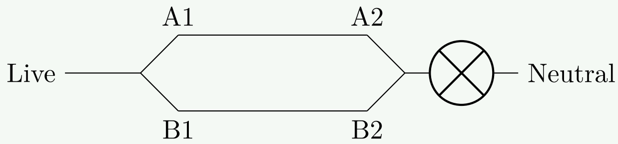
"Power Triangle: Please Qualify Students"

Question 5(c OR) [7 marks]

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

Answer

1. One Place Control: Simple series circuit with Switch (S) and Lamp (L).
Diagram: Live $\rightarrow$ Switch $\rightarrow$ Lamp $\rightarrow$ 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"