Fundamentals of Electrical Engineering (DI01000101) - Winter 2024 Solution

Milav Dabgar

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Question 1(a) [3 marks]

Explain ohm's law with its limitation and application.

Solution

Answer:
Ohm's Law Summary:

Table 1. Ohm's Law Summary

Aspect	Description
Statement	Current through conductor is directly proportional to voltage
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
- **AC circuits**: Modified form needed for reactive components

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

Mnemonic

""Voltage Is Really Important" (V = I × R)"

Question 1(b) [4 marks]

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

Solution

Answer:
Faraday's Laws:
- **First Law**: EMF is induced when magnetic flux changes through conductor
- **Second Law**: Magnitude of EMF equals rate of flux change

Mathematical Expression:

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

Diagram:

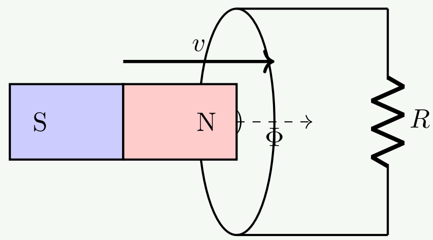


Figure 1. Faraday's Law Illustration

Applications:

- **Transformers**: Mutual induction principle
- **Generators**: Mechanical to electrical energy conversion
- **Inductors**: Self-induced EMF opposes current changes

Mnemonic

“”Flux Change Generates EMF” (dΦ/dt = EMF)”

Question 1(c) [7 marks]

Explain kirchhoff's voltage law and kirchhoff's current law with necessary diagram.

Solution

Answer:
Kirchhoff's Laws Comparison:

Table 2. Kirchhoff's Laws Comparison

Law	Statement	Mathematical Form	Application
KVL	Sum of voltages in closed loop = 0	$\Sigma V = 0$	Series circuits
KCL	Sum of currents at node = 0	$\Sigma I = 0$	Parallel circuits

KVL Diagram:

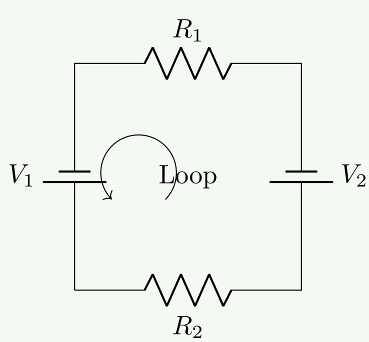


Figure 2. KVL Closed Loop

KCL Diagram:

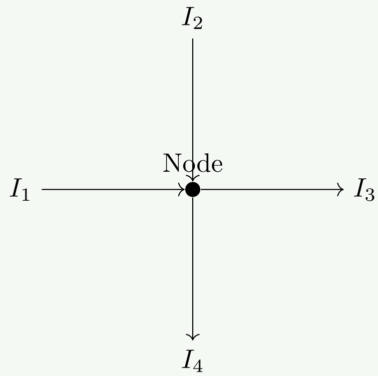


Figure 3. KCL Node

Key Points:

- **KVL**: Algebraic sum considers voltage polarities
- **KCL**: Considers current directions (incoming vs outgoing)
- **Applications**: Circuit analysis, finding unknown values

Mnemonic

“”Voltage Loops, Current Nodes” (KVL for loops, KCL for nodes)”

Question 1(c OR) [7 marks]

Differentiate statically induced emf and dynamically induced emf

Solution

Answer:
Static vs Dynamic EMF:

Table 3. Static vs Dynamic EMF

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	$e = -N(d\Phi/dt)$	$e = BLv$
Applications	AC circuits, power supplies	Power generation, motors

Static EMF Types:

- **Self-induced**: Same coil creates and experiences flux change
- **Mutually induced**: One coil affects another coil

Dynamic EMF Factors:

- **Magnetic field strength (B)**: Tesla
- **Conductor length (L)**: Meters
- **Velocity (v)**: m/s

Mnemonic

“”Static Stays, Dynamic Dances” (Static = stationary, Dynamic = motion)”

Question 2(a) [3 marks]

Explain various types of losses in transformer.

Solution

Answer:
Transformer Losses:

Table 4. Transformer Losses

Loss Type	Cause	Location	Characteristics
Iron Loss	Hysteresis + Eddy currents	Core	Constant, frequency dependent
Copper Loss	I^2R heating	Windings	Variable with load
Stray Loss	Leakage flux	Overall	Minimal

Iron Losses:
- **Hysteresis loss**: Magnetic domain reversal energy
- **Eddy current loss**: Circulating currents in core

Copper Losses:
- **Primary winding**: $I_1^2 R_1$
- **Secondary winding**: $I_2^2 R_2$

Mnemonic

“”Iron Core, Copper Coil” (Location of main losses)”

Question 2(b) [4 marks]

Explain working principle of transformer.

Solution

Answer:
Working Principle: Mutual electromagnetic induction between primary and secondary windings through common magnetic core.
Diagram:

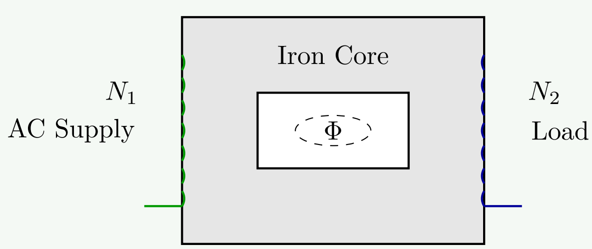


Figure 4. Transformer Principle

Operation Steps:
- **Step 1**: AC current in primary creates alternating flux
- **Step 2**: Flux links secondary through core
- **Step 3**: Changing flux induces EMF in secondary
- **Step 4**: Secondary EMF drives current through load

Key Relations:
- **Voltage ratio**: $V_2/V_1 = N_2/N_1$
- **Current ratio**: $I_1/I_2 = N_2/N_1$

Mnemonic

“”Primary Produces, Secondary Supplies” (Energy transfer direction)”

Question 2(c) [7 marks]

Derive emf equation of transformer.

Solution

Answer:
Given Parameters:

- N_1: Primary turns, N_2: Secondary turns
- Φ_m: Maximum flux, f: Frequency

EMF Derivation:
Step 1: Flux Variation

$$\Phi = \Phi_m \sin(2\pi f t)$$

Step 2: Rate of Flux Change

$$\frac{d\Phi}{dt} = 2\pi f \Phi_m \cos(2\pi f t)$$

Step 3: Maximum Rate

$$\left(\frac{d\Phi}{dt}\right)_{max} = 2\pi f \Phi_m$$

Step 4: RMS EMF Formula

$$E_1 = 4.44 \times f \times N_1 \times \Phi_m$$
$$E_2 = 4.44 \times f \times N_2 \times \Phi_m$$

EMF Equation Components:

Table 5. EMF Equation Components

Symbol	Parameter	Units
E	RMS EMF	Volts
f	Frequency	Hz
N	Number of turns	-
Φ_m	Maximum flux	Weber
4.44	Form factor constant	-

Transformation Ratio:

$$K = \frac{E_2}{E_1} = \frac{N_2}{N_1}$$

Mnemonic

“”Four-Forty-Four Flux Formula” (4.44 factor)”

Question 2(a OR) [3 marks]

Write application of transformer.

Solution

Answer:
Transformer Applications:

Table 6. Transformer Applications

Application	Purpose	Voltage Level
Power transmission	Reduce transmission losses	Step-up (400kV)
Distribution	Safe voltage for consumers	Step-down (230V)
Isolation	Electrical isolation	1:1 ratio
Electronic circuits	DC power supplies	Step-down

Industrial Applications:
- **Welding transformers**: High current, low voltage
- **Instrument transformers**: Measurement and protection
- **Audio transformers**: Impedance matching

Mnemonic

“”Power Distribution Isolation Electronics” (Main application areas)”

Question 2(b OR) [4 marks]

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

Solution

Answer:
Back EMF Equation:

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

Simplified Form:

$$E_b = K\phi N$$

Torque Equation:

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

Simplified Form:

$$T = K\phi I_a$$

Symbol Definitions:

Table 7. Symbol Definitions

Symbol	Parameter	Units
E_b	Back EMF	Volts
T	Torque	N-m
ϕ	Flux per pole	Weber
N	Speed	RPM
I_a	Armature current	Amperes
K	Motor constant	-

Mnemonic

“”Back EMF opposes, Torque proposes” (EMF opposes supply, torque drives rotation)”

Question 2(c OR) [7 marks]

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

Solution

Answer:
Construction Components:

Table 8. DC Motor Parts

Component	Function	Material
Stator	Provides magnetic field	Cast iron/steel
Rotor/Armature	Rotating part	Silicon steel laminations
Commutator	Current direction reversal	Copper segments
Brushes	Current collection	Carbon
Field windings	Electromagnets	Copper wire

Construction Diagram:

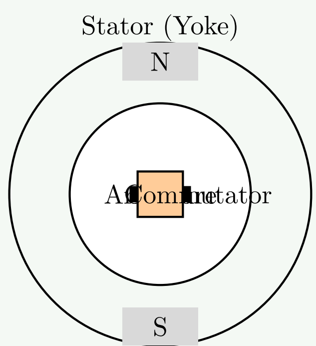


Figure 5. DC Motor Construction

Working Principle:
- **Step 1**: Current flows through armature conductors
- **Step 2**: Magnetic field interacts with current
- **Step 3**: Force generated by Fleming’s left-hand rule
- **Step 4**: Commutator reverses current direction
- **Step 5**: Continuous rotation maintained

Force Equation:

$$F = B \times I \times L$$

Mnemonic

“”Current Creates Circular motion” (Current interaction produces rotation)”

Question 3(a) [3 marks]

Explain construction of transformer.

Solution

Answer:
Transformer Construction:

Table 9. Transformer Construction

Component	Material	Function
Core	Silicon steel laminations	Magnetic flux path
Primary winding	Copper/Aluminum	Input energy
Secondary winding	Copper/Aluminum	Output energy
Insulation	Varnish/Paper	Electrical isolation
Tank	Steel	Oil containment & cooling

Core Types:
- **Shell type**: Windings surrounded by core
- **Core type**: Core surrounded by windings

Cooling Methods:
- **Air cooling**: Small transformers
- **Oil cooling**: Large transformers with radiators

Mnemonic

“”Core Carries Current Carefully” (Core design importance)”

Question 3(b) [4 marks]

Explain application of DC motor

Solution

Answer:
DC Motor Applications:

Table 10. DC Motor Applications

Motor Type	Speed Characteristic	Applications
Shunt	Constant speed	Fans, pumps, lathes
Series	Variable speed	Traction, cranes
Compound	Moderate variation	Elevators, compressors

Industrial Applications:
- **Shunt motors**: Machine tools requiring constant speed
- **Series motors**: Electric vehicles, starting heavy loads
- **Compound motors**: Rolling mills, punch presses

Advantages:
- **Easy speed control**: Voltage/field control
- **High starting torque**: Series motors
- **Reversible operation**: Change field/armature polarity

Mnemonic

“”Shunt Stays, Series Speeds” (Speed characteristics)”

Question 3(c) [7 marks]

Explain different types of DC motor.

Solution

Answer:
DC Motor Classification:

Table 11. DC Motor Classification

Type	Field Connection	Speed-Torque	Applications
Shunt	Parallel to armature	Constant speed, low starting torque	Fans, pumps
Series	Series with armature	Variable speed, high starting torque	Traction
Compound	Both series & shunt	Moderate characteristics	General purpose

Shunt Motor Diagram:

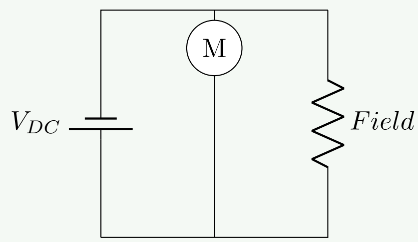


Figure 6. DC Shunt Motor

Characteristics:
- **Shunt**: Speed $\propto (V - I_a R_a)/\phi$
- **Series**: High starting torque, speed varies with load
- **Compound**: Combines advantages of both types

Speed Control Methods:
- **Armature control**: Vary armature voltage
- **Field control**: Vary field current
- **Resistance control**: Add external resistance

Mnemonic

“”Shunt Steady, Series Strong, Compound Combined” (Key characteristics)”

Question 3(a OR) [3 marks]

Explain transformation ratio of transformer.

Solution

Answer:
Definition: Transformation ratio (K) is the ratio of secondary to primary voltage or turns.
Mathematical Expression:

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

Transformation Ratio Types:

Table 12. Transformation Ratio Types

Ratio	Type	Voltage Change	Applications
$K > 1$	Step-up	Increases	Power transmission
$K < 1$	Step-down	Decreases	Distribution
$K = 1$	Isolation	Same	Safety isolation

Current Relationship:

$$\frac{I_1}{I_2} = \frac{N_2}{N_1} = K$$

Power Relationship:

$$P_1 = P_2 \text{ (Ideal transformer)}$$

Mnemonic

“”Turns Tell Transformation” (Turns ratio determines voltage ratio)”

Question 3(b OR) [4 marks]

Write application of autotransformer.

Solution

Answer:
Autotransformer Applications:

Table 13. Autotransformer Applications

Application	Advantage	Voltage Range
Motor starting	Reduced starting current	50-80% of rated
Voltage regulation	Fine voltage adjustment	±10% variation
Laboratory	Variable voltage source	0-110% of input
Power systems	Economic transmission	Close voltage ratios

Advantages:

- **Economy**: Less copper and iron required
- **Efficiency**: Higher than two-winding transformer
- **Size**: Compact design
- **Regulation**: Better voltage regulation

Limitations:

- **No isolation**: Common electrical connection
- **Safety**: Higher fault current

Mnemonic

“”Auto Adjusts Advantageously” (Automatic voltage adjustment benefit)”

Question 3(c OR) [7 marks]

Explain speed control of DC shunt motor

Solution

Answer:
Speed Control Methods:

Table 14. Speed Control Methods

Method	Range	Efficiency	Applications
Armature control	Below rated speed	High	Precise speed control
Field control	Above rated speed	High	Constant power drives
Resistance control	Below rated speed	Low	Simple applications

Armature Control Diagram:

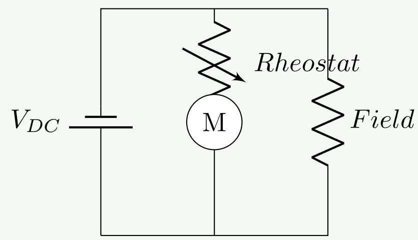


Figure 7. Armature Control Method

Speed Equations:
- **Armature control**: $N \propto (V - I_a R_a)/\phi$
- **Field control**: $N \propto V/\phi$
- **Resistance control**: $N \propto (V - I_a(R_a + R_{ext}))/\phi$

Modern Methods:
- **Chopper control**: PWM voltage control
- **Ward-Leonard system**: Motor-generator set
- **Electronic control**: Thyristor/IGBT drives

Characteristics:
- **Smooth control**: Stepless speed variation
- **Efficiency**: Armature control most efficient
- **Cost**: Field control economical

Mnemonic

“”Armature Accurate, Field Fast, Resistance Rough” (Control characteristics)”

Question 4(a) [3 marks]

Explain vector representation of alternating EMF.

Solution

Answer:
Vector Representation: Alternating EMF can be represented as a rotating vector (phasor) with constant magnitude and angular velocity.
Mathematical Form:

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

Diagram:

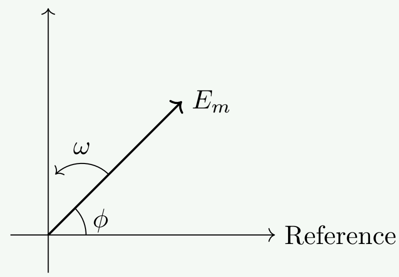


Figure 8. EMF Phasor Diagram

Vector Parameters:

Table 15. Vector Parameters

Parameter	Symbol	Units	Description
Magnitude	E_m	Volts	Maximum EMF
Angular velocity	ω	rad/s	Rotation speed
Phase angle	ϕ	Degrees	Initial phase
Frequency	$f = \omega/2\pi$	Hz	Cycles per second

Advantages:

- **Visual representation**: Easy to understand phase relationships
- **Mathematical simplification**: Complex calculations made easier

Mnemonic

“”Vectors Visualize Voltage Variation” (Phasor representation benefits)”

Question 4(b) [4 marks]

Define following terms w.r.t Alternating current: RMS value, Average value, Frequency, Time period

Solution

Answer:
AC Parameters Definition:

Table 16. AC Parameters Definition

Term	Definition	Formula	Units
RMS Value	Effective value producing same heating	$I_m/\sqrt{2}$	Amperes
Average Value	Mean value over half cycle	$2I_m/\pi$	Amperes
Frequency	Number of cycles per second	$f = 1/T$	Hz
Time Period	Time for one complete cycle	$T = 1/f$	Seconds

Mathematical Relations:

- **Form Factor**: RMS/Average $= \pi/2\sqrt{2} = 1.11$
- **Peak Factor**: Peak/RMS $= \sqrt{2} = 1.414$
- **Angular frequency**: $\omega = 2\pi f$

Mnemonic

“”Really Mean Square, Average Frequency Time” (Key AC parameters)”

Question 4(c) [7 marks]

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

Solution

Answer:
Star Connection Diagram:

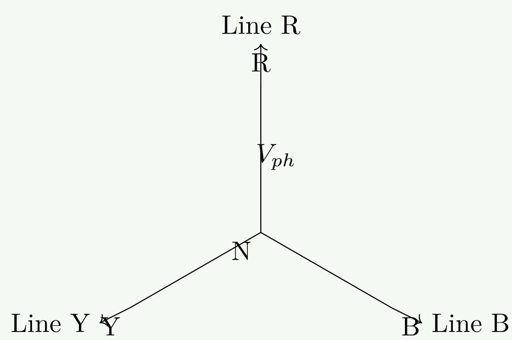


Figure 9. Star Connection

Voltage Relations:
- **Phase Voltages**: V_R, V_Y, V_B (with respect to neutral)
- **Line Voltages**: V_{RY}, V_{YB}, V_{BR} (between lines)

Phasor Analysis:

$$V_{RY} = V_R - V_Y$$

For balanced system:
- Phase voltages are equal in magnitude: $V_R = V_Y = V_B = V_{ph}$
- Phase difference = 120°

Vector Addition: Using phasor diagram and cosine rule:

$$V_L = \sqrt{V_{ph}^2 + V_{ph}^2 - 2V_{ph}V_{ph}\cos(120°)}$$
$$V_L = \sqrt{2V_{ph}^2 + V_{ph}^2} = \sqrt{3} \times V_{ph}$$

Final Relations:
Star Connection Relations:

Table 17. Star Connection Relations

Parameter	Relationship
Line Voltage	$V_L = \sqrt{3} \times V_{ph}$
Line Current	$I_L = I_{ph}$
Power	$P = \sqrt{3}V_L I_L \cos\phi$

Mnemonic

“”Star Scales Voltage, Same current” ($\sqrt{3}$ factor for voltage, current unchanged)”

Question 4(a OR) [3 marks]

Explain vector representation of alternating current.

Solution

Answer:
Vector Representation: AC current represented as rotating phasor with magnitude and phase angle.
Mathematical Expression:

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

Phasor Diagram:

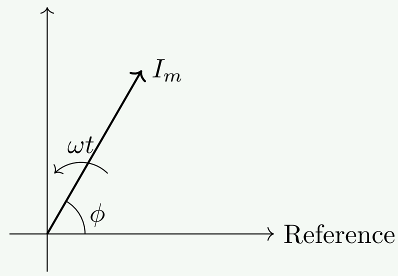


Figure 10. Current Phasor Diagram

Current Vector Elements:

Table 18. Current Vector Elements

Element	Symbol	Description
Magnitude	I_m	Peak current value
Phase	ϕ	Leading/lagging angle
Angular velocity	ω	Rotation speed
RMS value	$I = I_m/\sqrt{2}$	Effective current

Mnemonic

“”Current Circles Continuously” (Rotating phasor concept)”

Question 4(b OR) [4 marks]

Define following terms w.r.t Alternating current: Form factor, Peak factor, Angular velocity, Amplitude

Solution

Answer:
AC Current Parameters:

Table 19. AC Current Parameters

Term	Definition	Formula	Typical Value
Form Factor	RMS/Average value ratio	I_{rms}/I_{avg}	1.11 (sine wave)
Peak Factor	Peak/RMS value ratio	I_m/I_{rms}	1.414 (sine wave)
Angular Velocity	Rate of phase change	$\omega = 2\pi f$	314 rad/s (50Hz)
Amplitude	Maximum instantaneous value	I_m	Peak current

Practical Significance:
- **Design considerations**: Peak factors for insulation
- **Waveform analysis**: Form factors for distortion
- **Synchronization**: Angular velocity for timing

Mnemonic

"”Form Peak Angular Amplitude” (Four key factors)”

Question 4(c OR) [7 marks]

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

Solution

Answer:
Delta Connection Diagram:

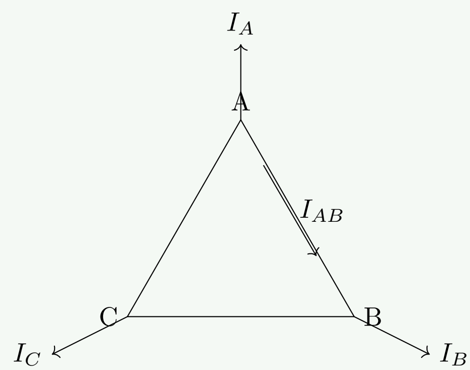


Figure 11. Delta Connection

Voltage Relations: In delta connection, line voltage equals phase voltage:

$$V_L = V_{ph}$$

Current Analysis: Each line current is vector sum of two phase currents.
For Line Current I_A:

$$I_A = I_{AB} - I_{CA}$$

Phasor Analysis: For balanced system with phase currents equal in magnitude:

- $I_{AB} = I_{CA} = I_{CB} = I_{ph}$
- Phase difference between currents = 120°

Vector Subtraction:

$$I_A = I_{AB} - I_{CA} = I_{AB} - (-I_{CA})$$

Using phasor diagram:

$$I_L = \sqrt{I_{ph}^2 + I_{ph}^2 - 2I_{ph}I_{ph}\cos(60^\circ)}$$
$$I_L = \sqrt{2I_{ph}^2 - I_{ph}^2} = \sqrt{3} \times I_{ph}$$

Delta Connection Relations:

Table 20. Delta Connection Relations

Parameter	Relationship
Line Voltage	$V_L = V_{ph}$
Line Current	$I_L = \sqrt{3} \times I_{ph}$
Power	$P = \sqrt{3}V_L I_L \cos\phi$

Mnemonic

“”Delta Doubles current, Same voltage” ($\sqrt{3}$ factor for current, voltage unchanged)”

Question 5(a) [3 marks]

Explain AC through pure resistor with necessary circuit and waveform.

Solution

Answer:
Circuit Diagram:

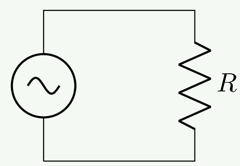
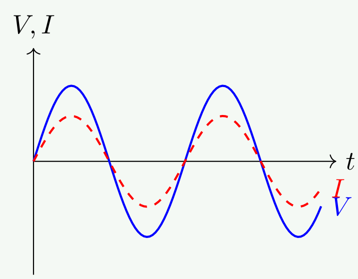


Figure 12. AC through Resistor

Waveform:



V and I in phase

Figure 13. Resistive Waveforms

AC through Resistor:

Table 21. AC through Resistor

Parameter	Relationship	Phase
Ohm's Law	$V = IR$	Same phase
Power	$P = VI = I^2R$	Always positive
Impedance	$Z = R$	Purely resistive

Mnemonic

“”Resistor Refuses phase Shift” (No phase difference)”

Question 5(b) [4 marks]

Define following terms w.r.t Alternating current: Impedance, Phase angle, Power factor, Reactive power

Solution

Answer:
AC Circuit Parameters:

Table 22. AC Circuit Parameters

Term	Definition	Formula	Units
Impedance	Total opposition to AC current	$Z = \sqrt{R^2 + X^2}$	Ohms
Phase Angle	Angle between V and I	$\phi = \tan^{-1}(X/R)$	Degrees
Power Factor	Cosine of phase angle	$PF = \cos\phi = R/Z$	-
Reactive Power	Power in reactive components	$Q = VI\sin\phi$	VAR

Power Triangle:

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

Mnemonic

“”Impedance Phase Power Quadrature” (Four key AC parameters)”

Question 5(c) [7 marks]

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

Solution

Answer:
Protective Devices:

Table 23. Protective Devices

Device	Protection Against	Application
Fuse	Overcurrent	Low/Medium voltage
MCB	Overload, Short circuit	Domestic/Commercial
ELCB	Earth leakage	Safety protection
Relay	Various faults	Industrial systems
Surge arrester	Overvoltage	Transmission lines

MCB (Miniature Circuit Breaker) - Detailed Explanation:
Construction:

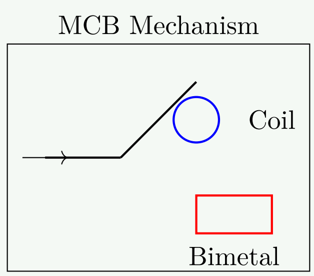


Figure 14. MCB Simplified Internal Structure

Components:
- **Fixed and moving contacts**: Current carrying parts
- **Bimetallic strip**: Thermal protection
- **Electromagnetic coil**: Magnetic protection

- **Arc quenching chamber**: Arc extinction
- **Operating mechanism**: Manual/automatic operation

Working Principle:

- **Overload Protection**: Current heats bimetallic strip → Strip bends → Trips mechanism.
- **Short Circuit Protection**: High current → Strong magnetic field in coil → Instantaneous trip.

Advantages:

- **Reusable**: Reset after fault clearance
- **Reliable operation**: Dual protection mechanism
- **Easy maintenance**: Accessible contacts

Mnemonic

“”MCB Magnetically Controls Both” (Thermal and magnetic protection)”

Question 5(a OR) [3 marks]

Derive equation of AC current passing through pure inductor

Solution

Answer:
Given: Pure inductor with inductance L, applied voltage $v = V_m \sin(\omega t)$
Voltage-Current Relationship:

$$v = L \times \frac{di}{dt}$$

Substituting applied voltage:

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

Integration:

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

At steady state, $C = 0$:

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

Pure Inductor Characteristics:

- **Current amplitude**: $I_m = V_m/\omega L$
- **Phase**: Current lags voltage by 90°
- **Power**: $P = 0$ (average)

Mnemonic

“”Inductor Impedes, Current lags” (XL opposes current, 90 degree lag)”

Question 5(b OR) [4 marks]

Explain concept of power and power triangle in AC circuit.

Solution

Answer:
AC Power Components:

Table 24. AC Power Components

Power Type	Symbol	Formula	Units
Active Power	P	$VI\cos\phi$	Watts
Reactive Power	Q	$VI\sin\phi$	VAR
Apparent Power	S	VI	VA

Power Triangle:

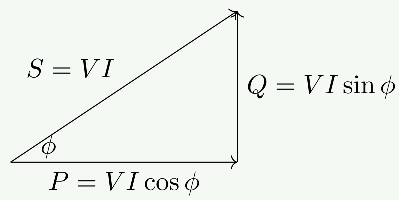


Figure 15. Power Triangle

Significance:
- **Active power**: Does useful work
- **Reactive power**: Maintains fields
- **Power factor**: Efficiency indicator (P/S)

Mnemonic

“”Power Triangle: Please Qualify Students” (P, Q, S components)”

Question 5(c OR) [7 marks]

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

Solution

Answer:
1. Lamp Control from One Place:
Circuit Diagram:

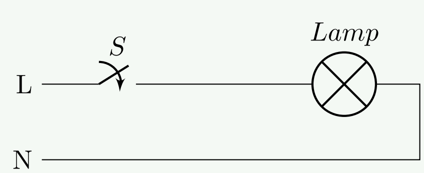


Figure 16. One-way Control

Components:
- **SPST Switch**: Single pole, single throw
- **Live wire control**: Switch in live wire for safety

2. Staircase Wiring (Two-Way Control):
Circuit Diagram:

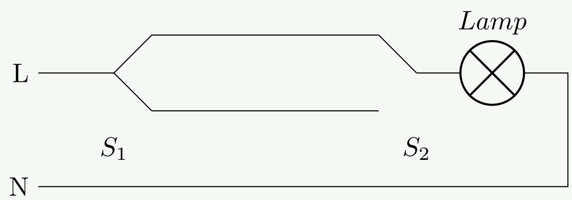


Figure 17. Two-way Staircase Wiring

Switch Positions:

Table 25. Staircase Logic

S1 Position	S2 Position	Lamp Status
Up	Up	ON
Up	Down	OFF
Down	Up	OFF
Down	Down	ON

Applications:

- **Staircase lighting**: Control from top and bottom
- **Long corridors**: Control from both ends
- **Bedroom lighting**: Control from bed and door

Mnemonic

“”Two-way Toggles, Two places” (Two switches, two locations)”