Fundamentals of Electrical Engineering (4311101) - Winter 2024 Solution

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Question 1(a) [3 marks]

Define current, electric Power and energy.

Solution

Answer:

Table 1. Basic Electrical Terms

Term	Definition
Current	The rate of flow of electric charge through a conductor (measured in amperes, A).
Electric Power	The rate at which electrical energy is transferred or consumed (measured in watts, W).
Energy	The capacity to do work, measured as power multiplied by time (measured in joules or watt-hours).

Mnemonic

"CPE: Charge-Per-second, Product-of-VI, Energy-over-time"

Question 1(b) [4 marks]

Explain the effect of temperature on the value of resistance of pure metal, alloys and insulators.

Solution

Answer:

Table 2. Temperature Effect on Resistance

Material Type	Temperature Effect	Equation
Pure Metals	Resistance increases with temperature (Positive Temperature Coefficient).	$R_2 = R_1[1 + \alpha(T_2 - T_1)]$
Alloys	Slight increase with temperature (Very low α).	$R_2 = R_1[1 + \alpha(T_2 - T_1)]$
Insulators	Resistance decreases with temperature (Negative Temperature Coefficient).	$R_2 = R_1 e^{\beta(1/T_2 - 1/T_1)}$

Where α is the temperature coefficient, T is temperature, and R is resistance.

Mnemonic

"MAI: Metals Add, Alloys Increase-little, Insulators Invert"

Question 1(c) [7 marks]

State and explain KCL and KVL with examples.

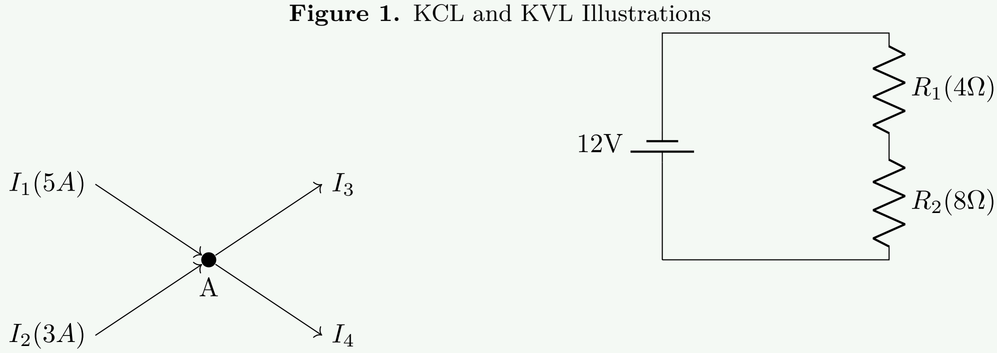
Solution

Answer:
Kirchhoff's Laws:

Table 3. KCL vs KVL

Law	Statement	Equation
KCL	Sum of currents entering a node equals sum of currents leaving the node.	$\sum I_{in} = \sum I_{out}$
KVL	Sum of voltage drops equals sum of voltage rises in a closed loop.	$\sum V = 0$

Figure 1. KCL and KVL Illustrations



KCL: $I_1 + I_2 = I_3 + I_4$
$8A$ Leaving

KVL: $12V = I(4+8)$
$\sum V = 0$

Example:

- **KCL**: At node A, if $I_1 = 5A$ and $I_2 = 3A$ entering, then $I_3 + I_4 = 8A$ must be leaving.
- **KVL**: In a loop with battery 12V and resistors $R_1(4\Omega)$ and $R_2(8\Omega)$, $12V = I(4\Omega + 8\Omega)$.

Mnemonic

"CLAN: Currents Leave And eNter equally, Voltage Around Loop is Null"

Question 1(c) OR [7 marks]

Explain series and parallel connections of resistors with necessary equations.

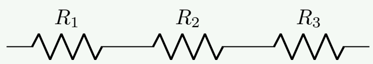
Solution

Answer:

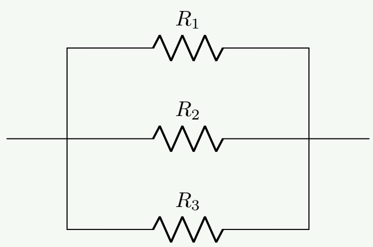
Table 4. Series vs Parallel Connections

Connection	Equation	Characteristics
Series	$R_{eq} = R_1 + R_2 + R_3 + \cdots + R_n$	Same current through all resistors. Total R increases.
Parallel	$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_n}$	Same voltage across all resistors. Total R decreases.

Figure 2. Resistor Connections



Series: Current I constant



Parallel: Voltage V constant

Mnemonic

"SPARC: Series Plus All Resistors, parallel Combines with reciprocals"

Question 2(a) [3 marks]

Write factors affecting the Resistance value.

Solution

Answer:
The resistance R of a conductor depends on:

Table 5. Factors Affecting Resistance

Factor	Effect on Resistance	Relation
Length (l)	Directly proportional	$R \propto l$
Cross-sectional Area (A)	Inversely proportional	$R \propto 1/A$
Material (ρ)	Depends on resistivity	$R \propto \rho$
Temperature (T)	Usually increases with temperature	$R \propto T$

Combined Formula: $R = \rho \frac{l}{A}$

Mnemonic

"LAMT: Length Adds, Area Minimizes, Material matters, Temperature transforms"

Question 2(b) [4 marks]

Draw power triangle and define active and reactive power.

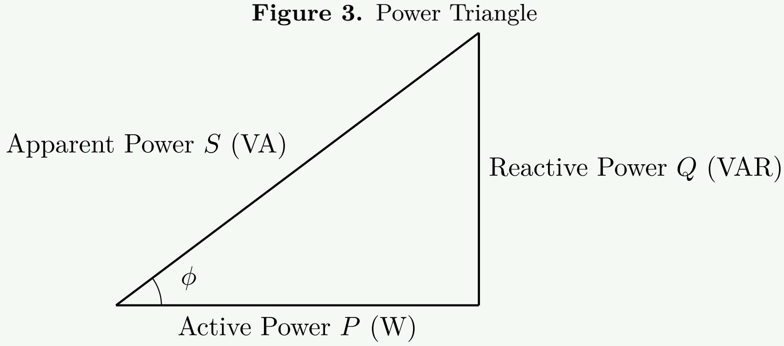
Solution

Answer:

Table 6. Types of AC Power

Power Type	Definition	Unit	Formula
Active Power (P)	Actual power consumed by device doing useful work.	Watt (W)	$P = VI\cos\phi$
Reactive Power (Q)	Power oscillating between source and load, maintaining fields.	VAR	$Q = VI\sin\phi$
Apparent Power (S)	Vector sum of active and reactive power.	VA	$S = VI$

Figure 3. Power Triangle



Power Triangle: $S^2 = P^2 + Q^2$

Mnemonic

"PAWS: Power Active Works, Apparent is Slant-hypotenuse, reactive Qoscillates"

Question 2(c) [7 marks]

Explain concept of cell and battery. List out various rating and types of battery.

Solution

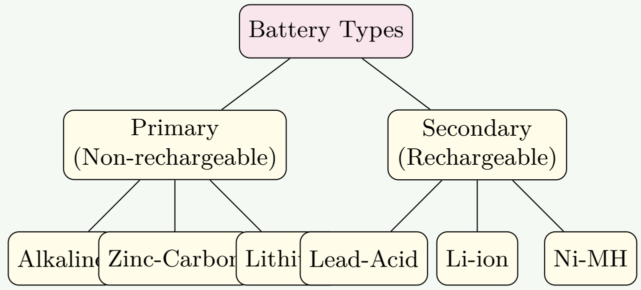
Answer:
Difference:

- **Cell**: Basic electrochemical unit that converts chemical energy to electrical energy.
- **Battery**: Collection of one or more cells connected in series (for voltage) or parallel (for current).

Battery Ratings:

- **Voltage**: Potential difference (Volts, V).
- **Capacity**: Amount of charge stored (Ampere-hour, Ah).
- **Energy**: Total energy available (Watt-hour, Wh).
- **C-Rate**: Rate of charge/discharge relative to capacity.
- **Cycle Life**: Number of charge/discharge cycles before degradation.

Figure 4. Battery Classification



Mnemonic

"CAVE: Cells Are Voltage Elements, batteries Bundle And TallY Energy"

Question 2(a) OR [3 marks]

Define the terms resistance, conductance and conductivity.

Solution

Answer:

Table 7. Electrical Material Properties

Term	**Definition**	**Unit**	**Formula**
Resistance (R)	Opposition offered by material to flow of current.	Ohm (Ω)	$R = \rho l/A$
Conductance (G)	Reciprocal of resistance; ease of current flow.	Siemens (S)	$G = 1/R$
Conductivity (σ)	Material property representing ability to conduct current.	S/m	$\sigma = 1/\rho$

Where ρ is resistivity.

Mnemonic

"RCG: Resist Current Gladly, Conduct Generously, Sigma Gets current through"

Question 2(b) OR [4 marks]

Prove that for pure inductive circuit, the current lags applied voltage by 90°.

Solution

Answer:
Consider a pure inductive circuit with inductance L.

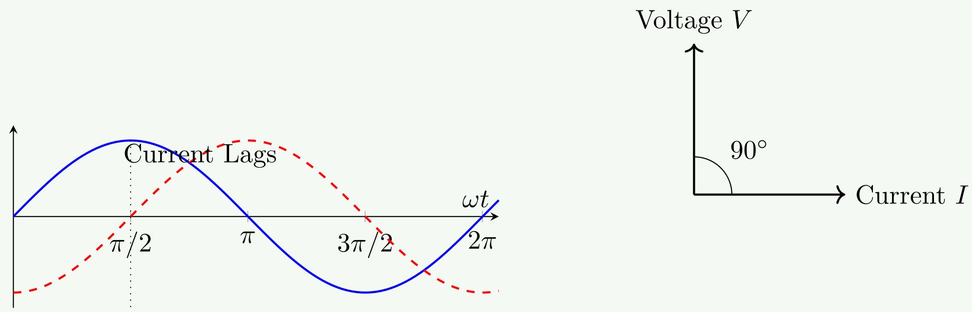
- Applied Voltage: $v = V_m \sin(\omega t)$
- For an inductor, the back EMF opposes voltage: $v = L\frac{di}{dt}$
- Rearranging for current: $di = \frac{v}{L}dt = \frac{V_m}{L}\sin(\omega t)dt$
- Integrating both sides:

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

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

- This shows current i lags voltage v by 90°.

Figure 5. Inductive Circuit Waveforms



Mnemonic

"ELI: Voltage Leads current In inductor by 90 degrees"

Question 2(c) OR [7 marks]

Describe Resistor, Inductor and Capacitor with their formula.

Solution

Answer:

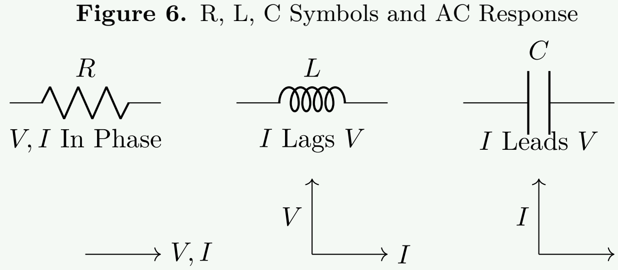
Table 8. Passive Circuit Components

Component	Parameter	Description	V-I Formula	Energy
Resistor	Resistance (R)	Opposes flow of current, dissipates energy as heat.	$V = IR$	None (Dissipates)
Inductor	Inductance (L)	Opposes change in current, stores energy in magnetic field.	$V = L\frac{di}{dt}$	$E = \frac{1}{2}LI^2$
Capacitor	Capacitance (C)	Opposes change in voltage, stores energy in electric field.	$I = C\frac{dv}{dt}$	$E = \frac{1}{2}CV^2$

Effect on AC Circuit:

- **Resistor**: Current in phase with voltage. Power Factor = 1.
- **Inductor**: Current lags voltage by 90°. Power Factor = 0 lagging.
- **Capacitor**: Current leads voltage by 90°. Power Factor = 0 leading.

Figure 6. R, L, C Symbols and AC Response



Mnemonic

"RIC: Resistor Impedes Current, Inductor Catches current-changes, Capacitor Controls voltage-changes"

Question 3(a) [3 marks]

Define and explain R.M.S value and average value of AC signal.

Solution

Answer:

Table 9. RMS vs Average Value

Value	Definition	Formula (Sine Wave)	Relation
RMS Value	Square root of mean of squared values.	$V_{rms} = \frac{V_{max}}{\sqrt{2}} = 0.707V_{max}$	Equivalent DC heating effect.
Average Value	Mean of rectified signal over half cycle.	$V_{avg} = \frac{2V_{max}}{\pi} = 0.637V_{max}$	Used for battery charging.

Mnemonic

"RAM: Rms-Average Method: Root-mean-square And Mean-of-absolute"

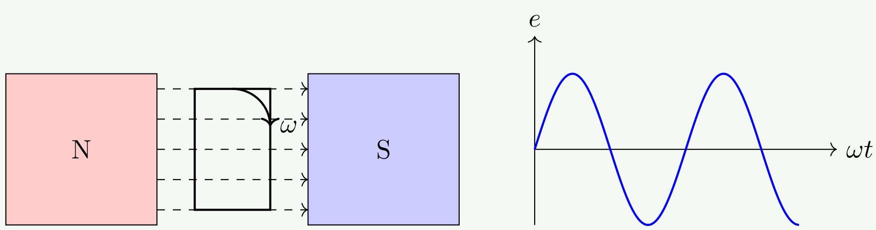
Question 3(b) [4 marks]

With necessary diagrams explain how alternating EMF is generated?

Solution

Answer:
Principle: When a coil rotates in a uniform magnetic field, the magnetic flux linking with it changes, inducing an EMF (Faraday's Law).

Figure 7. AC EMF Generation



Sine Waveform

- Coil rotates, cutting flux (ϕ).
- $e = -N\frac{d\phi}{dt} = NBA\omega \sin(\omega t)$.
- Direction changes every half cycle.

Mnemonic

"FARM: Flux And Rotation Make alternating voltage"

Question 3(c) [7 marks]

Explain A.C analysis of purely resistive AC circuit.

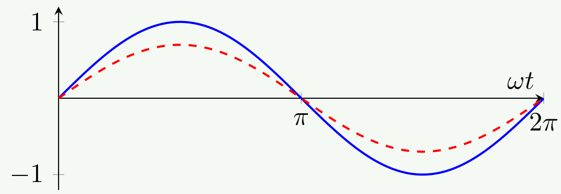
Solution

Answer:
Purely Resistive Circuit:
- Applied Voltage: $v = V_m \sin \omega t$
- Current: $i = \frac{v}{R} = \frac{V_m}{R} \sin \omega t = I_m \sin \omega t$

Table 10. Resistive Circuit Analysis

Parameter	Formula	Relationship
Voltage	$v = V_m \sin \omega t$	In Phase with Current
Current	$i = I_m \sin \omega t$	Follows Ohm's Law
Power	$p = vi = V_m I_m \sin^2 \omega t$	Always positive
Avg Power	$P = V_{rms} I_{rms} = I^2 R$	Constant heating

Figure 8. Resistive Circuit Waveforms



Mnemonic

"VIPS: Voltage In-Phase with current, Same waveform, Power always Positive"

Question 3(a) OR [3 marks]

Alternating current is given by I = 28.28sin(2π50t). Find R.M.S value of current.

Solution

Answer:
Given: $I = 28.28 \sin(2\pi 50t)$ compare with $I = I_m \sin(\omega t)$.
- $I_m = 28.28$ A

Calculation:

$$I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{28.28}{1.414} = 20 \text{ A}$$

Result: RMS Current = 20 A

Mnemonic

"PER: Peak to Effective by Root-2"

Question 3(b) OR [4 marks]

Find maximum value and R.M.S value of sinusoidal voltage if Vav=60V.

Solution

Answer:
Given: $V_{av} = 60$ V.

Table 11. Calculations

Step	Formula	Calculation
Find Max (V_m)	$V_{av} = 0.637V_m \implies V_m = \frac{V_{av}}{0.637}$	$V_m = \frac{60}{0.637} = 94.2$ V
Find RMS (V_{rms})	$V_{rms} = 0.707V_m$	$V_{rms} = 0.707 \times 94.2 = 66.6$ V

Result: Max Value = 94.2 V, RMS Value = 66.6 V

Mnemonic

"AVR: Average to peak Via multiplying by (pi/2), Rms is peak/root2"

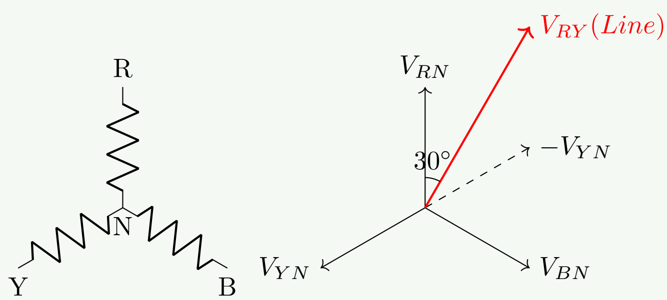
Question 3(c) OR [7 marks]

Derive equation of line and phase voltage for balanced star connected load with help of phasor diagram.

Solution

Answer:

Figure 9. Star Connection and Phasor



Derivation:

- Line Voltage V_{RY} is vector difference of V_{RN} and V_{YN}.
- $V_{RY} = V_{RN} - V_{YN}$
- Magnitude: $V_L = \sqrt{V_P^2 + V_P^2 + 2V_PV_P\cos(60°)} = \sqrt{3V_P^2}$
- **Result**: $V_L = \sqrt{3}V_P$
- Line voltage leads Phase voltage by 30°.

Mnemonic

"PALS: Phase to Line in Star: multiply by Square-root-3"

Question 4(a) [3 marks]

Write statement of Faraday's law and Lenz's law with expression.

Solution

Answer:

Table 12. Laws of Induction

Law	Statement	Expression
Faraday's Law	INDUCED EMF is directly proportional to the rate of change of magnetic flux.	$e = -N\frac{d\phi}{dt}$
Lenz's Law	The direction of induced EMF opposes the cause producing it (indicated by negative sign).	Negative sign in $e = -N\frac{d\phi}{dt}$

Mnemonic

"FORC: Faraday's flux Over Rate Change, Lenz Opposes the Reason for Change"

Question 4(b) [4 marks]

State any four advantage of 3-phase supply over single-phase supply.

Solution

Answer:

- **Higher Power Density**: For same size, 3-phase machine produces more power.
- **Constant Power**: 3-phase power is constant (non-pulsating), unlike 1-phase.
- **Material Saving**: Requires less copper for same power transmission.
- **Self-Starting**: 3-phase motors are self-starting due to rotating magnetic field.

Mnemonic

"PCCS: Power higher, Constant delivery, Copper less, Self-starting motors"

Question 4(c) [7 marks]

Explain Fleming's right-hand rule for generators and left-hand rule for motors.

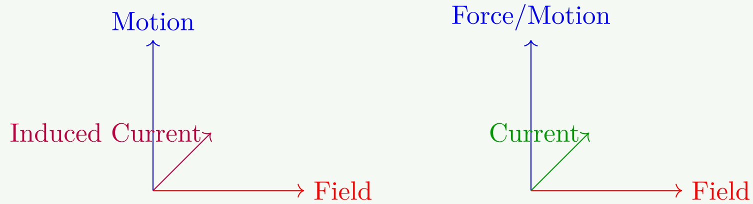
Solution

Answer:

Table 13. Fleming's Rules Comparison

Feature	Right-Hand Rule (Generator)	Left-Hand Rule (Motor)
Purpose	Find Induced EMF/Current Direction	Find Force/Motion Direction
Thumb	Motion of Conductor	Motion/Force
Forefinger	Magnetic Field (N to S)	Magnetic Field (N to S)
Middle Finger	Induced Current	Current

Figure 10. Fleming's Hand Rules



Right Hand (Generator) Left Hand (Motor)

Mnemonic

"FBI-MFC: Field-B-Induced current for right hand, Motion-Field-Current for left"

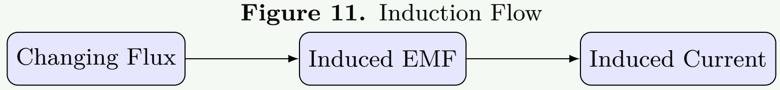
Question 4(a) OR [3 marks]

Describe phenomenon of electromagnetic induction.

Solution

Answer:
Electromagnetic Induction: The process of generating an electromotive force (EMF) across a conductor when it is exposed to a changing magnetic field.

Figure 11. Induction Flow



Mnemonic

"MICE: Motion Induces Current via Electromagnetic induction"

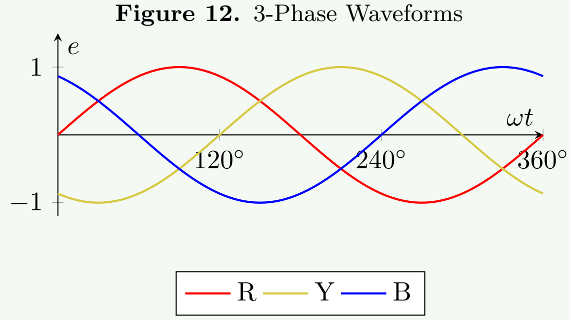
Question 4(b) OR [4 marks]

Explain the generation of 3-phase alternating EMF.

Solution

Answer:
Generation Principle:
- Three coils placed at 120° electrical displacement in space.
- Rotating these coils in a magnetic field induces three EMFs.
- EMFs have same magnitude and frequency but are phase-shifted by 120°.

Figure 12. 3-Phase Waveforms



Mnemonic

"CPS: Coils Produce Shifted waveforms at 120 degrees"

Question 4(c) OR [7 marks]

Differentiate statically and dynamically induced E.M.F.

Solution

Answer:

Table 14. Static vs Dynamic EMF

Parameter	Statically Induced EMF	Dynamically Induced EMF
Definition	EMF induced without moving parts (change in flux linkage).	EMF induced by relative motion between conductor and field.
Motion	Stationary conductor and field.	Moving conductor or field.
Formula	$e = -N\frac{d\phi}{dt}$	$e = Blv\sin\theta$
Example	Transformer	Generator, DC Dynamo

Mnemonic

"SMCE: Static-Moving, Change-External: static has changing flux, moving has constant flux"

Question 5(a) [3 marks]

Differentiate HAWT and VAWT.

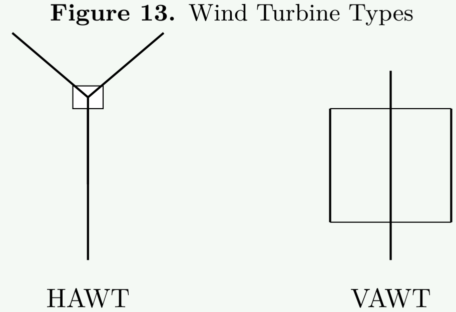
Solution

Answer:

Table 15. HAWT vs VAWT

Parameter	HAWT (Horizontal Axis)	VAWT (Vertical Axis)
Axis	Horizontal (parallel to ground)	Vertical (perpendicular to ground)
Wind Direction	Needs Yaw mechanism to face wind.	Omni-directional (accepts wind from any side).
Generation	Components at top of tower.	Generator can be on ground.

Figure 13. Wind Turbine Types



Mnemonic

"HV-DIT: Horizontal-Vertical, Directional-Independent, Tall-lower"

Question 5(b) [4 marks]

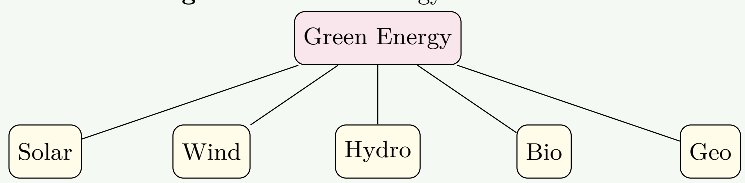
Classification of green energy.

Solution

Answer:

- **Solar Energy**: Photovoltaic, Thermal.
- **Wind Energy**: Onshore, Offshore.
- **Hydro Energy**: Dams, Tidal, Wave.
- **Geothermal**: Earth's heat.
- **Biomass**: Organic waste.

Figure 14. Green Energy Classification



Mnemonic

"SWHGBT: Sun Wind Hydro Geo Bio Tidal - Sources With Huge Green Benefits Today"

Question 5(c) [7 marks]

Explain wind power system.

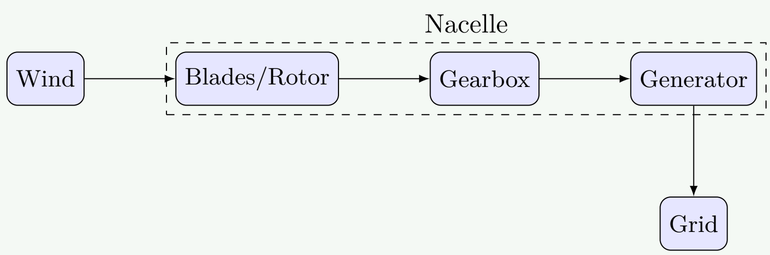
Solution

Answer:

Components:

1. **Blades**: Capture wind energy (Aerodynamic).
2. **Rotor**: Hub connecting blades.
3. **Gearbox**: Increases speed for generator.
4. **Generator**: Converts mechanical rotation to electricity.
5. **Yaw Drive**: Orients turbine towards wind.
6. **Tower**: Supports assembly at height.

Figure 15. Wind Power Block Diagram



Mnemonic

"WINGER: Wind In, Gearbox Enhances Rotation, Generator outputs"

Question 5(a) OR [3 marks]

List any three needs of green energy.

Solution

Answer:
- **Environmental Protection**: Reduce carbon footprint and pollution.
- **Sustainability**: Infinite source compared to fossil fuels.
- **Energy Security**: Reduce dependence on imported fuels.

Mnemonic

"ECO: Environment protected, Conservation of resources, Oil-independence"

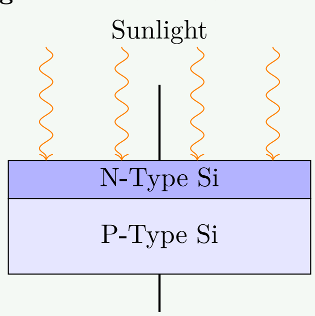
Question 5(b) OR [4 marks]

Write short note on PV cell.

Solution

Answer:
Photovoltaic (PV) Cell:
- Basic unit of solar system.
- Made of Semiconductor (Silicon).
- Works on **Photovoltaic Effect**: Photons strike PN junction → electron-hole pairs → Current.
- Output: DC voltage (0.5-0.6V per cell).

Figure 16. PV Cell Construction



Mnemonic

"SPEC: Sunlight Produces Electricity through Cells with p-n junctions"

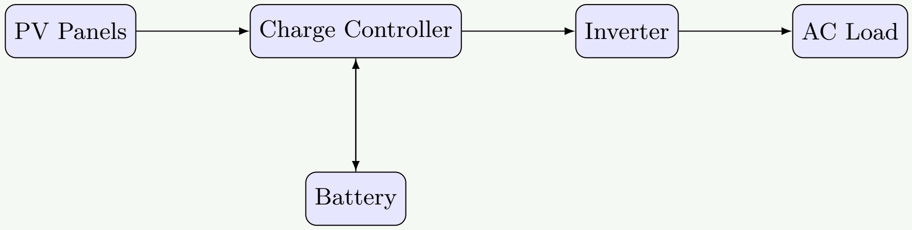
Question 5(c) OR [7 marks]

Explain solar system.

Solution

Answer:
Solar Power System:
1. **Solar Array**: Collection of PV panels to generate DC.
2. **Charge Controller**: Regulates voltage/current to battery.
3. **Battery Bank**: Stores energy for later use (Off-grid).
4. **Inverter**: Converts DC to AC for appliances.
5. **Load**: Electrical devices.

Figure 17. Solar System Block Diagram



Mnemonic

"SCBID: Solar Cells produce, Battery stores, Inverter converts, Distribution supplies"