Industrial Electronics (4331103) - Winter 2022 Solution

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Question 1(a) [3 marks]

Draw the construction of SCR and explain it.

Solution

SCR (Silicon Controlled Rectifier) is a four-layer PNPN semiconductor device with three terminals: Anode, Cathode, and Gate.

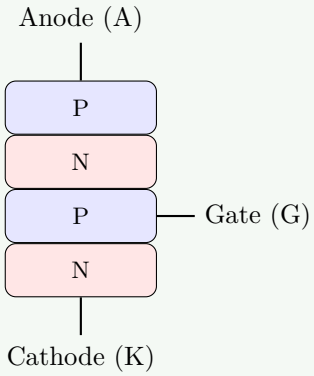

Figure 1. SCR Construction

- **P-N-P-N Layers**: Four alternating semiconductor layers.
- **Gate Terminal**: Controls turn-on of the device.
- **Current Flow**: Anode to cathode when triggered.

Mnemonic

"Silicon Controls Rectification: SCR controls current flow in one direction only when triggered."

Question 1(b) [4 marks]

Draw construction of TRIAC and explain it.

Solution

TRIAC (Triode for Alternating Current) is a bidirectional three-terminal semiconductor device that conducts in both directions when triggered.

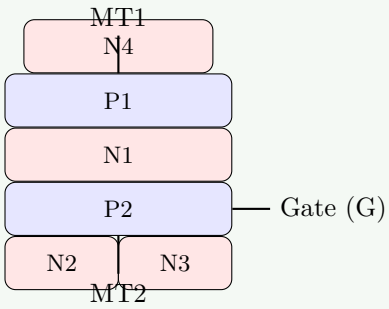

Figure 2. TRIAC Construction

- **Bidirectional Operation**: Conducts in both directions when triggered.
- **Gate Control**: Single gate controls conduction in both directions.
- **Equivalent Circuit**: Acts like two SCRs connected in anti-parallel.
- **AC Applications**: Widely used for AC power control applications.

Mnemonic

"TRI-direction AC controller: Controls current in both directions in AC circuits."

Question 1(c) [7 marks]

Describe construction & working of Opto-Isolators, Opto-TRIAC, Opto-SCR, and Opto-transistor. And list their applications.

Solution

Opto-isolators use light to transfer electrical signals between isolated circuits.

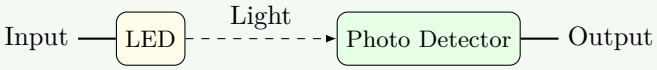

Figure 3. Basic Opto-Isolator Block Diagram

Table 1. Opto-Isolator Types and Applications

Device	Construction	Working	Applications
Opto-Isolator	LED + Photodetector	LED emits light when input current flows; photodetector activates output circuit	Signal isolation, Medical equipment, Industrial controls
Opto-TRIAC	LED + Photo-TRIAC	LED triggers the TRIAC through light; provides electrical isolation	AC power control, Solid state relays, Motor controls
Opto-SCR	LED + Photo-SCR	LED emits light to trigger SCR; provides high isolation	DC switching, Industrial controls, High voltage isolation
Opto-transistor	LED + Photo-transistor	LED light controls base current of phototransistor	Encoders, Level detection, Position sensing

- **Electrical Isolation**: Complete separation between input and output.
- **Noise Immunity**: High resistance to electrical noise.
- **Speed**: Response times in microseconds range.

Mnemonic

"LOST: Light Operates Semiconductor Terminals in all opto-devices."

Question 1(c OR) [7 marks]

Describe Explain working of SCR using two transistor analogies. List the various industrial applications of SCR.

Solution

SCR can be modeled as two interconnected transistors: PNP (T1) and NPN (T2).

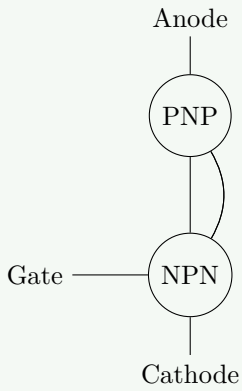

Figure 4. Two Transistor Analogy of SCR

Working Principle:

Step	Operation
Initial State	Both transistors are OFF
Gate Triggering	Current injected into gate (B2 of T2)
Regenerative Action	T2 turns ON → T1 base gets current → T1 turns ON → More current to T2 base
Latching	Self-sustaining current flow continues even if gate signal is removed

Industrial Applications of SCR:

- **Power Control**: AC/DC motor speed control.
- **Switching**: Static switches, solid-state relays.
- **Inverters**: DC to AC conversion.
- **Protection**: Overvoltage protection circuits.
- **Lighting**: Light dimmers, illumination control.

Mnemonic

"POWER: Power control, Overvoltage protection, Welding machines, Electronic converters, Regulated supplies."

Question 2(a) [3 marks]

Define Triggering in SCR and explain any two triggering techniques.

Solution

Triggering is the process of turning ON an SCR by applying appropriate signal to its gate terminal.
Two Triggering Techniques:

Table 2. Triggering Techniques

Technique	Description
Gate Triggering	Direct current pulse applied to gate-cathode circuit
Light Triggering	Photons striking junction provide energy for conduction

- **Gate Triggering**: Most common method using electrical pulse.
- **Light Triggering**: Uses photosensitive semiconductor properties.

Mnemonic

"GET: Gate Electrical Triggering is the most common method."

Question 2(b) [4 marks]

Write the differences between forced commutation and natural commutation.

Solution

Table 3. Forced vs Natural Commutation

Parameter	Forced Commutation	Natural Commutation
Definition	External circuitry forces SCR to turn OFF	SCR turns OFF naturally when current falls below holding value
Application	DC circuits	AC circuits
Components	Requires additional components (capacitors, inductors)	No additional components needed
Complexity	Complex circuit design	Simple circuit design
Energy	External energy needed for turn-off	No external energy needed

- **Forced Commutation**: Actively turns OFF SCR using external circuit.
- **Natural Commutation**: SCR turns OFF when AC current crosses zero.

Mnemonic

"FACE: Forced Active Commutation requires External components."

Question 2(c) [7 marks]

Design the snubber circuit for SCR.

Solution

Snubber circuit protects SCR from high dV/dt and limits rate of voltage rise.

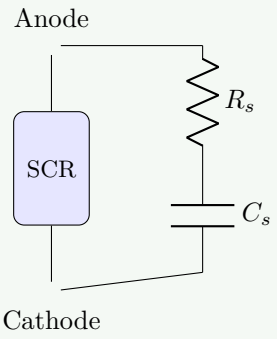

Figure 5. RC Snubber Circuit

Design Steps:

Step	Calculation
1. Calculate dV/dt rating	From datasheet (V/μs)
2. Determine R value	$R = V_1/I_L$ where V_1 is supply voltage and I_L is load current
3. Determine C value	$C = 1/(R \times (dV/dt)_{max})$
4. RC time constant	$\tau = R \times C$ (should be greater than SCR turn-off time)

- **Resistance R**: Limits discharge current of capacitor.
- **Capacitance C**: Absorbs transient energy and limits dV/dt.
- **Protection**: Prevents false triggering and damage.
- **Power Rating**: R must have sufficient power rating.

Mnemonic

"RCSS: Resistance-Capacitance Saves Silicon from Stress."

Question 2(a OR) [3 marks]

Define commutation and Explain class-E commutation for SCR.

Solution

Commutation is the process of turning OFF an SCR by reducing its anode current below the holding current level.
Class-E Commutation:

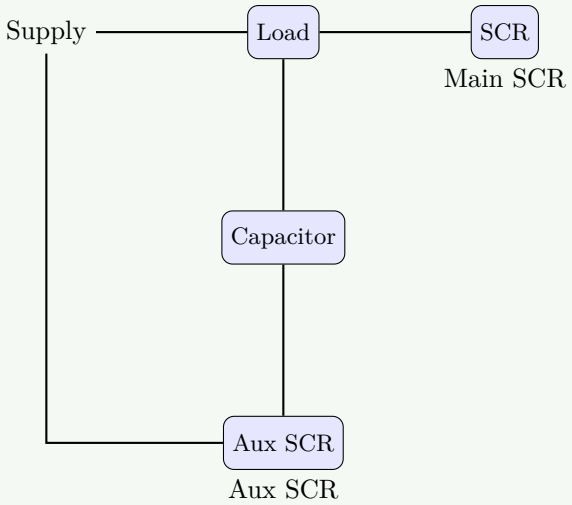

Figure 6. Class-E Commutation Circuit (Conceptual)

- **Auxiliary SCR**: Controls the commutation process.
- **Resonant Circuit**: Forms LC resonant circuit.
- **Operation**: Auxiliary SCR triggers capacitor discharge to reverse-bias main SCR.
- **Application**: Used in inverters and choppers.

Mnemonic

"ACE: Auxiliary Capacitor Extinguishes conduction."

Question 2(b OR) [4 marks]

Explain Triggering of Thyristor.

Solution

Table 4. Thyristor Triggering Methods

Triggering Method	Working Principle
Gate Triggering	Electrical pulse applied between gate and cathode
Temperature Triggering	Junction temperature increases to cause turn-on
Light Triggering	Photons create electron-hole pairs at junctions
dV/dt Triggering	Rapid voltage rise causes capacitive current flow
Forward Voltage Triggering	Exceeding breakover voltage causes avalanche conduction

- **Gate Triggering**: Most common and controllable method.
- **Parameter Control**: Pulse width, amplitude, and rise time.
- **Gate Sensitivity**: Varies with temperature.
- **Protection**: Required against unwanted triggering.

Mnemonic

"VITAL: Voltage, Illumination, Temperature And Level are all triggering methods."

Question 2(c OR) [7 marks]

Explain methods to protect SCR against over voltage and current in details.

Solution

Overvoltage Protection:

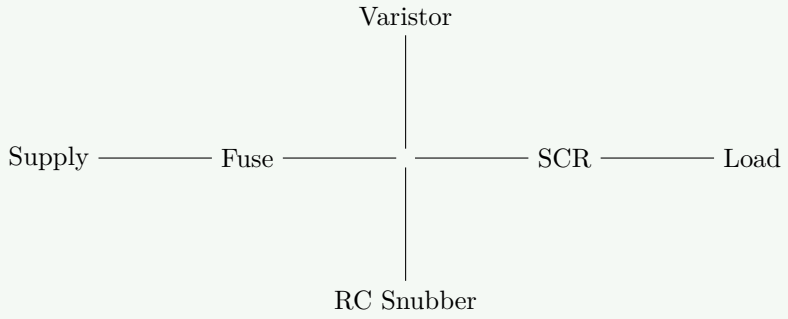

Figure 7. Overvoltage Protection Scheme

Table 5. Overvoltage Protection Methods

Protection Method	Working Principle
RC Snubber Circuit	Limits rate of rise of voltage (dV/dt)
Voltage Clamping	Using Zener diodes or MOVs to limit maximum voltage
Crowbar Protection	Deliberate short-circuit when voltage exceeds threshold

Overcurrent Protection:

Table 6. Overcurrent Protection Methods

Protection Method	Working Principle
Fuses/Circuit Breakers	Disconnects circuit during fault conditions
Current Limiting Reactors	Limits fault current magnitude
Electronic Current Limiting	Sensing and control circuits limit current

- **Coordination**: Protection devices must work in coordination.
- **Response Time**: Critical for effective protection.
- **Multiple Layers**: For critical applications, several methods are combined.

Mnemonic

"SCOPE: Snubbers, Clamps, Overload sensors, Protectors, and Electronic limiters."

Question 3(a) [3 marks]

List the differences between single phase rectifier and poly phase rectifier.

Solution

Table 7. Single Phase vs Poly Phase Rectifier

Parameter	Single Phase Rectifier	Poly Phase Rectifier
Input	Single phase AC supply	Multiple phase (usually 3-phase) AC supply
Output Ripple	Higher ripple content	Lower ripple content
Efficiency	Lower efficiency	Higher efficiency
Power Rating	Suitable for low power applications	Suitable for high power applications
Transformer Utilization	Lower utilization factor	Higher utilization factor

- **Ripple Factor**: Single phase has higher ripple compared to poly phase.
- **Form Factor**: Better in poly phase systems.
- **Size/Weight**: Poly phase systems have better power/weight ratio.

Mnemonic

"PERCH: Poly phase has Efficiency, Ripple improvement, Capacity, and Higher ratings."

Question 3(b) [4 marks]

Draw the circuit diagram of three phases Half Wave Rectifier and explain its Working.

Solution

Three-phase half-wave rectifier converts three-phase AC into pulsating DC using three diodes.

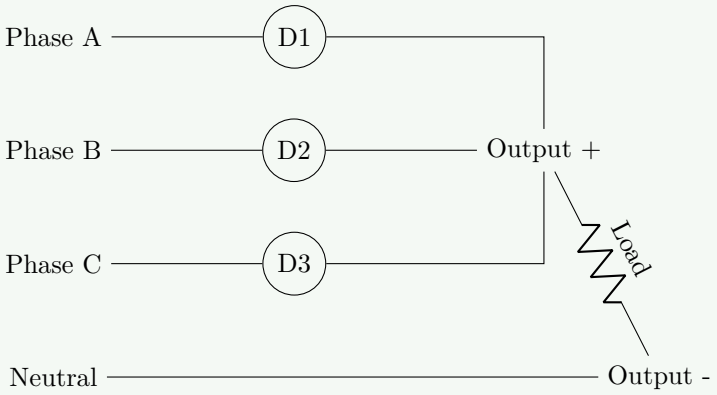

Figure 8. 3-Phase Half Wave Rectifier

Working:

- Each diode conducts when its phase voltage is most positive.
- Conduction angle of each diode is 120°.
- Ripple frequency is 3 times the input frequency.
- Average output voltage = $3V_m/2\pi$ (where V_m is peak phase voltage).
- Ripple factor = 0.17 (much lower than single-phase half-wave).

Mnemonic

"THREE-D: THREE Diodes conducting sequentially."

Question 3(c) [7 marks]

Describe the working of UPS & SMPS with the help of block diagram.

Solution

UPS (Uninterruptible Power Supply):

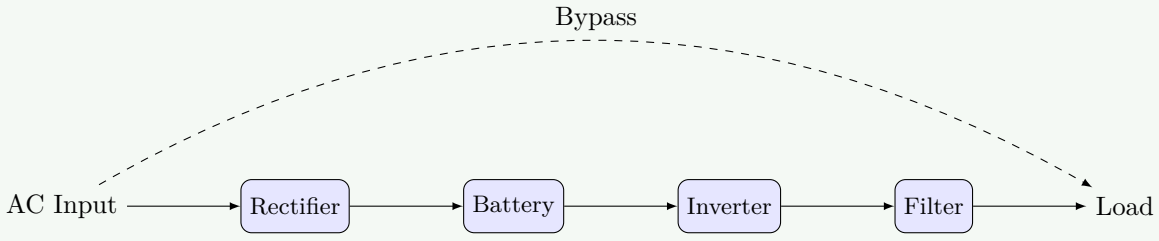

Figure 9. UPS Block Diagram

Table 8. UPS Blocks and Functions

Block	Function
Rectifier	Converts AC to DC for battery charging and inverter
Battery	Stores energy for backup during power failure
Inverter	Converts DC to AC for powering load
Filter	Smooths output waveform
Bypass	Provides direct AC during maintenance

SMPS (Switched Mode Power Supply):

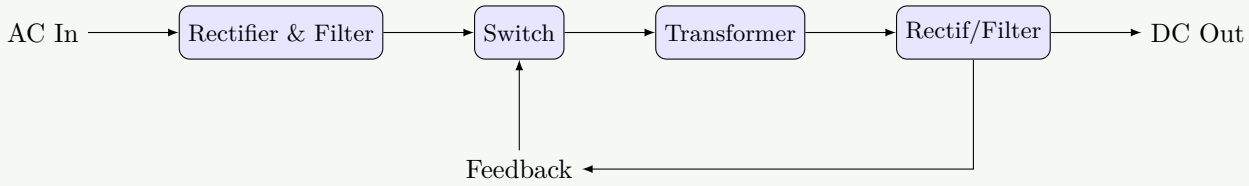

Figure 10. SMPS Block Diagram

- **UPS Efficiency**: 80-90%, provides backup power.
- **SMPS Efficiency**: 70-90%, much smaller than linear supplies.
- **Regulation**: Both provide regulated output voltage.

Mnemonic

"BRIEF: Battery backup, Rectification, Inversion, Efficient switching, Feedback control."

Question 3(a OR) [3 marks]

Explain the Principle & working of Chopper circuits.

Solution

Chopper is a DC-to-DC converter that converts fixed DC input voltage to variable DC output voltage.

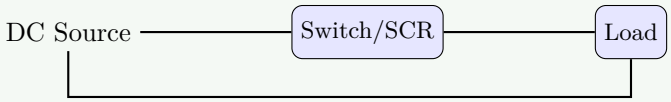

Figure 11. Basic Chopper Circuit

Principle:

- Switch (typically SCR, MOSFET, or IGBT) rapidly connects and disconnects source to load.
- Output voltage controlled by duty cycle (ON time / total time).
- Average output voltage = Input voltage × Duty cycle.
- **Time Ratio Control**: Varies duty cycle, keeping frequency constant.
- **Frequency Modulation**: Varies frequency, keeping ON time constant.

Mnemonic

"CHOP: Control High-speed Operation with Pulses."

Question 3(b OR) [4 marks]

Compare single-phase and Poly-phase rectifier circuits.

Solution

Table 9. Single-Phase vs Poly-Phase Rectifier

Parameter	Single-Phase Rectifier	Poly-Phase Rectifier
Supply	Single-phase AC	Three or more phase AC
Output Waveform	More pulsating	Smoother (less pulsating)
Ripple Content	Higher (0.48 for full wave)	Lower (0.042 for 3-phase full wave)
Filtering	More filtering required	Less filtering required
Power Handling	Limited power handling	Higher power handling
Transformer Utilization	0.812 (full wave)	0.955 (3-phase full wave)
Efficiency	Lower	Higher
Size	Smaller for same power	More compact for high power

- **Harmonic Content**: Lower in poly-phase systems.
- **TUF**: Higher in poly-phase systems.
- **Cost-Effectiveness**: Poly-phase more economical for high power.

Mnemonic

"PERIPHERY: Poly-phase Efficiency Ripple Improvement Power Handling Economy Rating Yield."

Question 3(c OR) [7 marks]

Describe the working of solar Photovoltaic (PV) based power generation with the help of block diagram.

Solution

Solar PV power generation converts sunlight directly into electricity using semiconductor materials.

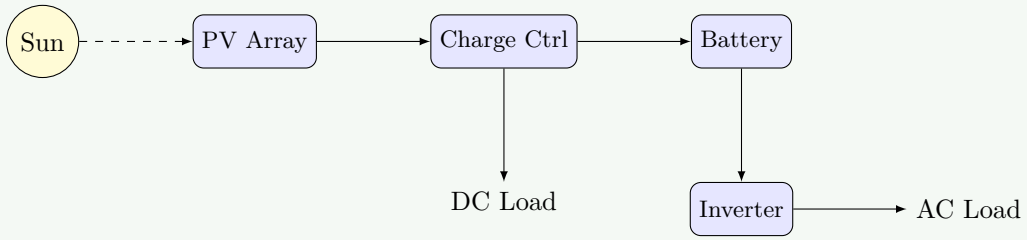

Figure 12. Solar PV Power Generation Block Diagram

Table 10. PV System Components

Component	Function
PV Array	Converts solar energy to DC electricity through photovoltaic effect
Charge Controller	Regulates battery charging and prevents overcharging
Battery Bank	Stores energy for use during night or cloudy conditions
Inverter	Converts DC to AC for powering AC loads
Grid Connection	Optional connection for feeding excess power to grid

- **Photovoltaic Effect**: Photons from sunlight knock electrons free in semiconductor.
- **Efficiency**: Typically 15-22% for commercial panels.

Mnemonic

"SOLAR: Semiconductors Oriented Light-to-electricity Array Regulation."

Question 4(a) [3 marks]

List the advantages of static switch.

Solution

Table 11. Advantages of Static Switch

Features
No moving parts - higher reliability
Silent operation
Fast switching response (microseconds)
Longer operational life
No contact bounce or arcing
Compact size
Compatible with digital control systems
Lower maintenance requirements

- **Reliability**: No mechanical wear and tear.
- **Speed**: Much faster than mechanical switches.
- **Isolation**: Can provide electrical isolation.

Mnemonic

"SAFE: Speed, Arc-free, Fast response, Endurance."

Question 4(b) [4 marks]

Draw the circuit diagram of A.C. Power control using DIAC-TRIAC and Explain it.

Solution

DIAC-TRIAC circuit provides smooth AC power control for resistive and inductive loads.

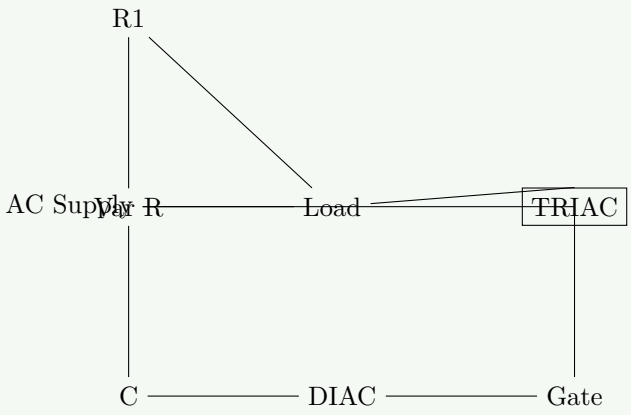

Figure 13. DIAC-TRIAC Phase Control

Working:

- Variable resistor R2 controls charging rate of capacitor C.
- When capacitor voltage reaches DIAC breakover voltage, DIAC conducts.
- DIAC delivers trigger pulse to TRIAC gate.
- TRIAC conducts for remainder of half-cycle.

- **Phase Control**: Controls power by varying firing angle.

Mnemonic

"DIRECT: DIAC Initiates Regulated Energy Control in TRIAC."

Question 4(c) [7 marks]

Describe function of DC power control circuit using SCR with UJT in triggering circuit.

Solution

UJT-triggered SCR circuit provides precise control of DC power to the load.

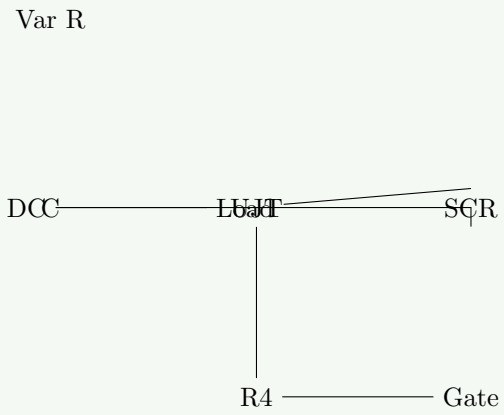

Figure 14. UJT Triggering Circuit (Simplified)

Table 12. UJT Triggering Operation

Stage	Operation
Charging	R1 and R2 control charging rate of capacitor C
UJT Firing	When capacitor voltage reaches UJT firing level, UJT conducts
Pulse Generation	UJT generates sharp trigger pulse across R4
SCR Triggering	Pulse triggers SCR gate, turning SCR ON
Power Control	Variable resistor R2 adjusts timing, controlling average power

- **Precise Control**: UJT provides stable, predictable triggering.
- **Advantages**: Low cost, high reliability, good temperature stability.

Mnemonic

"SCRUP: SCR Using Pulse from UJT for Power control."

Question 4(a OR) [3 marks]

Enlist applications of dielectric heating.

Solution

Table 13. Applications of Dielectric Heating

Applications
Plastic welding and sealing
Wood gluing and curing
Food processing (pre-cooking, defrosting)
Textile drying and processing
Paper and board drying
Pharmaceutical products drying
Medical applications (hyperthermia treatment)
Rubber vulcanization

- **Material Requirements**: Works best with poor conductors that have polar molecules.
- **Frequency Range**: Typically 10-100 MHz.

Mnemonic

"POWER: Plastics, Organics, Wood, Edibles, and Rubber processing."

Question 4(b OR) [4 marks]

Draw and explain three stage IC555 timer circuit.

Solution

Three-stage IC555 timer circuit provides sequential timing operations.

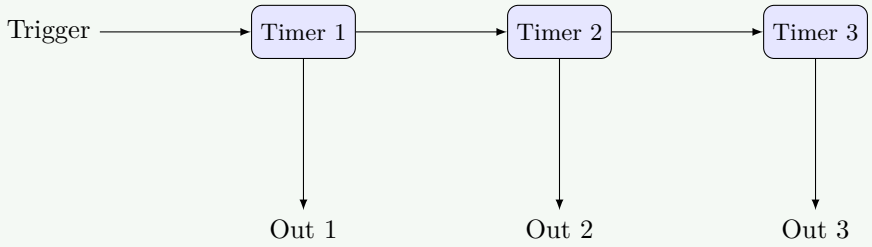

Figure 15. Sequential Timer Block Diagram

Working:

- First timer activated by external trigger.
- Output of first timer triggers second timer.
- Output of second timer triggers third timer.
- Each timer can be independently adjusted.
- **Applications**: Industrial sequencing, process control, animation effects.

Mnemonic

"THREE-SET: THREE Stage Electronic Timers in sequence."

Question 4(c OR) [7 marks]

Describe the working principle of Induction heating. And List merits-demerits of Induction

heating.

Solution

Induction heating uses electromagnetic induction to heat electrically conductive materials.

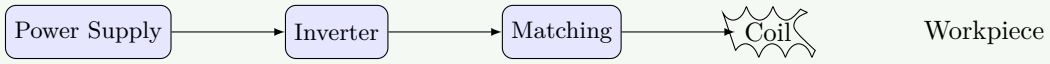

Figure 16. Induction Heating System

Table 14. Merits and Demerits of Induction Heating

Merits	Demerits
Rapid heating	High initial equipment cost
Energy efficient (80-90%)	Limited to electrically conductive materials
Precise temperature control	Requires high-frequency power supply
Clean process with no combustion	Complex coil design for specific applications
Localized heating possible	High power requirements
Consistent, repeatable results	Requires water cooling systems
Environmentally friendly	Electromagnetic interference issues
Improved working conditions	Limited penetration depth

Mnemonic

"EDDY: Electromagnetic Device Develops Yield of heat."

Question 5(a) [3 marks]

Draw & explain solid state circuit to control dc shunt motor speed.

Solution

Solid-state circuit for DC shunt motor speed control uses SCR to control armature voltage.

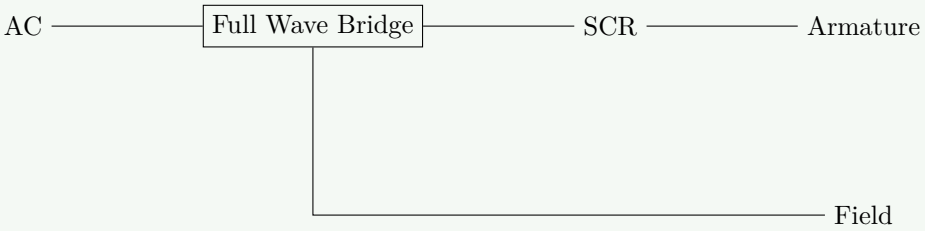

Figure 17. Solid State Speed Control

- **Armature Voltage Control**: SCR controls voltage to armature.
- **Field Winding**: Connected directly to DC supply.
- **Speed Control**: By varying SCR firing angle.

Mnemonic

"SAFE: SCR Armature Firing for Efficient control."

Question 5(b) [4 marks]

Explain working principle of stepper motor.

Solution

Stepper motor converts electrical pulses into discrete mechanical movements.

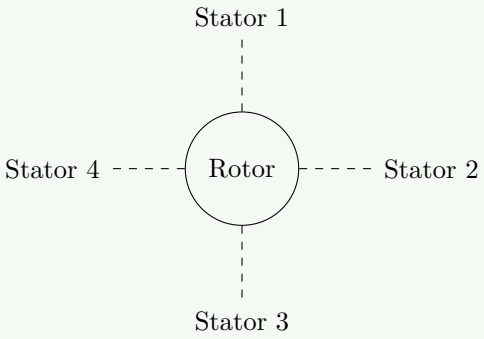

Figure 18. Stepper Motor Conceptual Digram

Working Principle:

- Energizing stator windings in sequence creates rotating magnetic field.
- Permanent magnet rotor aligns with magnetic field.
- Each pulse creates rotation by exact ”step” angle.
- Step angle determined by motor construction (typically 1.8° or 0.9°).

Table 15. Stepper Motor Types

Type	Characteristics
Variable Reluctance	No permanent magnet, relies on magnetic reluctance
Permanent Magnet	Uses permanent magnet rotor
Hybrid	Combines features of both types

Mnemonic

“STEP: Sequential Triggering Enables Precise positioning.”

Question 5(c) [7 marks]

Draw the block diagram of PLC and explain the function of each block.

Solution

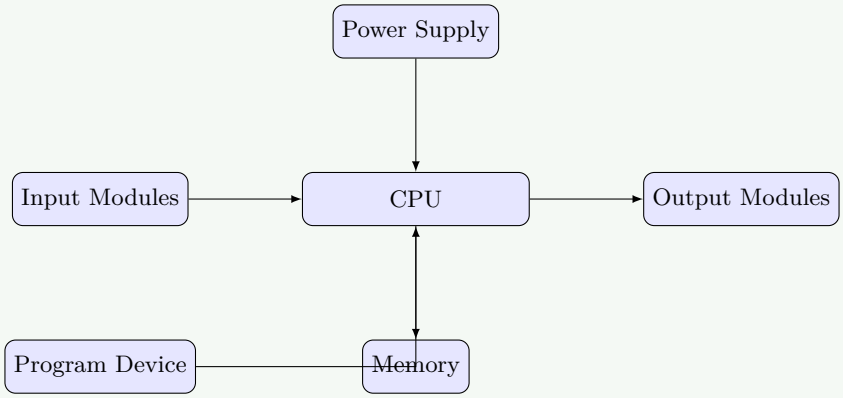

Figure 19. PLC Block Diagram

Table 16. PLC Block Functions

Block	Function
Power Supply	Converts main AC to DC for internal use
CPU	Executes program, processes data, manages operations
Input Modules	Interface with sensors, switches, and field devices
Output Modules	Control actuators, motors, valves, and indicators
Memory	Stores program and data (ROM, RAM, EEPROM)
Programming Device	External computer or terminal for programming
Communication Module	Interfaces with other PLCs, SCADA, HMI

Mnemonic

"PILOT: Processing Inputs and Logic for Outputs with Timing control."

Question 5(a OR) [3 marks]

Draw and explain the construction of DC servo motor.

Solution

DC servo motor is designed for precise position and speed control.

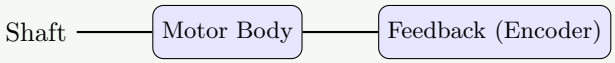

Figure 20. DC Servo Motor

Components:

- **Armature**: Low inertia for quick response.
- **Field System**: Provides magnetic field.
- **Feedback Device**: Position sensor (encoder/resolver/tachometer).
- **High Torque-to-Inertia Ratio**: Allows quick starts and stops.

Mnemonic

"SAFE: Sensitive Armature with Feedback for Exactness."

Question 5(b OR) [4 marks]

Draw and explain the circuit to control speed of a DC series motor.

Solution

DC series motor speed control circuit using SCR.

Figure 21. DC Series Motor Speed Control

- Bridge rectifier converts AC to DC.
- SCR controls average voltage to motor.
- Firing angle controlled by potentiometer.
- Series field and armature current is the same.

Mnemonic

"SCRAM: SCR Controls Rectified Armature and Motor speed."

Question 5(c OR) [7 marks]

Explain construction, working of Stepper motor Give and its applications

Solution

Stepper motor is an electromechanical device that converts electrical pulses into discrete mechanical movements.

Construction:

- **Stator**: Contains multiple coil windings arranged in phases.
- **Rotor**: Permanent magnet or soft iron (reluctance type).
- **Bearings**: Support shaft and allow rotation.

Applications:

- CNC machines and 3D printers.
- Robotics and automation.
- Medical equipment.
- Office equipment (printers, scanners).

Mnemonic

"REACT: Rotation Exactly At Controlled Timing."