

# Industrial Electronics (4331103) - Winter 2024 Solution

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## Question 1(a) [3 marks]

Draw the structure of IGBT and explain it.

### Solution

IGBT combines MOSFET's input with BJT's output characteristics.

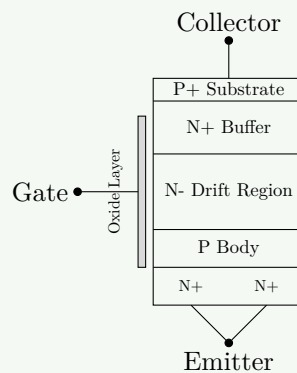


Figure 1. Structure of IGBT

- **Gate-Oxide Layer:** Controls device switching
- **N+ Emitter:** Source of electrons
- **P+ Collector:** Forms BJT section

### Mnemonic

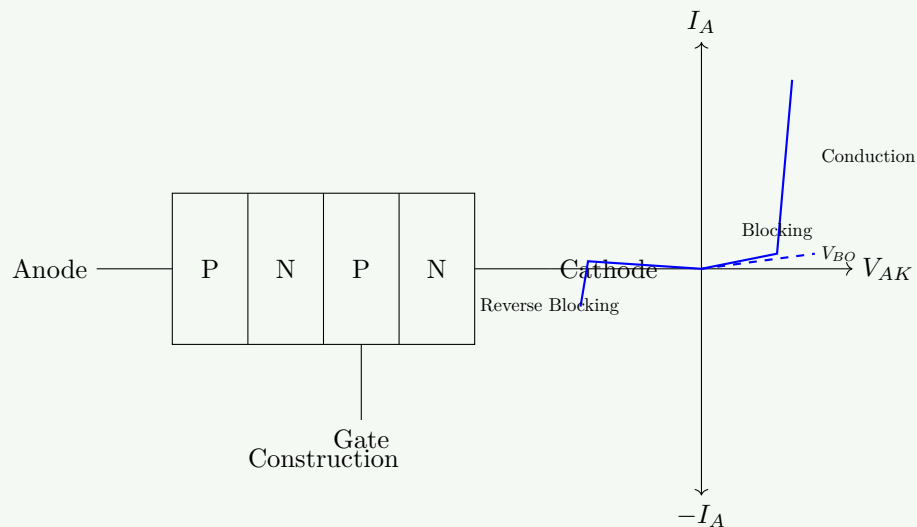
"MOSFET Input, BJT Output, IGBT Throughout"

## Question 1(b) [4 marks]

Draw and explain the construction of SCR. Also draw the characteristic curve of it.

### Solution

SCR is a four-layer PNPN semiconductor device with three terminals.



**Figure 2.** SCR Construction and V-I Characteristics

- **P-N-P-N Layers:** Forms two transistors (PNP, NPN)
- **Gate Terminal:** Triggers conduction
- **Holding Current:** Minimum to maintain conduction

#### Mnemonic

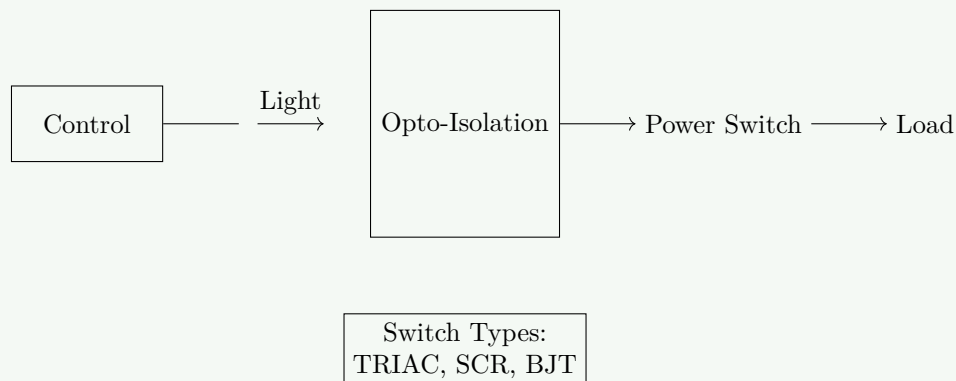
“PNPN Layers Form Two BJT Pairs”

### Question 1(c) [7 marks]

Explain the working of solid state relay using Opto TRIAC, Opto-SCR and Opto-transistor with the help of circuit diagram.

#### Solution

Solid state relays use optocouplers for electrical isolation between control and load circuits.



**Figure 3.** Solid State Relay Block Diagram

**Table 1.** Types of SSR

SSR Type	Input Circuit	Isolation	Output Circuit	Applications
Opto-TRIAC	DC control signal	LED + TRIAC detector	TRIAC power switch	AC loads
Opto-SCR	DC control signal	LED + photo-SCR	SCR power switch	DC loads
Opto-Transistor	DC control signal	LED + phototransistor	Power transistor	Low power DC

- **Working Principle:** Control signal activates LED → Light triggers photo-sensitive device → Switches power circuit
- **Zero-Crossing Detection:** Reduces EMI by switching at zero voltage
- **No Mechanical Parts:** Increases reliability and life

### Mnemonic

“LED Illuminates, Photo-device Conducts, Power Flows”

## Question 1(c OR) [7 marks]

Describe the working and constructional features of SCR, GTO and power MOSFET with the help of characteristic curve.

### Solution

**Table 2.** Comparison of Devices

Device	Construction	Characteristic Curve	Working Principle
SCR	PNPN 4-layer with gate	Latching - once ON stays ON	Gate pulse triggers, requires external commutation to turn OFF
GTO	Modified SCR with better gate control	Similar to SCR but can be turned OFF by gate	Negative gate pulse extracts carriers, turns OFF
Power MOSFET	Vertical structure with many cells	Non-latching - requires gate bias	Gate voltage creates channel, removed voltage turns OFF



**Figure 4.** Device Symbols

- **SCR:** High current capability, latching behavior
- **GTO:** Self turn-off capability, higher switching speed
- **MOSFET:** Voltage-controlled, fast switching, no secondary breakdown

### Mnemonic

“SCR Latches, GTO Self-Extinguishes, MOSFET Channels”

## Question 2(a) [3 marks]

Explain the methods to protect SCR against over current in details.

**Solution**

SCR over-current protection prevents device damage due to excessive current.

**Table 3.** Over Current Protection

Protection Method	Working Principle	Implementation
Fast-acting Fuses	Melts quickly during fault	Series with SCR
Circuit Breakers	Trips when current exceeds threshold	Main circuit protection
Current-limiting Reactors	Limits di/dt and peak current	Series with SCR

- **Heat Sinks:** Help dissipate excess heat
- **Snubber Circuits:** Reduce current spikes during switching

**Mnemonic**

“Fuses Fast, Reactors Restrict, Breakers Break”

**Question 2(b) [4 marks]**

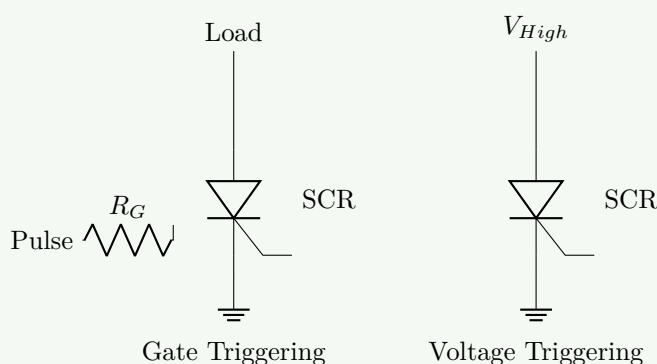
Explain any two methods to turn ON the SCR.

**Solution**

SCR can be turned ON through different triggering methods.

**Table 4.** Triggering Methods

Triggering Method	Circuit Implementation	Characteristics
Gate Triggering	Pulse applied between gate-cathode	Most common, controlled
Voltage Triggering	Anode voltage exceeds breakover voltage	No gate control, emergency

**Figure 5.** SCR Turn-ON Methods

- **Gate Triggering:** Controls firing angle precisely
- **Voltage Triggering:** Happens when forward voltage exceeds breakover voltage

**Mnemonic**

“Gate Gets Control, Voltage Ventures Automatically”

## Question 2(c) [7 marks]

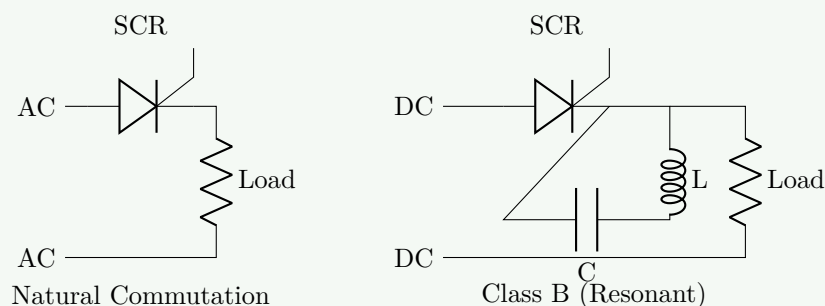
Enlist the various methods to turn OFF the SCR and explain each of it using circuit diagram in brief.

### Solution

SCR commutation methods are techniques to turn OFF a conducting SCR.

**Table 5.** Commutation Methods

Commutation Method	Circuit Principle	Applications
Natural Commutation	AC source crosses zero	AC circuits
Forced Commutation	External components force current to zero	DC circuits
Class A (Self)	Parallel LC oscillator	Simple circuits
Class B (Resonant)	LC circuit in series with SCR	Medium power
Class C (Complementary)	Second SCR to divert current	High power
Class D (Auxiliary)	Auxiliary SCR + LC	Controlled timing
Class E (External)	External voltage source	Reliable but complex



**Figure 6.** Commutation Circuits

- **Natural Commutation:** Current naturally falls to zero in AC cycles
- **Forced Commutation:** Artificially brings current to zero in DC circuits
- **Communication Classes:** A through E progressively more complex and reliable

### Mnemonic

“Natural Zeros, Forced Components, Classes Advance Reliability”

## Question 2(a OR) [3 marks]

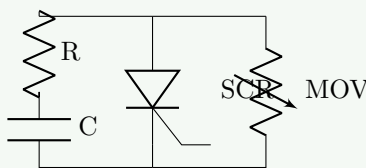
Explain the methods to protect SCR against over voltage in details.

### Solution

Over-voltage protection prevents damage from voltage transients.

**Table 6.** Over Voltage Protection

Protection Method	Working Principle	Implementation
Snubber Circuits	RC network limits $dv/dt$	Parallel with SCR
Metal Oxide Varistors	Clamps voltage spikes	Parallel with SCR
Zener Diodes	Breaks down at set voltage	Anode-cathode protection



**Figure 7.** Snubber and MOV Protection

- **Snubber Circuit:** Limits voltage rise rate ( $dv/dt$ )
- **MOV:** Absorbs energy from voltage spikes
- **Thyristor Rating:** Always use components with margin above circuit voltage

#### Mnemonic

“Snubbers Slow, Varistors Clamp, Zeners Zap”

## Question 2(b OR) [4 marks]

Explain triggering of Thyristor in detail.

#### Solution

Thyristor triggering involves activating the device from blocking to conduction state.

**Table 7.** Thyristor Triggering

Triggering Method	Working Mechanism	Advantages
Gate Triggering	Low power pulse at gate-cathode	Precise control
R-C Phase Shift	Varies phase angle for control	Simple circuit
UJT Triggering	Relaxation oscillator generates pulses	Stable timing
Light Triggering	Photons generate carriers (LASCR)	Electrical isolation

- **Gate Current:** Must exceed latching current
- **Gate Pulse:** Width and amplitude critical for reliable triggering
- **Triggering Angle:** Controls power delivered to load

#### Mnemonic

“Gate Gets Going, RC Rhythmically, UJT Uniformly, Light Liberates”

## Question 2(c OR) [7 marks]

Design and explain snubber circuit for SCR. Also explain the importance of it.

#### Solution

Snubber circuits protect SCR from voltage transients and control switching behavior.

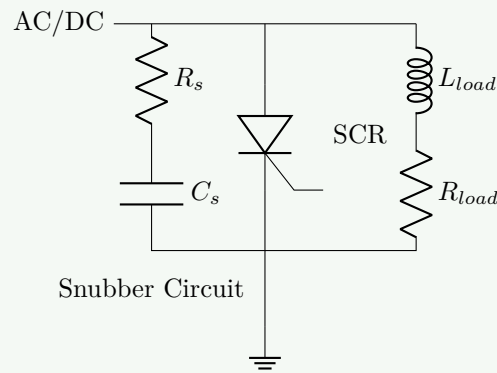


Figure 8. SCR with Snubber Circuit

Table 8. Snubber Components

Component	Function	Selection Criteria
Resistor (R)	Limits discharge current	$R > E/I_{max}$
Capacitor (C)	Absorbs voltage transients	$C = I_{load}/(dv/dt)$
Optional Diode	Provides discharge path	Fast recovery type

**Design Steps:**

1. Calculate maximum  $dv/dt$  from SCR datasheet
2. Determine load current and circuit voltage
3. Select C to limit  $dv/dt$  below SCR rating
4. Select R to limit discharge current and provide damping

**Importance:**

- **$dv/dt$  Protection:** Prevents false triggering
- **Turn-off Support:** Improves commutation
- **Switching Loss Reduction:** Reduces power dissipation
- **EMI Reduction:** Smooths voltage transitions

**Mnemonic**

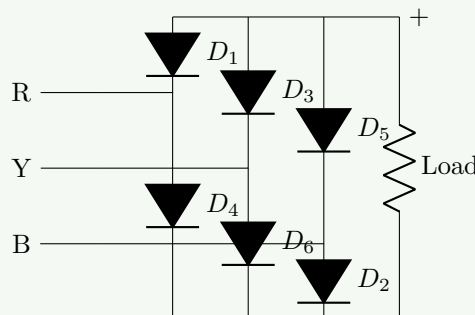
“Resistor Restrains, Capacitor Catches, Diode Directs”

**Question 3(a) [3 marks]**

Explain the working of three phase Full Wave Rectifier using circuit diagram.

**Solution**

Three-phase full-wave rectifier converts three-phase AC to DC with six diodes.



**Figure 9.** Three Phase Bridge Rectifier

- **Six Diodes:** Three for positive, three for negative half-cycles
- **Conduction:** Each diode conducts for  $120^\circ$  per cycle
- **Output:** Low ripple (4.2%) compared to single-phase

**Mnemonic**

“Six Diodes, Three Phases, Smooth DC”

**Question 3(b) [4 marks]**

Differentiate single phase and poly phase rectifier circuit.

**Solution****Table 9.** Comparison of Rectifiers

Parameter	Single Phase Rectifier	Poly Phase Rectifier
Input	Single AC source	Multiple AC sources (3 or more)
Diodes Required	2 (half-wave), 4 (full-wave)	3 (half-wave), 6 (full-wave)
Ripple Factor	0.482 (full-wave)	0.042 (3-phase full-wave)
Transformer Utilization	Lower (0.812)	Higher (0.955)
Output Waveform	Pulsating	Much smoother
Efficiency	Lower	Higher
Applications	Low power applications	Industrial power supplies

- **Form Factor:** Lower in poly-phase (better quality DC)
- **Power Handling:** Polyphase handles higher power more efficiently
- **Circuit Complexity:** Polyphase more complex but better performance

**Mnemonic**

“Single Pulses Heavily, Poly Provides Smoothly”

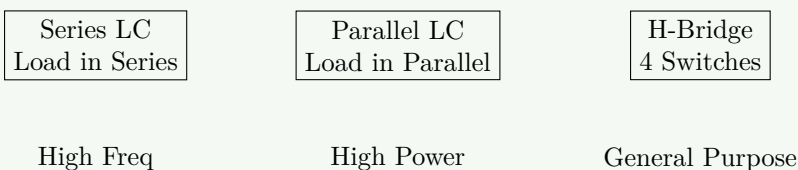
**Question 3(c) [7 marks]**

Describe the application of series, parallel and bridge type Inverter.

**Solution****Table 10.** Inverter Types



Inverter Type	Circuit Topology	Applications	Characteristics
Series Inverter	Resonant LC with load in series	Induction heating, Ultrasonic generators	<ul style="list-style-type: none"> <li>High frequency</li> <li>Voltage source</li> <li>Self-commutating</li> </ul>
Parallel Inverter	Resonant LC with load in parallel	Uninterruptible power supplies, Solar inverters	<ul style="list-style-type: none"> <li>Current source</li> <li>Better efficiency</li> <li>Wider load range</li> </ul>
Bridge Inverter	H-bridge with 4 switches	Motor drives, Grid-tied systems, General purpose	<ul style="list-style-type: none"> <li>Voltage/current source</li> <li>Most versatile</li> <li>Various control methods</li> </ul>



**Figure 10.** Inverter Topologies

- **Series Inverter:** Best for fixed-frequency, fixed-load applications
- **Parallel Inverter:** Handles load variations better
- **Bridge Inverter:** Most widely used for general applications

#### Mnemonic

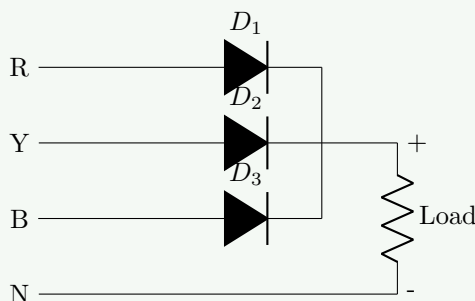
“Series Sings at High Frequency, Parallel Performs with Variety, Bridge Brings Versatility”

### Question 3(a OR) [3 marks]

Explain the working of three phase Half Wave Rectifier using circuit diagram.

#### Solution

Three-phase half-wave rectifier uses three diodes to convert three-phase AC to DC.



**Figure 11.** Three Phase Half Wave Rectifier

- **Three Diodes:** Each conducts during positive half-cycle of its phase
- **Conduction:** Each diode conducts for  $120^\circ$  per cycle
- **Output:** 13.4% ripple (higher than full-wave)

**Mnemonic**

“Three Diodes, Three Phases, One Direction”

**Question 3(b OR) [4 marks]**

Enlist the different types of charging technology and compare it.

**Solution**

**Table 11.** Charging Technologies

Charging Technology	Working Principle	Advantages	Disadvantages
Constant Current (CC)	Fixed current until voltage threshold	Simple, low cost	Longer charging time
Constant Voltage (CV)	Fixed voltage with declining current	Fast initial charge	Current not limited at start
CC-CV	Starts with CC, switches to CV	Optimal charging profile	Requires controller circuit
Pulse Charging	Current pulses with rest periods	Reduces heat, extends battery life	Complex control circuit
Trickle Charging	Very low constant current	Maintains charge	Not suitable for main charging
Fast Charging	High current with intelligent control	Significantly reduced charging time	Heat generation, battery stress
Wireless Charging	Inductive coupling	Convenient, no cables	Lower efficiency, alignment issues

- **Battery Types:** Different technologies suit different battery chemistries
- **Charging Profiles:** Must match battery specifications to avoid damage
- **Temperature Management:** Critical factor in charging efficiency and safety

**Mnemonic**

“Current Consistently, Voltage Varies, Pulse Pauses, Trickle Tops, Fast Finishes”

**Question 3(c OR) [7 marks]**

Explain the working of Solar Photovoltaic (PV) based power generation with the help of block diagram.

**Solution**

Solar PV systems convert sunlight directly into electricity through the photovoltaic effect.

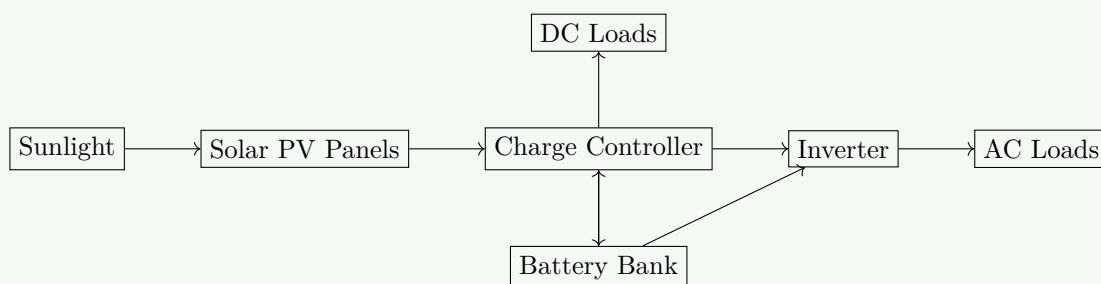


Figure 12. Solar PV System

Table 12. PV System Components

Component	Function	Types
Solar Panels	Convert light to DC electricity	Monocrystalline, Polycrystalline, Thin-film
Charge Controller	Regulates battery charging	PWM, MPPT
Battery Bank	Stores energy	Lead-acid, Lithium-ion, Flow
Inverter	Converts DC to AC	Pure sine wave, Modified sine wave
Distribution System	Delivers power to loads	Off-grid, Grid-tied, Hybrid

- **Photovoltaic Effect:** Light energy creates electron flow in semiconductor material
- **Maximum Power Point Tracking:** Optimizes power extraction under varying conditions
- **Grid Integration:** Can operate standalone or connected to utility grid

#### Mnemonic

“Sunlight Strikes Semiconductors, Controllers Charge, Batteries Bank, Inverters Interface”

### Question 4(a) [3 marks]

State the merits and demerits of Induction heating.

#### Solution

Table 13. Induction Heating Pros and Cons

Merits of Induction Heating	Demerits of Induction Heating
Rapid heating without direct contact	High initial installation cost
Precise temperature control	Requires electrical power source
Energy efficient (80-90%)	Limited to electrically conductive materials
Clean and pollution-free	Requires proper cooling systems
Localized heating possible	EMI generation may affect nearby electronics
Uniform heating throughout material	May require specialized coil designs

- **Working Principle:** Eddy currents induced in workpiece generate heat
- **Applications:** Melting, hardening, annealing, welding

#### Mnemonic

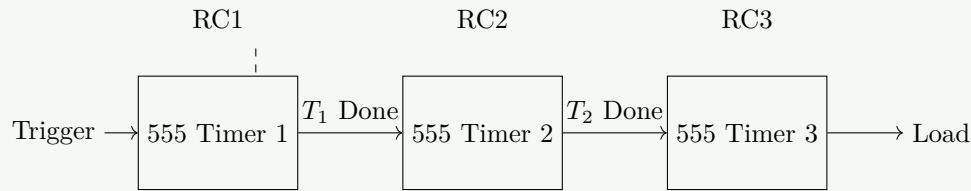
“Fast, Focused, Efficient but Costly, Conductive, Complex”

### Question 4(b) [4 marks]

Draw the circuit of sequential timer using IC-555 and explain its working.

#### Solution

Sequential timer provides multiple timed outputs in sequence.



**Figure 13.** Sequential Timer Block Diagram

#### Working:

1. First 555 timer operates in monostable mode
2. Output triggers second timer when first timing cycle completes
3. Second timer triggers third timer
4. Each timer's period determined by its RC time constant
  - **RC Values:**  $T = 1.1 \times R \times C$  determines each stage's timing
  - **Cascading:** Multiple stages provide sequential timing events
  - **Applications:** Process control, industrial sequencing

#### Mnemonic

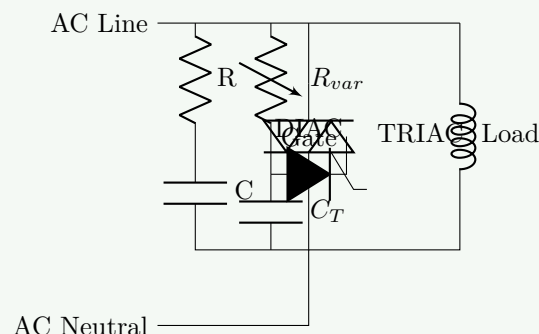
"One Timer Triggers Another Sequentially"

### Question 4(c) [7 marks]

Draw the schematic circuit for single phase AC power control using TRIAC and explain it in detail.

#### Solution

TRIAC-based AC power control regulates power to loads through phase angle control.



**Figure 14.** TRIAC Power Control Circuit

**Table 14.** Circuit Components

Component	Function	Selection Criteria
TRIAC	Bidirectional power switch	Current rating > load current
DIAC	Triggers TRIAC symmetrically	Breakover voltage < trigger voltage
RC Network	Phase shifting for firing angle	R determines firing angle range
Snubber Circuit	dv/dt protection	Based on TRIAC specifications

**Operation Principle:**

1. RC network creates phase shift from AC input
2. DIAC breaks over when capacitor voltage reaches threshold
3. DIAC triggers TRIAC at specific phase angle
4. Varying R changes phase angle, controlling power
  - **Firing Angle:** 0° (full power) to 180° (zero power)
  - **Applications:** Light dimmers, heater control, motor speed control
  - **Advantages:** Smooth control, no moving parts, high reliability

**Mnemonic**

“Resistance Changes Phase, DIAC Delivers Pulse, TRIAC Transmits Power”

**Question 4(a OR) [3 marks]**

Enlist the merits and demerits of Dielectric heating.

**Solution**

**Table 15.** Dielectric Heating Pros and Cons

Merits of Dielectric Heating	Demerits of Dielectric Heating
Uniform heating throughout material	High initial equipment cost
Rapid heating (even for insulators)	High frequency power source required
Selective heating possible	Not effective for conductive materials
Energy efficient for certain materials	RF radiation safety concerns
Clean and pollution-free	Complex impedance matching requirements
Works with non-conductive materials	Power loss in transmission lines

- **Working Principle:** Dipole rotation in high-frequency electric field generates heat
- **Applications:** Plastic welding, wood drying, food processing

**Mnemonic**

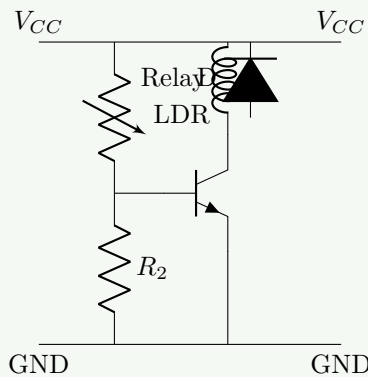
“Uniform, Rapid, Insulator-friendly but Expensive, Complex, RF-intensive”

**Question 4(b OR) [4 marks]**

Draw the circuit diagram of photo-electric relay using LDR and explain its working.

**Solution**

Photo-electric relay uses light-dependent resistor to detect light and control a relay.



**Figure 15.** Photo-Electric Relay Circuit

**Working:**

1. LDR resistance decreases when light falls on it
  2. Voltage divider (LDR + R2) provides base current to transistor
  3. Transistor turns ON when sufficient base current flows
  4. Relay activates when transistor conducts
- **Light Threshold:** Adjustable via potentiometer
  - **Applications:** Automatic lighting, counting systems, alarm systems
  - **LDR Characteristics:** Resistance inversely proportional to light intensity

**Mnemonic**

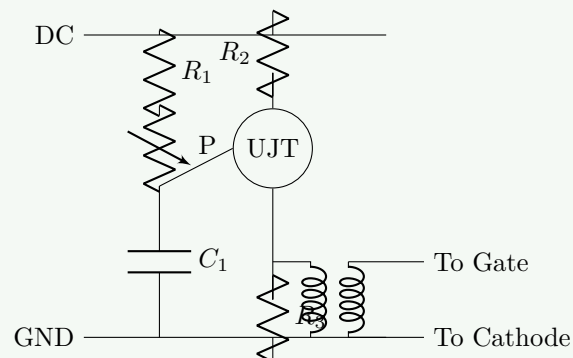
“Light Lowers Resistance, Transistor Turns, Relay Responds”

## Question 4(c OR) [7 marks]

Draw the circuit of DC power control using SCR with UJT in triggering circuit and explain in detail.

**Solution**

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



**Figure 16.** UJT Triggering Circuit

**Table 16.** Circuit Components

Component	Function	Selection Criteria
UJT	Generates trigger pulses	$\eta$ (intrinsic standoff ratio) = 0.5-0.8
$R_1 + P$	Timing resistor	Controls charging rate of $C_1$
$C_1$	Timing capacitor	Determines pulse frequency
Transformer	Isolates UJT circuit from SCR	Pulse transmission capability
SCR	Main power control	Current rating > load current

**Working Principle:**

1. UJT relaxation oscillator generates pulses
2. Potentiometer varies charging rate, changing pulse frequency
3. Pulses are coupled through transformer to SCR gate
4. SCR conducts for portion of cycle based on trigger timing
  - **Control Range:** From minimum to maximum power
  - **Advantages:** Precise control, high efficiency
  - **Applications:** DC motor control, heating elements, battery chargers

**Mnemonic**

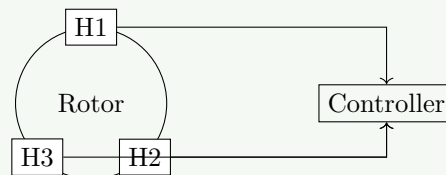
“Resistor Regulates Rate, UJT Unleashes Pulses, SCR Switches Current”

**Question 5(a) [3 marks]**

Explain the hall effect sensor in BLDC driver circuit.

**Solution**

Hall effect sensors detect rotor position in BLDC motors for precise commutation timing.



**Figure 17.** Hall Sensor Placement

**Table 17.** Hall Sensor Basics

Hall Sensor	Function	Output
Position Detection	Senses magnetic field of rotor	Digital (ON/OFF)
Placement	120° apart for 3-phase motors	Provides 6 unique states
Signal Processing	Inputs to microcontroller	Determines switching sequence

- **Working Principle:** Voltage generated perpendicular to current and magnetic field
- **Commutation Sequence:** Each sensor pattern corresponds to specific switching combination

**Mnemonic**

“Magnet Moves, Hall Senses, Controller Commutates”

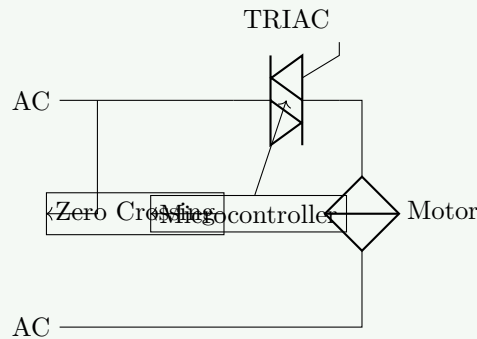
**Question 5(b) [4 marks]**

Draw and explain solid state circuit to control speed of single phase Induction motor using

## TRIAC.

### Solution

TRIAC-based speed control for induction motors uses phase control principles.



**Figure 18.** Induction Motor Speed Control

### Working Principle:

1. Zero-crossing detector identifies voltage zero-crossings
  2. Microcontroller calculates delay based on speed setting
  3. After delay, gate pulse sent through opto-isolator to TRIAC
  4. TRIAC conducts for remainder of half-cycle
  5. Varying firing angle controls voltage to motor, adjusting speed
- **TRIAC Rating:** Must handle starting current ( $5-7\times$  running current)
  - **Speed Range:** Limited at low end due to motor characteristics
  - **Applications:** Fans, pumps, small machine tools

### Mnemonic

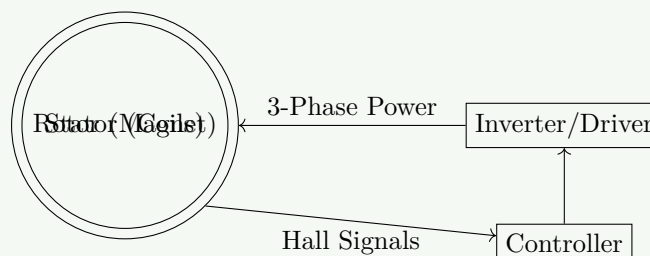
“Zero Detected, Delay Determined, TRIAC Triggered”

## Question 5(c) [7 marks]

Explain the construction and working of BLDC motor using diagram. Also enlist its applications.

### Solution

Brushless DC motors use electronic commutation instead of mechanical brushes.



**Figure 19.** BLDC Motor System

**Table 18.** BLDC Components



Component	Function	Types/Variations
Stator	Contains copper windings	Slotted/slotless designs
Rotor	Permanent magnets	Surface/interior mounted
Hall Sensors	Position detection	60°/120° configurations
Controller	Commutation logic	Microcontroller-based
Driver	Power switching	MOSFET/IGBT-based

**Working Principle:**

1. Hall sensors detect rotor position
2. Controller determines correct energizing sequence
3. Driver powers appropriate stator windings
4. Magnetic interaction produces rotation
5. Process repeats continuously

**Applications:**

- Computer cooling fans and hard drives
- Electric vehicles and hybrid cars
- Industrial automation and robotics
- Medical equipment (pumps, ventilators)
- Drones and RC models
- Home appliances (washers, refrigerators)
- Precision instruments

**Mnemonic**

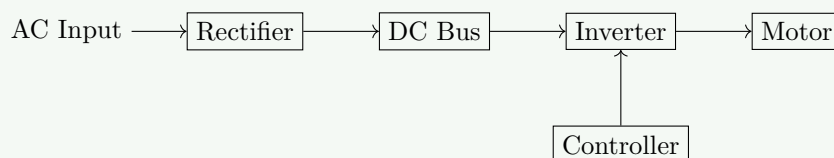
“Magnets Move, Sensors See, Electronics Energize”

**Question 5(a OR) [3 marks]**

Explain the working of variable frequency drive (VFD).

**Solution**

Variable Frequency Drives control motor speed by varying the frequency and voltage.



**Figure 20.** VFD Block Diagram

**Table 19.** VFD Sections

VFD Section	Function	Components
Rectifier	Converts AC to DC	Diodes or SCRs
DC Bus	Filters and stores energy	Capacitors, inductors
Inverter	Converts DC to variable AC	IGBTs or MOSFETs
Controller	Manages frequency/voltage	Microprocessor

- **V/f Control:** Maintains constant V/f ratio for stable torque
- **Operating Range:** Typically 10-200% of rated speed
- **Efficiency:** High efficiency across wide speed range

**Mnemonic**

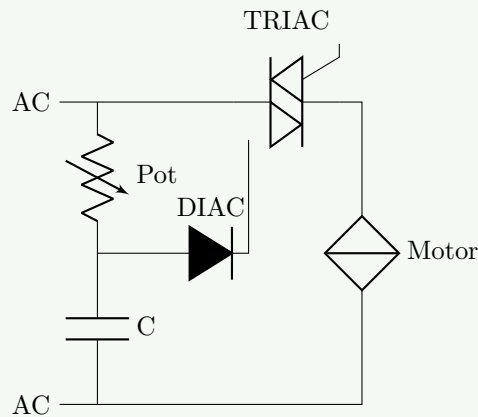
“Rectify to DC, Invert to AC, Vary Frequency”

**Question 5(b OR) [4 marks]**

Draw and explain the circuit to control speed of Universal motor.

**Solution**

Universal motors can run on AC or DC and allow simple speed control methods.



**Figure 21.** Universal Motor Speed Control

**Working Principle:**

1. RC network creates phase shift from input voltage
2. Potentiometer adjusts phase shift amount
3. DIAC triggers when voltage reaches breakover
4. TRIAC conducts for remainder of half-cycle
5. Adjusting potentiometer varies firing angle and motor speed
  - **Speed Range:** Wide control range (10-100%)
  - **Torque Characteristics:** Decreases somewhat at lower speeds
  - **Applications:** Power tools, household appliances, sewing machines

**Mnemonic**

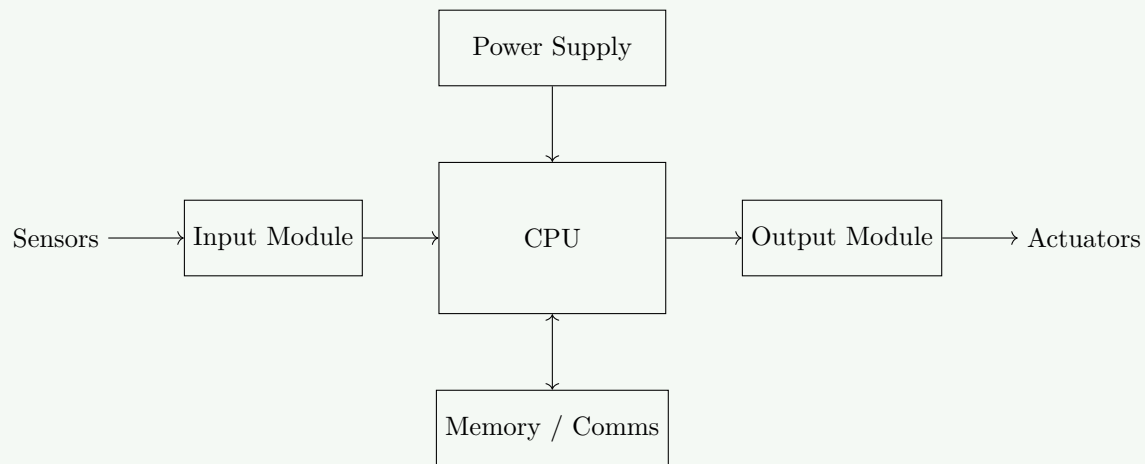
“Resistance Changes Phase, DIAC Delivers, TRIAC Conducts”

**Question 5(c OR) [7 marks]**

Draw the block diagram of PLC and explain the function of each block in brief. And enlist the advantages and applications of it.

**Solution**

Programmable Logic Controllers (PLCs) are industrial computers for automation control.



**Figure 22.** PLC Block Diagram

**Table 20.** PLC Functions

PLC Block	Function	Types/Characteristics
Power Supply	Provides regulated power	Typically 24VDC or 110/220VAC
CPU	Executes program, processes I/O	Scan-based operation
Input Modules	Interface with field sensors	Digital, analog, special
Output Modules	Control field devices	Relay, transistor, triac
Memory	Stores program and data	RAM, EEPROM, Flash
Communication	Network connectivity	Ethernet, Profibus, Modbus

#### Advantages:

- Reliability in harsh industrial environments
- Flexibility for reprogramming
- Compact size compared to relay-based systems
- Built-in diagnostics and troubleshooting
- Modular expandability
- High-speed operation
- Cost-effective for complex control systems

#### Applications:

- Manufacturing production lines
- Process control in plants
- Material handling systems
- Building automation
- Power generation and distribution
- Water/wastewater treatment
- Packaging machinery
- Food processing

#### Mnemonic

“Power Provides, CPU Computes, Inputs Inform, Outputs Operate, Memory Maintains”