Subject Name Solutions

4331103 – Summer 2024

Semester 1 Study Material

Detailed Solutions and Explanations

Question 1(a) [3 marks]

Explain two transistor analogies of SCR.

Solution

SCR can be represented as a two-transistor model with interconnected PNP and NPN transistors.

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Anode] {-{-}{-} B1[PNP Base]}
    B1 {-{-}{-} C1[PNP Collector]}
    C1 {-{-}{-} E2[NPN Emitter]}
    E2 {-{-}{-} B2[NPN Base]}
    B2 {-{-}{-} C2[NPN Collector]}
    C2 {-{-}{-} K[Cathode]}
    G[Gate] {-{-}{-} B2}
    E1[PNP Emitter] {-{-}{-} A}
    E1 {-{-}{-} B2}
    C2 {-{-}{-} B1}
{Highlighting}
{Shaded}
```

- **Regenerative action**: When gate current triggers NPN, it causes PNP to conduct, creating self-sustaining current
- **Latching mechanism**: Once both transistors are ON, gate loses control as feedback path maintains conduction

Mnemonic

"Push-Pull Network Triggers Sustained Conduction"

Question 1(b) [4 marks]

Explain working and characteristic of IGBT.

Solution

IGBT (Insulated Gate Bipolar Transistor) combines MOSFET input characteristics with BJT output capabilities.

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    G[Gate] {-{-}{-} MOS[MOSFET Section]}
    MOS {-{-}{-} BJT[BJT Section]}
    BJT {-{-}{-} C[Collector]}
    E[Emitter] {-{-}{-} BJT}
```

```
{Highlighting}
{Shaded}
```

Characteristics Table:

Feature	Characteristic
Switching	Fast turn-on, moderate turn-off
Control	Voltage-controlled like MOSFET
Conduction	Low forward voltage drop like BJT
Applications	High voltage, medium frequency switching

- **Input advantage**: Voltage-controlled gate with high impedance requires minimal drive power
- **Output advantage**: Low on-state voltage drop even at high current densities

Mnemonic

"MOSFET Input, BJT Output, Makes Perfect Power Switch"

Question 1(c) [7 marks]

Explain construction, working and characteristic of DIAC.

Solution

DIAC (DIode for Alternating Current) is a bidirectional triggering device used in thyristor control circuits.
Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Terminal A] {-{-}{-} P1[P{-}region]}
    P1 {-{-}{-} N1[N{-}region]}
    N1 {-{-}{-} P2[P{-}region]}
    P2 {-{-}{-} N2[N{-}region]}
    N2 {-{-}{-} B[Terminal B]}
{Highlighting}
{Shaded}
```

Characteristics Curve:

```
                I
                \^{}
                |      /
                |     /
                |    /
    {-{-}{-}{-}{-}{-}{-}+{-}{-}{-}/{-}{-}{-}{-}{-}{-}{-}{-} V}
               /|
              / |
             /  |
            /   |
          Break{-over voltage}
```

Construction & Operation Table:

Feature	Description
Structure	Five-layer P-N-P-N with no gate terminal
Operation	Blocks current until break-over voltage is reached
Breakover	Typically 30-40V in either direction
Symmetry	Identical response in both directions
Application	Trigger device for TRIACs in AC circuits

- **Blocking state**: Below breakover voltage, high resistance prevents current flow
- **Conducting state**: Above breakover voltage, negative resistance region enables sudden conduction
- **Bidirectional**: Functions identically for positive and negative voltages

Mnemonic

"Break Voltage Both Ways, Then Current Flows"

Question 1(c) OR [7 marks]

Explain construction and working of Opto-Isolator and Opto-SCR

Solution

Opto-devices use light to transfer signals while maintaining electrical isolation between circuits.

Opto-Isolator Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Input] {-{-}{-} L[LED]}
    L {-{-}{-} G[Glass/Plastic]}
    G {-{-}{-} D[Phototransistor]}
    D {-{-}{-} O[Output]}
{Highlighting}
{Shaded}
```

Opto-SCR Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Input] {-{-}{-} L[LED]}
    L {-{-}{-} G[Glass/Plastic]}
    G {-{-}{-} S[Light{-}sensitive SCR]}
    S {-{-}{-} O[Output]}
{Highlighting}
{Shaded}
```

Comparison Table:

Feature	Opto-Isolator	Opto-SCR
Input	LED	LED
Output device	Phototransistor/photodiode	Light-sensitive SCR
Isolation	2-5 kV	2-5 kV
Current handling	Low-medium (100mA)	High (several amps)
Applications	Digital signal isolation	Power control, AC switching

- **Electrical isolation**: Complete electrical separation provides noise immunity and safety
- **Signal transfer**: Light coupling eliminates ground loops and voltage level issues
- **Triggering**: Light replaces gate current for SCR activation in Opto-SCR

Mnemonic

"Light Jumps Gaps While Electricity Stays Home"

Question 2(a) [3 marks]

Draw symbol and give application of 1) UJT 2) SCS 3) MCT.

Solution

UJT (Unijunction Transistor):

```
    B2
     |
     |
     Z
    /|
   / |
B1{-{-}{-}+{-}{-}{-}E}
```

SCS (Silicon Controlled Switch):

```
      A
      |
      |
  G2{-{-}+}
      |
      |
  G1{-{-}+}
      |
      |
      C
```

MCT (MOS-Controlled Thyristor):

```
      A
      |
     \_|\_
 G{-{-}|\_\_\_|}
     \_|\_
     {\_/}
      |
      |
      C
```

Applications Table:

Device	Applications
UJT	Relaxation oscillators, timing circuits, SCR triggering
SCS	Low power switching, level detection, pulse generation
MCT	High power switching, motor control, inverters

Mnemonic

"Unique timing, Controlled switching, Master power"

Question 2(b) [4 marks]

Explain importance of gate protection for SCR.

Solution

Gate protection circuits safeguard SCR against spurious triggering and voltage spikes.
Gate Protection Circuit:

```
       R
    .{-{-}{-}{-}www{-}{-}{-}{-}.}
```

```
    |          |
    |    D     |
{-{-}{-}+{-}{-}{-}{-}{-}|{-}{-}{-}{-}+{-}{-}{-} To SCR Gate}
    |          |
   {{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}}
```

Protection Table:

Problem	Protection Method	Purpose
Reverse voltage	Diode across gate	Prevents gate-cathode junction damage
Noise	RC filter	Blocks high-frequency transients
dV/dt triggering	RC snubber	Controls rate of voltage rise
False triggering	Gate resistor	Limits gate current and avoids noise triggering

- **Junction protection**: Prevents reverse voltage damage to gate-cathode junction
- **Noise immunity**: Filters out electrical noise that could cause unwanted triggering

Mnemonic

"Guard the Gate to Prevent Problems"

Question 2(c) [7 marks]

List out various methods of triggering SCR and explain any three of them.

Solution

SCR triggering methods convert the device from blocking to conducting state through gate activation.
Triggering Methods Table:

Method	Principle	Applications
Gate triggering	Direct current to gate	Most common method
Thermal triggering	Temperature increase	Thermal protection
Light triggering	Photons on junction	Remote activation
dV/dt triggering	Fast voltage rise	Often undesirable triggering
Voltage triggering	Exceeding breakover voltage	Protection circuits
RF triggering	Radio frequency signals	Wireless control

1. **Gate Current Triggering:**

```
         A
         |
     \_\_\_|\_\_\_
    |    |    |
    |    R    |
G{-{-}{-}{-}{-}+{-}{-}{-}|{-}{-}+}
    |\_\_\_|\_\_\_|
         |
         K
```

   - **Direct control**: Small gate current initiates large anode current flow
   - **Current range**: 10-100mA typically required depending on SCR rating

2. **Light Triggering (LASCR):**

```
         A
         |
     \_\_\_|\_\_\_
    |  {   |}
    |  {   | {-}{-} Light}
G{-{-}{-}{-}{-}+{-}{-}{-}|{-}{-}+}
    |\_\_\_|\_\_\_|
         |
         K
```

   - **Optical control**: Photons generate carriers at junction
   - **Isolation**: Provides electrical isolation between control and power circuit

3. **dV/dt Triggering:**

```
        dV
        {-{-} = high}
        dt
         A
         |
     \_\_\_|\_\_\_
    |    |    |
    |         |
G{-{-}{-}{-}{-}+{-}{-}{-}|{-}{-}+}
    |\_\_\_|\_\_\_|
         |
         K
```

   - **Rate sensitivity**: Rapid voltage rise causes junction capacitance charging
   - **Prevention**: Snubber circuits (RC networks) control voltage rise rate

Mnemonic

"Gates, Light, and Voltage Changes Turn SCRs On"

Question 2(a) OR [3 marks]

Explain working of solid state relay using opto-SCR.

Solution

Solid state relays (SSRs) use opto-SCR for contactless switching with electrical isolation.

SSR Block Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
```

```
graph LR
    I[Control Input] {-{-}{} LED[LED]}
    LED {-{-}{} OSCR[Opto{-}SCR]}
    OSCR {-{-}{} ZC[Zero Crossing Circuit]}
    ZC {-{-}{} TS[Thyristor Switch]}
    TS {-{-}{} O[Output Load]}
{Highlighting}
{Shaded}
```

Operation Table:

Stage	Function	Benefit
Input stage	Drives LED using control signal	Low power control
Isolation	Light bridges electrical gap	Safety and noise immunity
Triggering	Light activates SCR	No mechanical contacts
Switching	Thyristors conduct load current	No arcing or contact wear

- **Silent operation**: No mechanical noise during switching
- **Long life**: No contact degradation as in electromechanical relays

Mnemonic

"Light Links Logic to Load"

Question 2(b) OR [4 marks]

Define snubber circuit and explain importance of snubber circuit.

Solution

A snubber circuit is a protective network that suppresses voltage and current transients in switching devices.
Basic RC Snubber:

```
          A
          |
     C    |
    |{-{-}{-}{-}{-}|}
    |     |
    |     Z SCR
    |     Z
    |     |
   {-{-}{-}    |}
   {-{-}{-} R  |}
    |     |
    |{-{-}{-}{-}{-}|}
          |
          K
```

Importance Table:

Function	Benefit	Implementation
dV/dt suppression	Prevents false triggering	RC circuit across SCR
Voltage spike reduction	Protects from overvoltage	Capacitor absorbs energy
Oscillation damping	Reduces EMI	Resistor provides damping
Turn-off assistance	Improves commutation	Diverts current during turn-off

- **Circuit protection**: Extends thyristor life by limiting stress on the device
- **Noise reduction**: Minimizes electromagnetic interference in surrounding circuits

Mnemonic

"Suppress Noise Upsetting Balanced Behaviors Easily Restored"

Question 2(c) OR [7 marks]

List various commutation methods of SCR and explain any two of them

Solution

Commutation is the process of turning OFF an SCR by reducing its anode current below holding value.
Commutation Methods Table:

Method	Principle	Applications
Natural	AC zero crossing	AC power control
Forced	External circuit	DC applications
Class A	LC resonance	Inverters
Class B	Auxiliary SCR	DC choppers
Class C	LC with load	Variable frequency
Class D	Auxiliary source	Motor control
Class E	External pulse	Electronic circuits

1. Natural Commutation:

```
        AC
        {}
        |
        Z SCR
        Z
        |
        R Load
        |
       {-{-}{-}}
       GND
```

- **Zero crossing**: SCR turns off when AC crosses zero and anode current falls below holding
- **Simplicity**: No additional components required for commutation
- **Limitation**: Works only in AC circuits at fixed frequency

2. Forced Commutation (Class B):

```
    +Vdc
      |
      |    C
      Z    |
 SCR1 Z    |
      |{-{-}{-}{-}+{-}{-}{-}{-},}
      |    |    |
      R    Z SCR2
 Load |    Z    |
      |    |    |
    {-{-}{-}  {-}{-}{-}  {-}{-}{-}}
    GND  GND  GND
```

- **Auxiliary SCR**: Second SCR (SCR2) discharges capacitor to reverse bias main SCR
- **Timing control**: Precise control over when SCR turns off
- **Application**: Used in DC circuits where natural commutation isn't possible

Mnemonic

"Nature Follows Current, Forced Creates Current Collapse"

Question 3(a) [3 marks]

Explain advantages of polyphase rectifier over single phase rectifier.

Solution

Polyphase rectifiers offer significant improvements over single-phase designs in power applications.
Advantages Table:

Parameter	Single Phase	Polyphase
Ripple factor	Higher (0.482 for FW)	Lower (0.042 for 3-phase)
Form factor	Higher	Lower
Efficiency	Lower	Higher (better transformer utilization)
Power rating	Limited	Higher power handling
Harmonic content	More	Less (smoother DC)

- **Output smoothness**: Significantly less ripple requiring smaller filtering components
- **Transformer utilization**: Better utilization factor (0.955 vs 0.812) reduces transformer size

Mnemonic

"More Phases Mean Smoother Power"

Question 3(b) [4 marks]

Write short note on UPS.

Solution

UPS (Uninterruptible Power Supply) provides continuous power during main supply failure.
UPS Block Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[AC Input] {-{-}{} R[Rectifier]}
    R {-{-}{} C[DC Bus]}
    C {-{-}{} I[Inverter]}
    I {-{-}{} O[AC Output]}
    C {{-}{-}{} B[Battery Bank]}
    S[Static Switch] {-{-}{} O}
    A {-{-}{} S}
{Highlighting}
{Shaded}
```

Types of UPS Table:

Type	Operation	Applications
Online	Always through battery/inverter	Critical systems, medical
Offline	Switches to battery on failure	Personal computers, small offices
Line-interactive	Voltage regulation + backup	Servers, network equipment

- **Backup time**: Typically 5-30 minutes depending on battery capacity
- **Protection**: Surge protection, voltage regulation, and frequency stabilization

Mnemonic

"Power Constantly Protected Under Switch"

Question 3(c) [7 marks]

Give function of Inverter and explain basic principle of Inverter also explain series inverter with neat diagram and waveform.

Solution

Inverters convert DC power to AC power by switching DC through a transformer or directly to create alternating waveforms.

Function Table:

Function	Description
DC to AC conversion	Transforms steady DC to alternating AC
Frequency control	Generates variable frequency output
Voltage regulation	Maintains stable output despite load variations
Wave shaping	Produces sine, square, or modified sine waves

Basic Principle Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    D[DC Source] {-{-}{} S[Switching Circuit]}
    S {-{-}{} T[Transformer/Filter]}
    T {-{-}{} A[AC Output]}
    C[Control Circuit] {-{-}{} S}
{Highlighting}
{Shaded}
```

Series Inverter Circuit:

```
    +Vdc
      |
      |
    \_\_|\_\_
   |     |
   C     L
   |     |
   |     |
   |     |
   |    \_|\_
   |    { /}
   |    SCR
   |    \_|\_
   |     |
   |     |
   |     |
  {-{-}{-}   {-}{-}{-}}
  GND   GND
```

Waveforms:

```
Voltage
   \^{}
   |     \_\_\_\_
   |    /    {}
   |\_\_\_/      {\_\_\_\_}
   |
   |           \_\_\_\_
   |          /    {}
   |\_\_\_\_\_\_\_\_\_\_/      {\_\_\_\_}
   +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-} Time}

Current
   \^{}
   |    /{}
   |   /  {}
   |\_\_/    {\_\_/\_\_}
   |          {  }
   |           {  }
   |            {  }
   |             {/}
   +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-} Time}
```

- **Oscillation**: Series LC circuit creates resonant oscillation when SCR triggers
- **Commutation**: SCR turns off naturally when current reverses through resonance
- **Frequency**: Determined by LC values: f = 1/(2)

Mnemonic

"Direct Current Switches To Alternating Current Through Resonant Circuit"

Question 3(a) OR [3 marks]

Explain basic principle of chopper.

Solution

A chopper is a DC-to-DC converter that switches DC input on/off to produce controllable average DC output.
Basic Chopper Circuit:

```
    +Vdc
      |
      |
     \_|\_
     { /}
      S Switch
     \_|\_
      |
      |
      R Load
      |
      |
     {-{-}{-}}
     GND
```

Principle Table:

Parameter	Relation	Control
Output voltage	Vo = Vdc $\times (Ton/T)$	Duty cycle adjustment
Duty cycle	k = Ton/T	Controls output voltage
Frequency	f = 1/T	Affects ripple
Voltage regulation	Varies with load	Feedback control adjusts duty cycle

- **Switching action**: Rapidly turns ON/OFF to chop DC input
- **Pulse width modulation**: Controls voltage by varying ON-time ratio

Mnemonic

"Chopping Creates Controllable DC"

Question 3(b) OR [4 marks]

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

Solution

SMPS (Switched Mode Power Supply) converts input power to regulated output using high-frequency switching.
SMPS Block Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[AC Input] {-{-}{} F[EMI Filter]}
    F {-{-}{} R[Rectifier \& Filter]}
    R {-{-}{} S[Switching Circuit]}
    S {-{-}{} T[Transformer]}
```

```
    T {-{-}{} O[Output Rectifier]}
    O {-{-}{} OF[Output Filter]}
    OF {-{-}{} OUT[DC Output]}
    FB[Feedback Control] {-{-}{} S}
    OUT {-{-}{} FB}
{Highlighting}
{Shaded}
```

Blocks Function Table:

Block	Function
EMI Filter	Suppresses noise from entering/leaving SMPS
Rectifier & Filter	Converts AC to unregulated DC
Switching Circuit	Chops DC at high frequency (20-200kHz)
Transformer	Provides isolation and voltage transformation
Output Rectifier	Converts high-frequency AC back to DC
Output Filter	Smooths DC output and removes ripple
Feedback Control	Regulates output by adjusting duty cycle

- **High efficiency**: 70-90% vs 30-60% for linear supplies
- **Small size**: High frequency allows smaller transformer and components

Mnemonic

"Filter, Rectify, Switch Through Transformer, Rectify, Filter"

Question 3(c) OR [7 marks]

Explain 1 phase half wave rectifier with waveform also explain 3 phase full wave rectifier with waveform.

Solution

Rectifiers convert AC to DC by allowing current flow in one direction while blocking reverse flow.

1-Phase Half Wave Rectifier:

```
     AC
     {}
     |
    \_|\_
    { /}
     D
    \_|\_
     |
     R Load
     |
    {-{-}{-}}
    GND
```

1-Phase Half Wave Waveforms:

```
Input AC
   \^{}
   |    /{         /}
   |   /  {       /  }
   |\_\_/    {\_\_\_\_\_/    \_\_\_\_}
   |
   |        /{         /}
   |       /  {       /  }
   |{     /         /    }
   +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-} Time}
```

```
Output DC
   \^{}
   |    /{         /}
   |   /  {       /  }
   |\_\_/    {\_\_\_\_\_/    \_\_\_\_}
   |
   |
   |
   |
   +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-} Time}
```

3-Phase Full Wave Rectifier:

```
    A o{-{-}{-}D1{-}{-}{-}.}
               |
               |
    B o{-{-}{-}D3{-}{-}{-}+{-}{-}{-}o +Vdc}
               |
               |
    C o{-{-}{-}D5{-}{-}{-}.}

    A o{-{-}{-}D2{-}{-}{-}.}
               |
               |
    B o{-{-}{-}D4{-}{-}{-}+{-}{-}{-}o {-}Vdc}
               |
               |
    C o{-{-}{-}D6{-}{-}{-}.}
```

3-Phase Full Wave Waveforms:

```
3{-Phase Input}
   \^{}
   |    /{    /    /    /}
   |   /  {  /    /    /  }
   |\_\_/\_\_\_\_{/\_\_\_\_/\_\_\_\_/\_\_\_\_}
   |  { / / / / / / /}
   |   {/  /  /  /  /  /}
   |
   +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-} Time}

Rectified Output
   \^{}
   |   nnnnnnnnnnnnnnnnnnnnn
   |  n  n  n  n  n  n  n  n
   |\_n\_\_\_\_n\_\_\_\_n\_\_\_\_n\_\_\_\_n\_\_\_
   |
   |
   |
   |
   +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-} Time}
```

Comparison Table:

Parameter	1-Phase Half Wave	3-Phase Full Wave
Ripple factor	1.21	0.042
Rectification efficiency	40.6%	95.5%
TUF	0.287	0.955
Peak inverse voltage	Vm	2.09Vm
Form factor	1.57	1.0007

- **1-Phase Half Wave**: Simplest design but with high ripple and poor efficiency
- **3-Phase Full Wave**: Much smoother output with 6 pulses per cycle

Mnemonic

"Half Passes Only Peaks, Three Phases Fill Valleys"

Question 4(a) [3 marks]

Describe working of solar photovoltaic based power generation with block diagram.

Solution

Solar PV power generation converts sunlight directly into electricity through photovoltaic effect.
Solar PV System Block Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    S[Solar Panel Array] {-{-}{} C[Charge Controller]}
    C {-{-}{} B[Battery Bank]}
    B {-{-}{} I[Inverter]}
    I {-{-}{} L[AC Loads]}
    C {-{-}{} D[DC Loads]}
{Highlighting}
{Shaded}
```

Component Table:

Component	Function
Solar panels	Convert sunlight to DC electricity
Charge controller	Regulates charging, prevents overcharge
Battery bank	Stores energy for later use
Inverter	Converts DC to AC for household appliances
Distribution panel	Routes electricity to loads

- **Energy conversion**: Photons excite electrons in semiconductor material creating current
- **Scalability**: System size can be adjusted based on power requirements

Mnemonic

"Sunlight Produces Voltage, Batteries Invert Loads"

Question 4(b) [4 marks]

Explain use of SCR as static switch.

Solution

SCR functions as a solid-state switch with no moving parts for reliable and fast switching.
SCR Static Switch Circuit:

```
    +Vdc
      |
      |
     \_|\_
     { /}
     SCR
     \_|\_
```

```
       |
      {-{-}{-}  Trigger}
       |   Circuit
       R   |
 Load |    |
       |{-{-}{-}|}
       |
      {-{-}{-}}
      GND
```

Applications Table:

Application	Advantage	Implementation
Power control	Precise control, no arcing	Phase angle control
Motor starting	Smooth acceleration	Gradual voltage increase
Circuit protection	Fast response	Current sensing trigger
Heating control	Energy efficient	Zero-crossing switching

- **Latching action**: Once triggered, continues to conduct until current falls below holding value
- **High reliability**: No mechanical wear due to absence of moving parts

Mnemonic

"Semiconductor Switching Controls Running Loads"

Question 4(c) [7 marks]

Describe the working principle of Induction heating and dielectric heating also give comparison of Induction heating and dielectric heating.

Solution

Both heating methods use electromagnetic principles to generate heat without direct contact.
Induction Heating Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[AC Power] {-{-}{} B[High Frequency Generator]}
    B {-{-}{} C[Work Coil]}
    C {-{-}{} D[Magnetic Field]}
    D {-{-}{} E[Eddy Currents in Workpiece]}
    E {-{-}{} F[Heat Generation]}
{Highlighting}
{Shaded}
```

Dielectric Heating Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[RF Generator] {-{-}{} B[Applicator Plates]}
    B {-{-}{} C[Electric Field]}
    C {-{-}{} D[Molecular Friction in Material]}
    D {-{-}{} E[Heat Generation]}
{Highlighting}
{Shaded}
```

Comparison Table:

Parameter	Induction Heating	Dielectric Heating
Principle	Eddy currents and hysteresis	Molecular friction from oscillating field
Materials	Conductive metals	Non-conductive materials (plastics, wood)
Frequency	1-100 kHz	10-100 MHz
Penetration	Surface and shallow depth	Uniform through material
Efficiency	80-90%	50-70%
Applications	Metal hardening, melting, forging	Plastic welding, food processing, drying

- **Induction heating**: Works through electromagnetic induction creating eddy currents in conductive materials
- **Dielectric heating**: Causes rapid oscillation of polar molecules creating internal friction and heat

Mnemonic

"Induction Makes Metals Hot, Dielectrics Heat Non-Metals"

Question 4(a) OR [3 marks]

Draw and explain the circuit diagram of photo electric relay using photo diode.

Solution

Photo-electric relay uses light detection to control switching operations automatically.

Circuit Diagram:

```
+Vcc
  |
  R1
  |
  |{-{-}{-}{-}{-}{-}{-}{-}+}
  |       |
 {-{-}{-}      |}
 / {      |}
Photo    \_|\_
Diode    | |\_
 {-{-}{-}     |/  |}
  |      |   |
  |      |{  |}
  |      |   |
  +{-{-}{-}{-}{-}{-}+   |}
  |          |
  R2         |
  |          |
 {-{-}{-}         |       +Vcc}
 GND         |        |
             |       \_|\_
             +{-{-}{-}{-}{-}{-}{-}|  |}
                    | /
                    |{}
                    |/
                    |
                    Z
                    Z Load
                    |
                  {-{-}{-}}
                  GND
```

Operation Table:

Light Condition	Photodiode State	Transistor State	Relay Action
Dark	High resistance	OFF	De-energized
Light	Low resistance (conducts)	ON	Energized

- **Light detection**: Photodiode conducts when illuminated, changing bias on transistor
- **Switching**: Transistor amplifies small photodiode current to drive relay coil

Mnemonic

"Light Drives Diode, Diode Drives Transistor, Transistor Drives Relay"

Question 4(b) OR [4 marks]

Draw the circuit diagram of AC power control using DIAC-TRIAC and explain it.

Solution

DIAC-TRIAC circuit enables smooth control of AC power through phase angle adjustment.
Circuit Diagram:

```
    AC      R1      DIAC
    {       www     \_|\_}
    |       |       / {}
    |{-{-}{-}{-}{-}{-}{-}|{-}{-}{-}{-}{-}{-}{-}|{-}{-}{-}{-}{-}{-}{-}{-}.}
    |       |       {\_/      |}
    |       |        |       |
    |       |        |       |
    |       C        |      \_|\_
    |       |        |     |   |
    |       |        |     |   |
    |       |        {{-}{-}{-}{-}{-}|GT |}
    |       |              |   |
    |       |              |\_\_\_|
    |       |                | TRIAC
    |       |                |
    Z       |                |
    Z Load  |                |
    |       |                |
    |{-{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}}
    |
   {-{-}{-}}
   GND
```

Operation Table:

Component	Function
R1-C	Variable time constant for phase delay
DIAC	Triggers TRIAC when capacitor voltage reaches breakover
TRIAC	Controls load current based on triggering point
Load	Receives partial AC waveform based on phase control

- **Phase control**: RC network creates delay in triggering point within AC cycle
- **Bidirectional operation**: Works on both halves of AC cycle

Mnemonic

"Delay Initiates At Capacitor, Triggers Reliable Independent AC Control"

Question 4(c) OR [7 marks]

Explain IC555 three stage sequential timer working with waveform.

Solution

A three-stage sequential timer uses multiple 555 ICs to generate timed sequences for process control.

Circuit Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    T[Trigger] {-{-}{} IC1[555 Timer 1]}
    IC1 {-{-}{} O1[Output 1]}
    IC1 {-{-}{} D1[Delay]}
    D1 {-{-}{} IC2[555 Timer 2]}
    IC2 {-{-}{} O2[Output 2]}
    IC2 {-{-}{} D2[Delay]}
    D2 {-{-}{} IC3[555 Timer 3]}
    IC3 {-{-}{} O3[Output 3]}
    IC3 {-{-}{} R[Reset]}
    R {-.{-}{} IC1}
{Highlighting}
{Shaded}
```

Waveform:

```
Trigger
   \_
\_\_|  |\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Output 1
    \_\_\_\_\_\_\_\_\_\_\_\_
\_\_\_|            |\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Output 2
              \_\_\_\_\_\_\_\_\_\_\_\_
\_\_\_\_\_\_\_\_\_\_\_\_\_|            |\_\_\_\_\_\_

Output 3
                        \_\_\_\_\_\_\_\_
\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_|         |

   {{-}T1{-}|{-}{-}T2{-}{-}|{-}{-}T3{-}{-}|{-}T4{-}}
```

Sequential Operation Table:

Stage	Action	Duration	Next Stage Trigger
Initial	All outputs LOW	-	External trigger
Stage 1	Output 1 HIGH	T1 (R11)	Output 1 falling edge
Stage 2	Output 2 HIGH	T2 (R22)	Output 2 falling edge
Stage 3	Output 3 HIGH	T3 (R33)	Output 3 falling edge
Reset	All outputs LOW	T4 (reset time)	New external trigger

- **Cascading connection**: Output of first timer triggers second, and so on
- **Timing control**: Each stage duration independently adjustable with RC values
- **Applications**: Industrial sequencing, process control, automated systems

Mnemonic

"First Stage Finishes, Second Starts, Third Succeeds"

Question 5(a) [3 marks]

Draw and explain solid state control of DC shunt motor.

Solution

Solid-state DC motor control uses SCRs to regulate voltage applied to the motor.
Circuit Diagram:

```
    AC      Bridge      SCR
    {       Rect      \_\_\_|\_\_\_}
    |       \_\_\_\_      |       |
    |{-{-}{-}{-}{-}{-}|\_\_\_\_|{-}{-}{-}{-}|       |{-}{-}{-}{-}.}
    |                |\_\_\_\_\_\_\_|    |
    |                   |        |
    |                  \_|\_       |
    |                  { /       |}
    |                  Gate      |
    |                Circuit     |
    |                   |        |
    |                   |        |
    |       Field       |        |
    |       Winding     |     \_\_\_|\_\_\_
    |      \_\_\_\_\_\_\_         |    |       |
    |     |      |      |     | DC    |
    |{-{-}{-}{-}{-}|\_\_\_\_\_\_\_|{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}| Motor |}
    |                        |\_\_\_\_\_\_\_|
    |                           |
   {-{-}{-}                          {-}{-}{-}}
   GND                           GND
```

Control Method Table:

Method	Operation	Advantage
Phase control	Varies SCR firing angle	Smooth speed control
Chopper control	Pulse width modulation	High efficiency
Closed-loop	Feedback from tachometer	Precise speed regulation

- **Speed regulation**: Controls armature voltage to vary motor speed
- **Torque control**: Maintains high starting torque with current limiting

Mnemonic

"SCR Controls Current Delivering Motor Power"

Question 5(b) [4 marks]

Explain working principle of stepper motor.

Solution

Stepper motors convert digital pulses into precise mechanical rotation through electromagnetic principles.
Stepper Motor Structure:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    C[Controller] {-{-}{} D[Driver]}
    D {-{-}{} P[Phase Windings]}
    P {-{-}{} R[Rotor Movement]}
{Highlighting}
```

{Shaded}

Operation Principle Table:

Step Type	Rotation Angle	Control Method
Full step	Typically $1.8° or 0.9°$	One phase at a time
Half step	Half of full step	Two phases alternating
Micro-step	Fraction of full step	PWM current control
Wave drive	Full step angle	One phase energized

- **Digital positioning**: Each pulse rotates motor by precise angle
- **Holding torque**: Maintains position when energized without rotation

Mnemonic

"Pulses Produce Precise Positional Steps"

Question 5(c) [7 marks]

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

Solution

Programmable Logic Controller (PLC) is an industrial digital computer for automation control.
PLC Block Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    P[Power Supply] {-{-}{} CPU[Central Processing Unit]}
    CPU {-{-}{} M[Memory]}
    CPU {-{-}{} I[Input Module]}
    CPU {-{-}{} O[Output Module]}
    I {-{-}{} S[Input Sensors/Switches]}
    O {-{-}{} A[Actuators/Motors]}
    CPU {-{-}{} C[Communication Module]}
    CPU {-{-}{} P[Programming Device]}
{Highlighting}
{Shaded}
```

PLC Components Table:

Component	Function
Power Supply	Converts main power to DC required by PLC
CPU	Executes program and makes decisions based on I/O
Memory	Stores program and data (ROM, RAM, EEPROM)
Input Module	Interfaces with sensors, switches, encoders
Output Module	Controls actuators, motors, valves, indicators
Communication Module	Connects to other PLCs, computers, networks
Programming Device	Used to write, edit, monitor PLC programs

- **Scan cycle**: Reads inputs, executes program, updates outputs continuously
- **Programming languages**: Ladder logic, function block, structured text, etc.
- **Advantages**: Reliability, flexibility, expandability, diagnostic capabilities

Mnemonic

"Power Centralizes Processing, Inputs/Outputs Make Automation"

Question 5(a) OR [3 marks]

Draw and explain construction of DC Servo motor.

Solution

DC servo motors provide precise position control with feedback for automation and robotics.
Construction Diagram:

```
      Feedback
      Device
        |
        v
    .{-{-}{-}{-}{-}{-}{-}{-}.      Shaft}
    |        |{-{-}{-}{-}{-}{-}{-}{-}{-}}
    |        |
    | Motor  |
    |        |
    |        |
    {{-}{-}{-}{-}{-}{-}{-}{-}}
        \^{}
        |
     Control
     Signal
```

Construction Table:

Component	Function
Armature	Rotates within magnetic field
Field magnets	Creates magnetic field (often permanent magnets)
Commutator	Transfers power to rotating armature
Feedback device	Encoder/tachometer for position/speed feedback
Brushes	Connect power to commutator

- **Low inertia**: Special design allows rapid acceleration/deceleration
- **High torque-to-inertia ratio**: Responds quickly to control signals

Mnemonic

"Precise Position Feedback Drives Exact Control"

Question 5(b) OR [4 marks]

Explain working of BLDC motor.

Solution

Brushless DC (BLDC) motors use electronic commutation instead of mechanical brushes and commutator.
BLDC Operation Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    PS[Power Supply] {-{-}{} C[Controller]}
    C {-{-}{} D[Driver Circuit]}
    D {-{-}{} W[Stator Windings]}
    HS[Hall Sensors] {-{-}{} C}
    W {-{-}{} R[Rotor Rotation]}
    R {-{-}{} HS}
{Highlighting}
{Shaded}
```

Working Principle Table:

Component	Function
Stator	Fixed windings that generate rotating magnetic field
Rotor	Permanent magnets that follow rotating field
Electronic controller	Replaces mechanical commutation
Hall sensors	Detect rotor position for synchronized switching
Driver circuit	Provides sequence of currents to stator coils

- **Commutation**: Electronic switching sequences power to stator windings
- **Efficiency**: Higher efficiency due to elimination of brush losses
- **Reliability**: No brush wear or sparking, longer lifespan

Mnemonic

"Electronic Switching Creates Rotation Without Brushes"

Question 5(c) OR [7 marks]

Explain construction and working of VFD.

Solution

Variable Frequency Drive (VFD) controls AC motor speed by varying frequency and voltage.
VFD Construction Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[AC Input] {-{-}{} R[Rectifier]}
    R {-{-}{} D[DC Bus/Filter]}
    D {-{-}{} I[Inverter]}
    I {-{-}{} M[Motor]}
    C[Control Circuit] {-{-}{} I}
    F[Feedback] {-{-}{} C}
{Highlighting}
{Shaded}
```

Construction and Working Table:

Section	Components	Function
Rectifier	Diodes/SCRs	Converts AC to DC
DC Bus	Capacitors, inductors	Filters and smooths DC
Inverter	IGBTs/transistors	Converts DC to variable frequency AC
Control circuit	Microprocessor	Controls switching frequency and patterns
Cooling system	Fans, heat sinks	Maintains safe operating temperature
Protection circuits	Sensors, relays	Prevents damage from faults

- **Speed control**: V/f ratio maintained to provide constant torque
- **Energy savings**: Adjusts power to actual load requirements
- **Soft start**: Gradual acceleration prevents mechanical shock

Mnemonic

"Rectify, Filter, Invert Frequency For Motor Control"