BRANCH-ELECTRICAL ENGINEERING (TH-1)
EEPC202, Fundamentals of Power Electronics
SEMESTER – IV

Unit I: Power Electronic Devices

2 Marks Questions

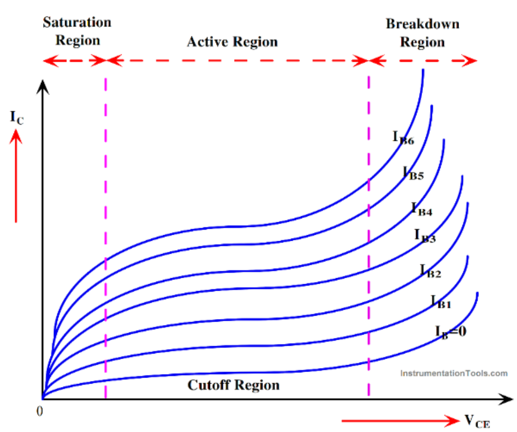
1. **Define power electronic devices.**
   Ans-Power electronic devices are specialized semiconductor components designed to act as high-speed switches or rectifiers in power conversion circuits. Unlike low-power signal transistors, these are engineered to handle high voltages and large currents (often hundreds of amps and kilovolts) while minimizing energy loss during switching.

2. **What is the basic construction of a power transistor?**

Ans: - A power BJT is a vertically oriented three-layer (NPN) device. To handle high power, it incorporates a four-region structure (n+ - p - n- - n+). The key addition is the lightly doped collector drift region (n-), which increases the voltage-blocking capability. The vertical arrangement allows for a larger cross-sectional area, which reduces resistance and improves current-handling capacity.

3. **Draw the V-I characteristics of a power transistor.**

Ans:-



4. **List two uses of power transistors.**
   Ans:-
   1. **Switch-Mode Power Supplies (SMPS):** Used to efficiently convert DC voltages.
   2. **Relay Drivers:** Acting as a switch to control high-power mechanical relays using low-power logic signals.

5. **Explain the construction of an IGBT.**
   Ans:-
   The **Insulated Gate Bipolar Transistor (IGBT)** is a functional integration ofa MOSFET and a BJT.
   - It features a **gate oxide layer** (like a MOSFET) which provides high input impedance.
   - Structurally, it is a four-layer device (p^+ - n^- - p - n^+).
   - The distinguishing feature is the **p^+ substrate (injection layer)** at the bottom, which injects holes into the drift region to reduce resistance, allowing it to handle higher currents than a standard MOSFET.

6. **What are the key V-I characteristics of an IGBT?**
   Ans:-
   The IGBT combines the best of both worlds:
   - **Input:** Voltage-controlled (like a MOSFET). It requires a gate-to-emitter voltage (V_{GE}) to turn on.
   - **Output:** The plot of I_C vs. V_{CE} resembles a BJT, but with a "threshold" or offset voltage (typically **0.7V to 1V**) before current starts flowing, due to the p-njunction at the collector.

7. **Mention two applications of IGBT.**
   Ans:- **Variable Frequency Drives (VFDs):** Used to control the speed of AC motors in industrial automation.
   Electric Vehicle (EV) Inverters: Converting DC battery power into AC to drive the vehicle's motor.

8. What is a Single Electron Transistor (SET)?
   Ans:-A **Single Electron Transistor (SET)** is a sensitive switching device that uses **quantum tunneling** to record the movement of individual electrons. It consists of a "gate" and two ultra-small electrodes (source and drain) separated by a "quantum dot" or "island." It operates based on the **Coulomb Blockade** effect, where the addition of a single electron prevents the entry of another until the voltage is changed.

9. **Define nanotechnology in the context of power electronics**.
   Ans:-In this context, **nanotechnology** refers to the use of materials and structures engineered at the nanoscale (1–100 nm) to improve device performance. This includes:
   - **Wide Bandgap (WBG) materials** like Gallium Nitride (GaN) or Carbon Nanotubes.
   - Enhancing thermal conductivity to dissipate heat faster.
   - Reducing the size of components while increasing switching speeds and efficiency.

10. **Why is SET considered for future power devices?**
    Ans:-While currently mostly experimental and limited by temperature, SETs are the future because:
    - **Ultra-Low Power Consumption:** Since they operate by moving single electrons, energy loss is virtually zero.
    - **Extreme Integration:** Their microscopic size allows for billions more devices on a single chip compared to silicon.
    - **High Sensitivity:** They can function as incredibly precise sensors or high-speed logic gates for next-gen "smart" power management.

5 Marks Questions

1**. Explain the working principle of a power transistor with a diagram.**

Ans- A power transistor is a semiconductor device designed to handle high current, high voltage, and high-power levels (typically >1 W) for amplification, switching, and control in power electronics applications.

Basic Principle

Power transistors operate on the same fundamental principle as small-signal transistors — controlling a large output current/voltage using a small input signal — but are optimized for:

- **Larger junction areas** to handle higher currents.
- **Robust packaging** with heat sinks for thermal dissipation.
- **Higher voltage ratings** due to modified doping profiles and thicker depletion layers.

How It Works (NPN BJT)

1. **Structure Layers:**
   - **Emitter (n+):** Heavily doped to inject electrons.
   - **Base (p):** Thin and lightly doped to allow most electrons to pass through.
   - **Collector (n-):** Lightly doped **n-drift region** (key for high-voltage operation) to widen depletion layer and prevent punch-through.
2. **Operation:**

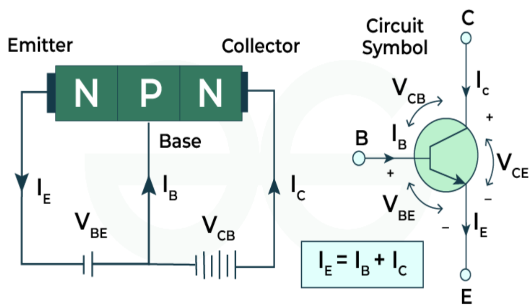
- When V_{BE} **> 0.7 V** (forward-biased base-emitter junction), electrons flow from emitter to base.
- Most electrons diffuse across the thin base into the collector region due to the reverse-biased **base-collector junction** (V_{CB} positive).

- **Collector current (I_C)** is proportional to **base current (I_B)**:

$$I_C = \beta I_B$$

Where β is the current gain (lower for power BJTs, typically 5–20, due to wider base for higher voltage).

3. **Key Features for Power Handling:**
   - **n- Drift region** increases breakdown voltage (BV_CEO) but also increases on-state resistance.
   - **Thermal management** is critical — power dissipated as heat $P = V_{CE} \cdot I_C$.
   - Operates in:
     - **Active region** (linear amplification).
     - **Saturation region** (switch ON, low V_CE).
     - **Cut-off region** (switch OFF).



2. Compare the V-I characteristics of power transistor and IGBT.

Ans-Here is a short and clear comparison of the V-I (output) characteristics of a power transistor (BJT) and an IGBT:

Feature	**Power BJT**	**IGBT**
Control type	Current (base current IB)	Voltage (gate voltage VGE)
VCE(sat) at high current	1.0 – 2.5 V (usually higher)	1.7 – 2.5 V (modern types often lower)
Active (linear) region	Long and clearly visible	Very short / almost missing
Quasi-saturation region	Prominent (curves bend noticeably)	Very small or absent
On-state voltage drop	Increases a lot with current	More stable (thanks to conductivity modulation)
Secondary breakdown	Yes (limits safe operating area)	No
Conduction losses at high power	Higher	Lower
Typical use today	Low–medium power, older designs	High power, inverters, EV, motor drives

Quick visual summary

- **Power BJT**: flatter active region + higher VCE(sat) + visible quasi-saturation bend

- **IGBT**: almost vertical rise after ~1–2 V → quickly reaches low VCE (sat)

3. Describe the construction and working of IGBT.

Ans-Construction (basic structure)

- N-channel IGBT has:
  - Collector → heavily doped P^+ layer (injects holes)
  - N^- drift region → thick, lightly doped (blocks high voltage)
  - P body → forms the base of internal BJT
  - N^+ emitter regions
  - Gate → insulated by thin oxide layer (like MOSFET)
  - Emitter metal → connects N^+ and P-body

It looks like a MOSFET on top + PNP transistor below.

Working (very simplified)

Turn ON:

- Apply positive voltage to gate (> ~5–6 V)
- MOSFET channel forms → electrons flow from emitter to drift region
- P^+ collector injects lots of holes into drift region
- Holes + electrons flood the drift region → conductivity modulation
- Result → very low voltage drop (VCE(sat) ≈ 1.8–2.5 V)

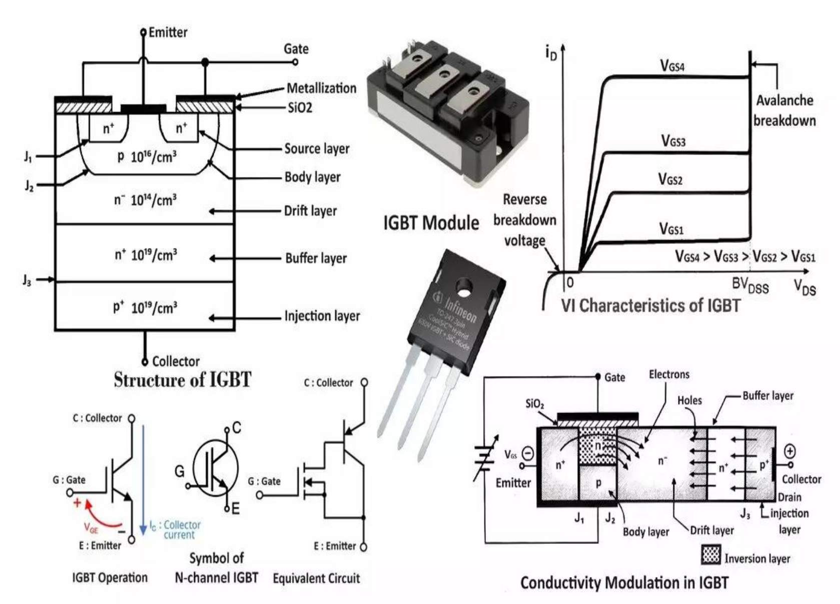
Turn OFF:

- Remove gate voltage → channel disappears
- Injection stops
- Remaining stored charge (holes) decays slowly → causes current tail
- Then device fully turns off and blocks voltage

Key Point

IGBT = easy gate control (like MOSFET)

- low conduction loss at high current (like BJT) thanks to hole injection and conductivity modulation.



4. **Discuss the concept of Single Electron Transistor (SET) with its advantages**.

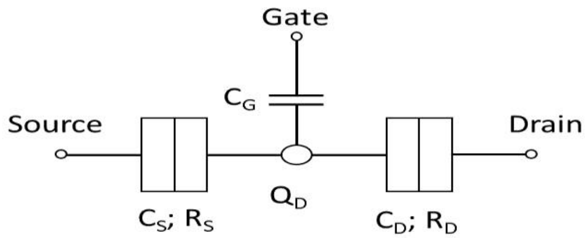
Ans- Single Electron Transistor (SET) is a nano-scale electronic device that can control and detect the movement of individual electrons — the ultimate limit of miniaturization in electronics.

Basic Concept & Structure

A typical SET consists of:

- A very small **conducting island** (also called **quantum dot** or **Coulomb island**) → size usually **few nm to ~100 nm**
- Two **tunnel junctions** connecting the island to **source** and **drain** electrodes

- A **gate electrode** capacitively coupled to the island (controls the potential)



Schematic structure

Working Principle — Coulomb Blockade

The SET operates based on two key quantum phenomena:

1. **Coulomb Blockade** Adding or removing even **one electron** from the tiny island costs a significant electrostatic energy: **$E = e^2 / 2C$** (where C = total capacitance of the island — very small → energy is large)

→ This creates an **energy barrier** that prevents electrons from tunnelling unless the gate voltage precisely compensates for it.

2. **Quantum Tunnelling** Electrons can tunnel through the thin insulating barriers (tunnel junctions) when the energy barrier is lowered or removed by gate voltage.

Behaviour:

- At most gate voltages → **Coulomb blockade** → **no current** flows (transistor is OFF)
- At specific gate voltages (when island potential matches Fermi level alignment) → one electron can tunnel → current flows in discrete steps
- Current shows **periodic oscillations** (Coulomb oscillations) as gate voltage is swept — each peak corresponds to adding/removing **exactly one electron**

5. **Explain aspects of nanotechnology relevant to power electronics.**

Ans-Nanotechnology is revolutionizing power electronics by overcoming the physical limitations of traditional silicon-based components. By manipulating materials at the atomic or molecular scale (1 to 100 nm), engineers can create devices that are smaller, faster, and significantly more efficient.

Here are the key aspects where nanotechnology intersects with power electronics:

1. Wide Band gap (WBG) Nanomaterial

Traditional power transistors use silicon (Si), but nanotechnology has enabled the practical use of Gallium Nitride (GaN) and Silicon Carbide (SiC).

- Higher Efficiency: These materials have a "wide band gap," meaning they can operate at much higher voltages and temperatures than silicon.
- Faster Switching: Nano structuring allows these components to switch ON and OFF millions of times per second with minimal energy loss.
- Relevance to your Lab: In Experiment 10, while a standard C.R.O. might struggle to capture ultra-fast transients, nanotech-based switching is what makes modern, compact "GaN chargers" possible.

2. Carbon Nanotubes (CNTs) and Graphene

Carbon nanotubes are cylindrical molecules of carbon with extraordinary electrical and thermal properties.

- Thermal Management: One of the biggest hurdles in power electronics is heat. CNTs have thermal conductivity much higher than copper, making them ideal for "Thermal Interface Materials" (TIMs) that pull heat away from power transistors.
- Current Density: CNTs can carry much higher current densities than metal wires without melting (electro migration), allowing for further miniaturization of power modules.

3. Nano composite Dielectrics for Capacitors

Capacitors in power electronics store and release energy. Nanotechnology improves them through Nano composites:

- By embedding ceramic nanoparticles into polymer matrices, engineers create capacitors with a much higher dielectric constant.
- This results in "Super capacitors" or high-energy-density capacitors that are smaller but can handle the massive "ripple currents" found in the power lines you study in Experiment 9.

4. Nano crystalline Magnetic Cores

Transformers and inductors (like those you measure in Experiment 2 using Maxwell and Anderson bridges) rely on magnetic cores.

- Reduced Core Losses: Using Nano crystalline ribbons (metals with grain sizes in the nanometre range) significantly reduces "eddy current losses."
- Higher Permeability: This allows inductors to be much smaller while maintaining the same inductance (L), which is critical for shrinking the size of power converters.

5. Nano-Solder and Interconnects

As power transistors get smaller, the "glue" that holds them to circuit boards must improve.

- Nano-silver sintering: This technology uses silver nanoparticles to create joints that have high electrical conductivity and can withstand the extreme temperatures generated in high-power circuits without failing.

10 <u>Marks Questions</u>

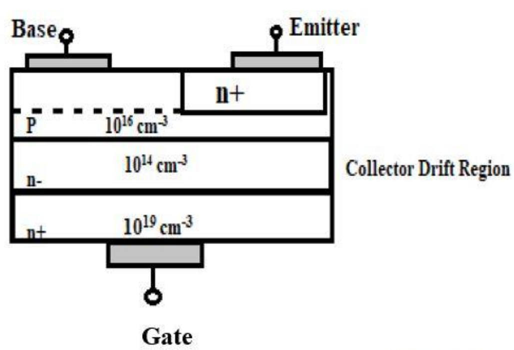
1. With neat diagrams, explain the construction, working principle, V-I characteristics, and uses of power transistor and IGBT.

Ans -**Power Transistor (BJT)**

Power transistors are high-power versions of Bipolar Junction Transistors (BJTs), typically NPN type, designed for handling large currents (up to 100 A) and power (up to 500 W). They operate as current-controlled switches or amplifiers.

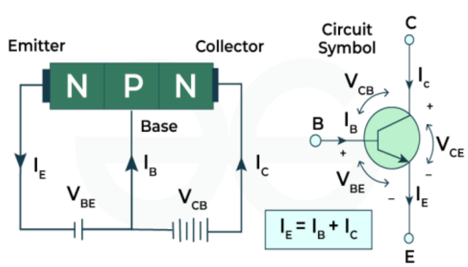
Construction

A power BJT consists of three semiconductor layers: heavily doped N+ emitter, thin lightly doped P base, and large moderately doped N collector. The collector is larger for heat dissipation, and the device is often packaged with heat sinks (e.g., TO-220, TO-3).



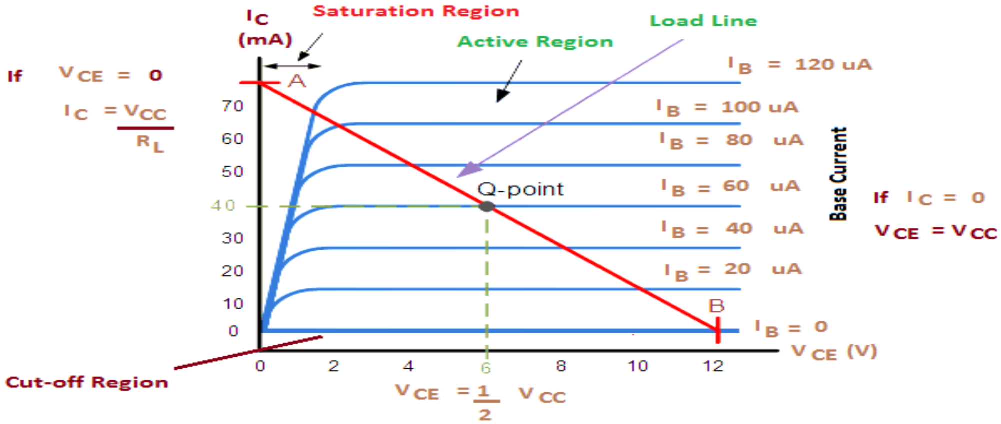
Working Principle

In active mode, a small base current (IB) forward-biases the base-emitter junction, injecting electrons from emitter to base. Most electrons diffuse across the thin base to the reverse-biased collector-base junction, where they are swept into the collector as IC (IC ≈ β * IB, β = 20-200). This amplifies current. In saturation, both junctions are forward-biased for low VCE; in cut-off, no current flows.



V-I Characteristics

Output characteristics (I_C vs V_{CE} at fixed IB) show cut-off (I_C=0), active region (flat I_C), quasi-saturation (bend), and saturation (low V_{CE} ~1-2.5 V). Quasi-saturation is prominent due to high currents



Uses

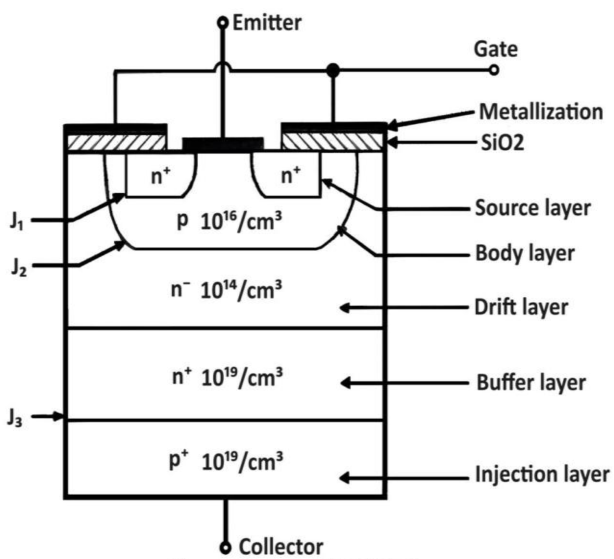
- Switching in power supplies and motor controls (low to medium power).
- Audio amplifiers and voltage regulators.
- Legacy designs in inverters and UPS (replaced by IGBTs in high-power apps).

Insulated Gate Bipolar Transistor (IGBT)

IGBT is a voltage-controlled hybrid of MOSFET and BJT, ideal for high-voltage (600-6500 V) and high-current switching with low conduction losses.

Construction

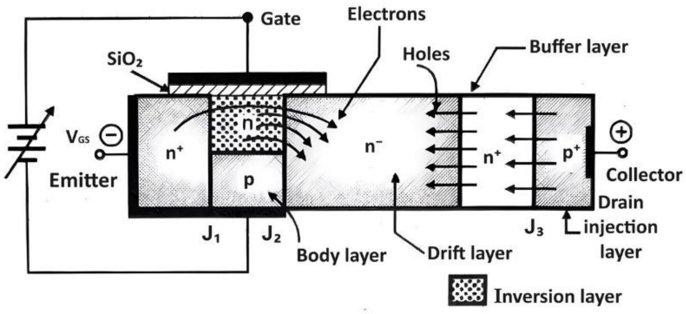
Vertical structure: P+ collector (injection layer), N- drift region (voltage blocking), P body, N+ emitter regions, insulated gate (SiO2). Equivalent to MOSFET driving a PNP BJT.



Structure of IGBT

Working Principle

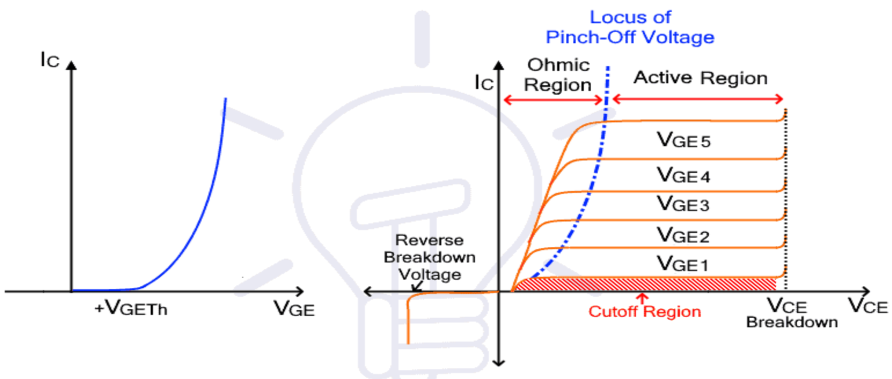
Apply V_{GE} > threshold (~5 V): MOSFET channel forms, electrons flow to drift region, forward-biasing P+ collector to inject holes. This causes conductivity modulation, reducing on-resistance for low V_{CE}(sat) ~1.8-2.5 V. Turn-off involves tail current from stored charges.



Conductivity Modulation in IGBT

V-I Characteristics

Output (I_C vs V_{CE} at fixed V_{GE}): Short active region, quick saturation with low V_{CE}(sat), steep curves due to modulation. No prominent quasi-saturation; better SOA than BJT.



I-V Characteristics of IGBT

Uses

- High-power inverters, motor drives, and EV chargers.
- Induction heating, welding, and renewable energy converters.
- Preferred over BJT for medium-high frequency (5-50 kHz) due to lower losses.

2. Discuss the concept of Single Electron Transistor (SET) and aspects of nanotechnology in power electronics, including potential applications and challenges.

Ans-Concept of Single Electron Transistor (SET)

The Single Electron Transistor (SET) is a nanoscale device that operates by controlling the tunneling of individual electrons through a tiny conducting island, leveraging quantum mechanical effects for ultra-precise charge manipulation. It represents the pinnacle of transistor miniaturization, where electron flow is quantized rather than continuous.

Structure and Working Principle

An SET typically consists of a small metallic or semiconductor island (quantum dot, ~1-100 nm in size) isolated by two tunnel junctions (thin insulating barriers) connected to source and drain electrodes. A capacitively coupled gate electrode modulates the island's potential without direct current flow.

The core phenomenon is Coulomb blockade: The energy required to add one electron to the island is $E = e^2 / 2C$ (where e is electron charge and C is the island's capacitance). For small C (pico- or femtofarads), this energy exceeds thermal energy (kT) even at low temperatures, blocking electron tunnelling unless the gate voltage aligns energy levels precisely.

- Off state: Coulomb blockade prevents current.
- On state: At specific gate voltages, single electrons tunnel sequentially (source → island → drain), producing discrete current steps (Coulomb oscillations or staircase in I-V curves).
- Operation often requires cryogenic temperatures (~mK to K) for classical SETs, though advanced designs (e.g., with silicon or graphene islands) aim for room temperature

SETs are a cornerstone of nanotechnology, bridging classical electronics with quantum computing, but their low current (~pA-nA) limits them to low-power applications rather than high-power switching.

Aspects of Nanotechnology in Power Electronics

Nanotechnology integrates materials and structures at the 1-100 nm scale into power electronics, which deals with efficient conversion, control, and conditioning of electrical power (e.g., in inverters, converters, and grids). Key aspects include:

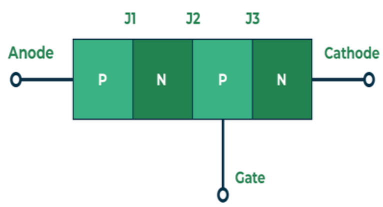
- Nanomaterials for Enhanced Components: Graphene, carbon nanotubes (CNTs), and 2D materials like molybdenum disulfide (MoS_2) offer superior electrical conductivity, thermal management, and mechanical strength compared to bulk silicon or GaN. For instance, nano-engineered semiconductors reduce on-resistance in switches, while nanocomposites improve insulators' dielectric properties.
- Quantum and Nano-Scale Effects: Devices exploit tunnelling, quantum confinement, or plasmonics for better efficiency. Examples include nanowire-based transistors or quantum dot-enhanced solar converters integrated into power systems.
- Miniaturization and Integration: Nano-fabrication enables ultra-compact power modules with higher switching frequencies (MHz+), reducing size and losses in systems like EV chargers or renewable inverters.
- Energy Harvesting and Storage Integration: Nanotech blurs lines between power electronics and energy sources, e.g., via piezoelectric nanomaterial for self-powered sensors in smart grids.

These aspects aim to address demands for higher efficiency (>99%), lower losses, and sustainability in power systems.

Unit II: Thyristor Family Devices

2 Marks Questions

1. **Draw the construction diagram of SCR.**
   ANS- An SCR is a four-layer, three-junction **P-N-P-N** semiconductor device. It has three terminals: **Anode (A)**, **Cathode (K)**, and **Gate (G)**.



2. **What is the two-transistor analogy of SCR?**

ANS- The SCR can be visualized as a combination of one **PNP** transistor (Q_1) and one **NPN** transistor (Q_2).

- The collector of Q_1 is connected to the base of Q_2.
- The collector of Q_2 is connected to the base of Q_1.
  This creates a regenerative feedback loop; once a small gate current starts the process, the transistors "latch" each other into conduction.

3. **List types of thyristors.**

ANS- Beyond the standard SCR, the family includes:

- **DIAC** (Diode AC Switch)
- **TRIAC** (Triode AC Switch)
- **GTO** (Gate Turn-Off Thyristor)
- **LASCR** (Light Activated SCR)
- **SCS** (Silicon Controlled Switch)
- **MCT** (MOS Controlled Thyristor)

4. **Explain SCR mounting.**

ANS- **SCR Mounting**
Since SCRs handle high currents, they generate significant heat. Mounting is the process of attaching the device to a **heat sink** to dissipate this thermal energy. Common methods include:

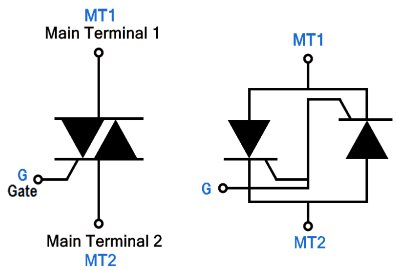
- **Lead mounting:** For low-power SCRs.
- **Stud mounting:** Using a threaded bolt to secure it to a chassis.
- **Press-fit/Bolt-down:** Ensuring maximum surface contact for cooling.

5. **What is LASCR?**

ANS - **LASCR** stands for **Light Activated Silicon Controlled Rectifier**. It is a thyristor that is triggered by incident light (photons) hitting the gate region instead of an electrical signal. This provides excellent electrical isolation between the control source and the power circuit.

6. **Draw the symbol of TRIAC**.

ANS- The TRIAC acts like two SCRs connected in anti-parallel with a common gate, allowing current flow in both directions.



TRIAC Symbol

7. **What is the operating principle of DIAC?**

ANS- A **DIAC** is a bidirectional trigger diode. It remains in a non-conducting state until the applied voltage (in either direction) reaches its **breakover voltage** (V_{BO}). Once V_{BO} is exceeded, the DIAC exhibits negative resistance and begins to conduct heavily.

8. **Explain over-voltage protection in thyristors.**

ANS- Thyristors are sensitive to voltage spikes. To protect them, **Varistors (MOV)** or **Selenium thyristor diodes** are used. These devices have high resistance at normal voltages but become low-resistance paths during a spike, "clamping" the voltage to a safe level.

9. **What is a snubber circuit?**

ANS- A snubber circuit is an **RC network** (a resistor and capacitor in series) connected in parallel with the SCR. Its purpose is to prevent accidental triggering caused by a high rate of rise of forward voltage (dv/dt). The capacitor "soaks up" the sudden voltage surge.

10. **Define crowbar protection.**

ANS- **Crowbar protection** is a "fail-safe" mechanism used to protect a load from over-voltage. If the voltage exceeds a set limit, an SCR is triggered to deliberately create a **short circuit** across the power lines. This high current flow quickly blows a fuse or trips a circuit breaker, disconnecting the power.

5 Marks Questions

1. **Explain the construction and two-transistor analogy of SCR.**

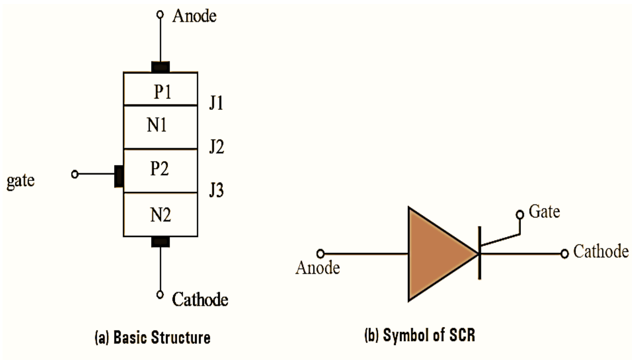
Ans- **Silicon Controlled Rectifier (SCR)**
Construction and Two-Transistor Analogy
1. Construction of SCR
An SCR (also called Thyristor) is a four-layer semiconductor device with **three terminals**:

- **Anode (A)**
- **Cathode (K)**
- **Gate (G)**

It has **four alternating layers** of P and N type semiconductor material:

Layer	Type	Name / Role
P1	P-type	Anode layer (heavily doped)
N1	N-type	First base layer
P2	P-type	Second base layer (thin, lightly doped)
N2	N-type	Cathode layer (heavily doped)

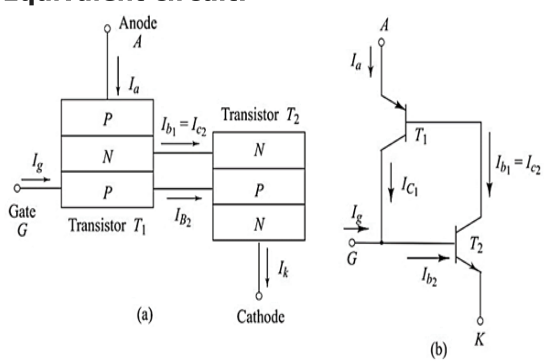
Physical structure (vertical cross-section):



2. Two-Transistor Analogy of SCR

The four-layer SCR can be modelled as **two transistors** connected in a **positive feedback loop** (regenerative action).

Equivalent circuit:



How the two-transistor model explains SCR behavior:

1. **OFF state (Forward blocking)**
   - No gate current → both transistors are in cut-off.
   - Very small leakage current flows (≈ μA).
   - SCR blocks forward voltage like a reverse-biased diode.
2. **Triggering / Turn-ON**
   - Apply a small positive **gate current Ig** into P2 layer.
   - This forward-biases the base-emitter junction of **Q2 (NPN)**.
   - Q2 starts conducting → its collector current becomes base current for **Q1 (PNP)**.
   - Q1 starts conducting → its collector current becomes additional base current for Q2. → This creates a **strong positive feedback loop** (regeneration).
   - Very quickly both transistors saturate → SCR turns fully ON.
   - Anode current becomes very large and is now limited only by the external circuit.
3. **Latching** Once triggered, the regenerative feedback keeps both transistors ON **even if gate current is removed**. → SCR remains in ON state (latched) until anode current drops below **holding current (IH)**.
4. **Turn-OFF**
   - Reduce anode current below **holding current** (by reducing load or reversing voltage).
   - Both transistors come out of saturation → regenerative action stops → SCR turns OFF.

Summary – One-liner explanation of two-transistor analogy

The SCR behaves like a **PNP and NPN transistor** connected in such a way that the collector current of one supplies the base current of the other — creating a **latching regenerative action** that turns the device ON with a small gate pulse and keeps it ON until the main current is interrupted.

2. Describe types, working, and characteristics of SCR.

Ans- The Silicon Controlled Rectifier (SCR) is a four-layer semiconductor device that acts as a controlled switch. It is a member of the Thyristor family and is widely used in power electronics for high-power switching and motor control.

1. Structure and Types

The SCR is a p-n-p-n device with three junctions (J_1, J_2, and J3) and three terminals: Anode (A), Cathode (K), and Gate (G).

Common Types:

- Planar Type: Used for low-power SCRs, integrated into circuits.
- Mesa Type: Used for medium to high power, providing better heat dissipation.
- Press-fit / Stud Type: Designed for very high-power industrial applications, easily mounted on heat sinks.
- Disk/Puck Type: Used in massive industrial converters for maximum cooling from both sides.

2. Working Principle

The SCR operates in three distinct modes based on the biasing and gate signal:

- Forward Blocking Mode: The Anode is positive relative to the Cathode, but no signal is applied to the Gate. Junctions J_1 and J_3 are forward-biased, but J_2 is reverse-biased, preventing current flow (except for a tiny leakage current).
- Forward Conduction Mode (Triggering): When a positive pulse is applied to the Gate, it injects charges into the J_2 junction, breaking it down. The SCR "fires" and becomes a conductor. Once it starts conducting, the Gate loses control—the SCR stays ON even if the gate signal is removed.
- Reverse Blocking Mode: The Anode is negative relative to the Cathode. All junctions block current, and the SCR acts as an open switch, similar to a reverse-biased diode.

3. V-I Characteristics

The characteristic curve of an SCR defines its behavior under different electrical conditions.

- Latching Current (I_L): The minimum anode current required to transition the SCR from the OFF state to the ON state and keep it there after the gate pulse is removed.
- Holding Current (I_H): The minimum anode current required to maintain the SCR in the ON state. If the current drops below this level, the SCR turns OFF.
- Forward Break over Voltage (V_{BO}): The voltage at which the SCR will start conducting even without a gate signal (this can damage the device if not controlled).

3. Discuss GTO and its V-I characteristics.

Ans- Gate Turn-Off Thyristor (GTO)

The Gate Turn-Off Thyristor (GTO) is a high-power semiconductor device that belongs to the thyristor family. Unlike the conventional SCR, the GTO can be turned on and turned off by applying appropriate gate signals, making it more controllable in DC and forced-commutated applications.

Key Features of GTO

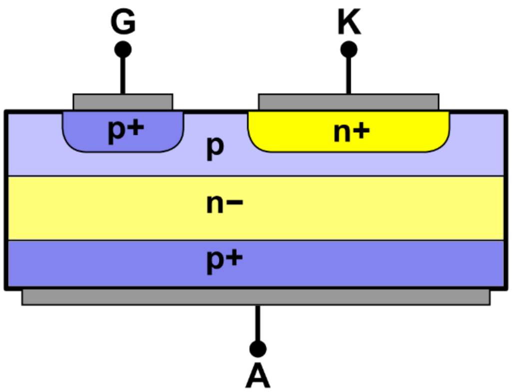
- Four-layer PNPN structure (similar to SCR)
- Gate-controlled turn-on and gate-controlled turn-off
- High voltage and current ratings (typically 600 V – 6000 V, 100 A – 4000 A)
- Used in high-power applications where forced commutation is required

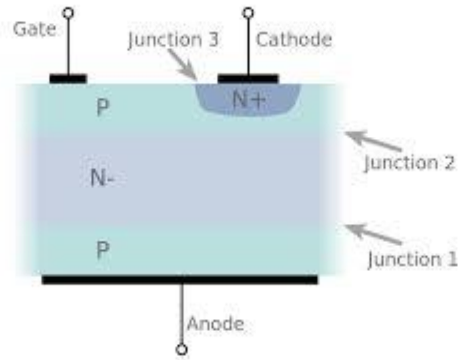
Construction (Simplified Cross-Section)

The GTO has a modified structure compared to standard SCR to enable gate turn-off:

- Anode → P^+ layer (heavily doped)
- n^- drift region → lightly doped (supports high voltage)
- p-base → divided into many small segments
- n^+ cathode → heavily doped, segmented into many small emitter fingers
- Gate → connected to the p-base regions between cathode segments

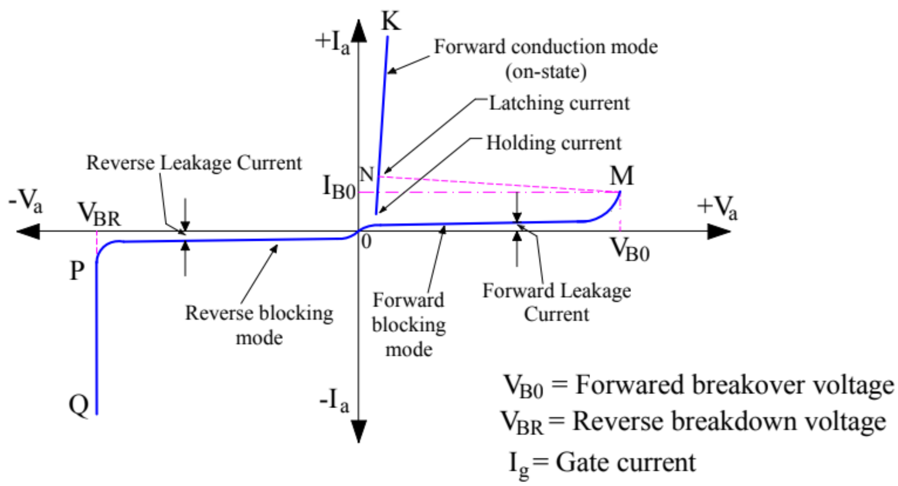
The key modification is the interdigitated cathode-gate structure — many tiny cathode islands surrounded by gate regions. This allows negative gate current to extract carriers from the p-base and break the regenerative action.





V-I Characteristics of GTO

The V-I (voltage-current) characteristic curve of a GTO is similar to that of an SCR in the **forward conduction** and **blocking** regions, but with important differences due to gate turn-off capability.

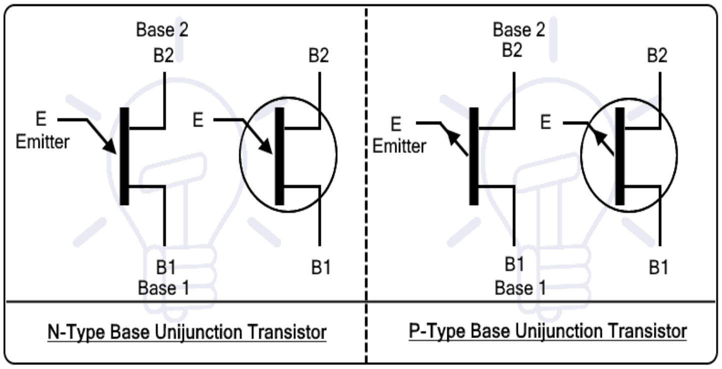


Main Regions of V-I Characteristics

Region	Description	Key Points / Parameters
Reverse Blocking	Anode negative w.r.t. cathode	Blocks voltage up to VRRM (similar to SCR)
Forward Blocking	Anode positive, no gate signal	High impedance, leakage current only, up to VDRM
Forward Breakover	Very high forward voltage without gate trigger	Turns on uncontrollably at VBO (avoid this mode)
Forward Conduction (ON)	After positive gate pulse (turn-on)	Low on-state voltage drop (VT ≈ 1.5–3 V)
Turn-Off Region	Negative gate current applied (Ig negative)	Current falls to zero — unique to GTO
Holding / Latching	Minimum current to keep device ON after gate signal removed	IH (holding) and IL (latching) current

4. Explain UJT and PUT with symbols and principles.

Ans- 1. UJT (Unijunction Transistor)



Terminals: E (Emitter), B1 (Base 1), B2 (Base 2)

- B1 and B2 are the two base terminals; E is the single emitter.

Basic Construction

- A lightly doped N-type silicon bar acts as the base region.
- Two ohmic contacts at the ends → B1 and B2.
- A heavily doped P-type region is alloyed or diffused near one end (closer to B2) → this forms the emitter (E) junction.
- The emitter junction divides the N-bar into two parts with different resistances.

Principle of Operation – Negative Resistance Characteristic

The UJT exhibits a negative resistance region, which makes it useful for triggering and oscillator circuits.

Key parameter – Intrinsic Stand-off Ratio (η) $\eta = R_{B1} / (R_{B1} + R_{B2})$ Typical value: 0.4 to 0.8

Operating regions:

Region	Condition	Behavior	Emitter Current
Cut-off	$V_E < V_p$ (peak voltage)	Very small leakage current (reverse biased junction)	≈ 0
Negative Resistance	$V_E = V_p$ to V_V (valley voltage)	As VE increases slightly, IE increases sharply (negative slope)	Increasing
Saturation / ON	$V_E < V_V$ (after valley point)	Low resistance, emitter-base junction forward biased strongly	High

How negative resistance occurs:

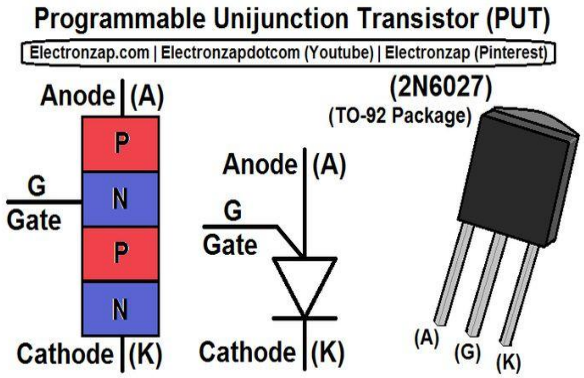
1. Initially, emitter junction is reverse biased → only leakage current.
2. When VE reaches Vp (peak point), emitter junction becomes forward biased.
3. Holes are injected from P-emitter into N-base → they move toward B1.
4. This hole injection reduces the resistance between E and B1 (modulation effect).
5. More current flows → further reduction in resistance → snap action (negative resistance region).
6. After valley point (VV), device behaves like a saturated low-resistance path.

Main Parameters

- Peak voltage (V_p) ≈ $\eta \times V_{BB} + 0.7$ V
- Valley voltage (V_V) ≈ 1–3 V
- Peak current (I_p), Valley current (I_v)
- Interbase resistance ($R_{BB} = R_{B1} + R_{B2}$) ≈ 4–12 Kohm

2. PUT (Programmable Unijunction Transistor)

Symbol



- Terminals: Anode (A), Cathode (K), Gate (G)

Basic Construction

PUT is essentially a four-layer PNPN device (similar to SCR), but designed to behave like a UJT. It has:

- Anode (P-type)
- N-base
- P-gate region
- Cathode (N-type)

The gate terminal allows external control of the triggering voltage.

Principle of Operation

PUT combines SCR-like structure with UJT-like negative resistance behavior.

Key feature: The gate terminal is used to program the peak voltage (Vp) at which the device triggers.

Operating principle:

1. A resistor divider (R1 and R2) is connected to the gate.
2. The voltage at gate sets the effective triggering level.
3. When anode voltage VA exceeds the gate-set threshold (Vp), the device triggers into the negative resistance region.
4. After triggering, it conducts heavily between anode and cathode (low voltage drop ~1 V).
5. It remains ON until anode current falls below holding current.

Programmable aspect: Vp ≈ VG + 0.7 V (where VG is the voltage set at the gate by external resistors)

Comparison: UJT vs PUT

Feature	UJT	PUT
Terminals	E, B1, B2	Anode, Cathode, Gate
Triggering control	Fixed (determined by η)	Programmable via gate voltage
Structure	Single N-bar + P-emitter	Four-layer PNPN device
Symbol similarity	UJT symbol	Looks like small SCR with gate
Peak voltage (Vp)	Fixed by construction (η × VBB)	Adjustable by external resistors
Typical use	Relaxation oscillator	Precision timing, triggering circuits
Negative resistance	Yes	Yes
Temperature stability	Poor	Better (gate control helps)

Summary

- UJT → Classic negative resistance device with fixed trigger point → widely used in simple oscillators and triggering SCRs/triacs.
- PUT → Modern, programmable version → offers better control and stability → used where precise and adjustable triggering is needed.

6. Describe over-current and snubber protection circuits for thyristors.

Ans- A. Over-Current Protection for Thyristors

- Purpose
    - Protects thyristor from damage due to excessive current
    - Prevents destruction from short-circuits, inrush currents, or faults

- Why thyristors are vulnerable
    - Once turned on, on-state resistance is very low
    - Can carry extremely high current in microseconds
    - Thermal runaway occurs very quickly if current is excessive
- Main over-current protection methods

1. Fast-acting semiconductor fuses
    - Most important and fastest protection
    - Types: aR (ultra-fast) or gR class fuses
    - Response time: few hundred microseconds to few milliseconds
    - Selected based on I^2t rating (must be less than thyristor I^2t)
    - One-time use (sacrificial protection)
2. Current limiting reactors / chokes
    - Series inductor in the line
    - Limits di/dt (rate of rise of current)
    - Reduces peak fault current
    - Helps thyristor and fuse survive longer during fault
3. Circuit breakers (MCCB / ACB)
    - Used for overload and sustained faults
    - Magnetic trip for short-circuit protection
    - Response time: 10–50 ms (slower than fuse)
    - Resettable and reusable
4. Electronic over-current detection + crowbar
    - Current transformer (CT) senses current
    - Comparator detects over-current
    - Triggers auxiliary SCR (crowbar) to short the supply
    - Very fast (microseconds to milliseconds)
    - Protects thyristor and load
5. Over-current relays
    - Used for long-time overload protection
    - Operates contactor or breaker
    - Slow response (50–200 ms)
    - Not suitable for short-circuit protection

- Typical practical combination (high-power systems)
    - Fast-acting semiconductor fuse (primary short-circuit protection)
    - Current limiting reactor (di/dt control)
    - Over-current relay (overload protection)

B. Snubber Protection Circuits for Thyristors

- Purpose
    - Protects against unwanted triggering due to high dv/dt
    - Suppresses voltage transients and spikes
    - Improves turn-off performance (especially in GTO, fast thyristors)
- Why snubber is needed
    - High dv/dt → capacitive current through junction capacitance → false triggering
    - Inductive load switching → high voltage spikes → can exceed VDRM/VRRM
    - During turn-off → high dv/dt can cause retriggering
- Main types of snubber circuits

1. RC Snubber (most common)
    - Resistor (R) and capacitor (C) connected in series
    - Placed across anode-cathode of thyristor
    - Limits dv/dt
    - Absorbs energy from transients
    - Typical values: C = 0.1–1 μF, R = 10–100 Ω
2. RCD Snubber
    - RC snubber + fast recovery diode in parallel with R
    - Diode allows fast discharge of C during turn-on
    - Better for highly inductive loads
    - Reduces power loss in resistor
3. MOV + RC Snubber combination
    - Metal Oxide Varistor (MOV) connected across thyristor
    - Clamps voltage spikes to safe level

- RC snubber handles dv/dt
- MOV rating ≈ 1.5 × normal peak working voltage

4. Static dv/dt Snubber
    - Only capacitor (sometimes with small resistor)
    - Used when very high dv/dt protection is required
    - Simple but less effective for high-energy transients

- Basic RC Snubber placement
    - Connected directly across the thyristor terminals (A–K)
    - Sometimes one snubber per thyristor in series/parallel arrangements
- Snubber design considerations
    - Capacitor voltage rating > 2 × working voltage
    - Resistor power rating sufficient to handle discharge energy
    - C ≈ 0.5–2 × junction capacitance of thyristor
    - R ≈ √(L/C) for critical damping (L = load inductance)

10 Marks Questions

1. **With diagrams, explain the construction, working, V-I characteristics of SCR.**

Ans-The Silicon Controlled Rectifier (SCR), also known as a Thyristor, is a fundamental power semiconductor device widely used in power electronics for controlling high-power AC and DC circuits. Invented in the late 1950s, the SCR revolutionized power control by providing a reliable, efficient, and compact alternative to mechanical switches and relays. It is essentially a unidirectional switch that can handle voltages up to several thousand volts and currents up to thousands of amperes, making it ideal for applications like motor speed control, lighting dimmers, and high-voltage DC transmission.

An SCR is a four-layer, three-junction, three-terminal device that operates on the principle of regenerative feedback. Once triggered, it "latches" into a conducting state and remains ON until the current through it is reduced below a certain threshold. This latching behavior distinguishes it from transistors like BJTs or MOSFETs, which require continuous control signals. SCRs are fabricated from silicon using diffusion or epitaxial growth techniques, and they come in various packages such as TO-220 for low-power versions or stud-mounted capsules for high-power industrial use.

In the following sections, I'll explain the construction, working principle, and V-I characteristics in detail, supported by diagrams.

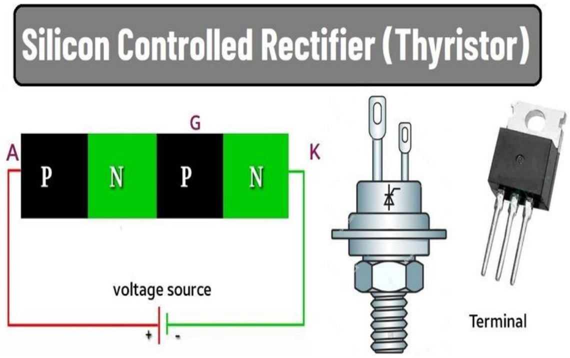
Construction of SCR

The SCR is built as a monolithic structure with four alternating layers of P-type and N-type semiconductor materials, forming three PN junctions (J1, J2, and J3). This PNPN configuration is what gives the SCR its unique switching properties. The layers are doped at different levels to optimize performance:

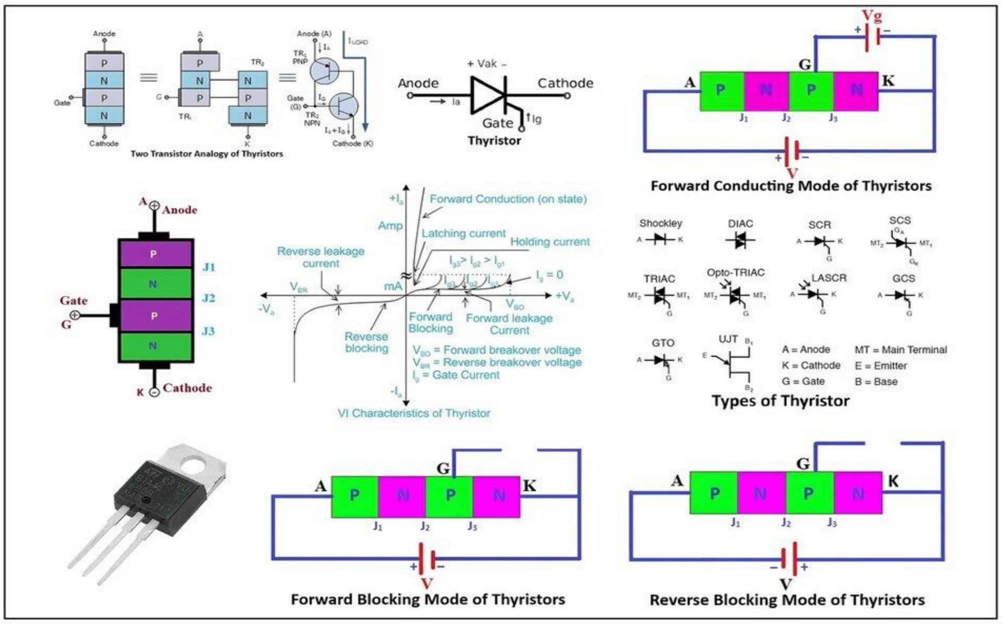
- Anode Layer (P1): Heavily doped P-type material connected to the Anode (A) terminal. This layer serves as the entry point for positive current.
- N-Base Layer (N1): Lightly doped N-type region that supports high blocking voltages. It forms Junction J1 with P1.
- P-Base Layer (P2): Moderately doped P-type layer, which is thin to allow efficient carrier diffusion. The Gate (G) terminal is connected here, and it forms Junction J2 with N1.
- Cathode Layer (N2): Heavily doped N-type material connected to the Cathode (K) terminal. It forms Junction J3 with P2.

The entire structure is typically vertical (planar or mesa type) to handle high currents, with the anode and cathode on opposite sides for better heat dissipation. In high-power SCRs, the silicon wafer is often alloyed with metals like molybdenum for mechanical strength and thermal management. The gate contact is usually a small metal pad on the P2 layer, allowing a low-power signal to control the device.

Here is a detailed construction diagram:

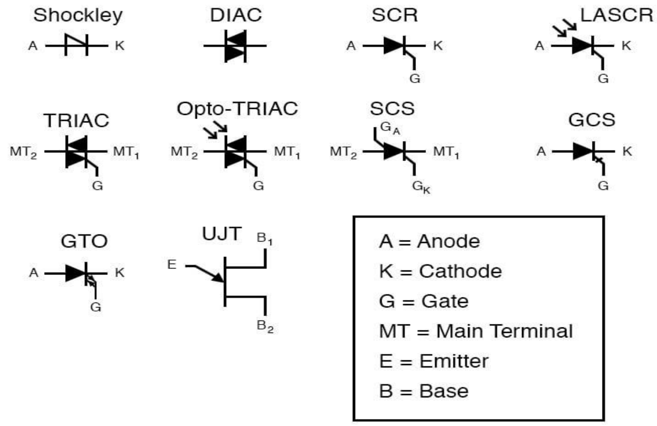


Silicon Controlled Rectifier (SCR): Construction & Working
Another illustrative diagram showing the layered structure and junctions:



2. What is Thyristor? Construction Working and Applications

This construction ensures the SCR can block high voltages in the off-state while conducting large currents with low voltage drop in the on-state. The doping levels are critical: heavy doping in P1 and N2 reduces on-state resistance, while light doping in N1 enhances voltage-blocking capability.
Circuit Symbol of SCR
The standard circuit symbol for an SCR resembles a diode with an additional gate lead, emphasizing its unidirectional nature and gate control. The anode is shown as the arrowhead (positive terminal), the cathode as the bar (negative terminal), and the gate as a line branching from the cathode side. Here is a diagram of the SCR symbol along with related thyristor symbols for context:



The Thyristor | Circuit Schematic Symbols | Electronics Textbook

In schematic diagrams, the symbol is oriented with the anode at the top and cathode at the bottom, with the gate entering from the side. This symbol helps engineers quickly identify the device's polarity and control mechanism.

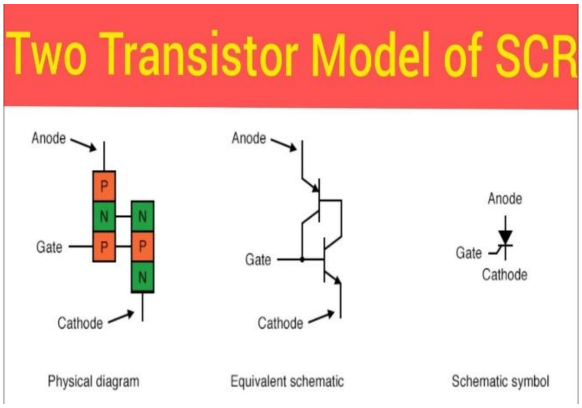
Working Principle of SCR

The working of an SCR is based on the interaction of its three junctions and the regenerative action of minority carriers. It can be understood through the two-transistor analogy, where the PNPN structure is modeled as a PNP transistor (Q1) and an NPN transistor (Q2) connected in a feedback loop.

Two-Transistor Analogy

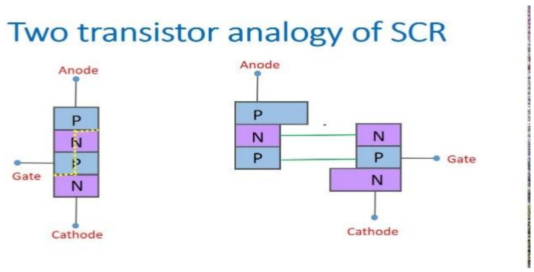
- Q1 (PNP Transistor): Formed by layers P1-N1-P2 (Emitter: P1, Base: N1, Collector: P2).
- Q2 (NPN Transistor): Formed by layers N1-P2-N2 (Emitter: N2, Base: P2, Collector: N1).
- The collector of Q1 drives the base of Q2, and the collector of Q2 drives the base of Q1, creating positive feedback.

Here is a diagram illustrating the two-transistor model:



Two Transistor Model of SCR | Two Transistor Analogy of SCR

Another view of the analogy:



Two Transistor Analogy of Silicon controlled Rectifier (SCR)/ Thyristor

Operating Modes in Detail

1. Reverse Blocking Mode:
   - Anode is negative relative to cathode (V_AK < 0).

- Junctions J1 and J3 are forward-biased, but J2 is reverse-biased.
- The device blocks current, with only a small reverse leakage current (typically μA) flowing.
- If voltage exceeds the reverse breakdown voltage (V_BR), avalanche breakdown occurs, which can damage the device unless protected.

2. Forward Blocking Mode:
    - Anode is positive relative to cathode (V_AK > 0), but no gate signal.
    - Junctions J1 and J3 are reverse-biased, while J2 is forward-biased.
    - Very small forward leakage current flows (α1 + α2 < 1, where α is current gain).
    - The SCR remains OFF, blocking up to its rated forward voltage (V_DRM, typically 400–6500 V).
3. Forward Conduction Mode (Turn-ON):
    - A positive gate pulse (I_G > I_GT, typically 10–200 mA) is applied.
    - This injects holes into P2, forward-biasing J3 and turning on Q2.
    - Q2's collector current becomes Q1's base current, turning on Q1.
    - Feedback loop amplifies: α1 + α2 approaches 1, causing regenerative action.
    - The SCR "latches" ON: voltage drop collapses to ~1–2 V (V_T), and high current flows (up to rated I_T, e.g., 10–2000 A).
    - Once latched, gate signal can be removed; conduction continues as long as current > holding current (I_H, 10–500 mA).
4. Turn-OFF Mechanism:
    - SCR does not turn off via gate (unlike GTO or IGBT).
    - Anode current must drop below I_H (e.g., via natural AC zero-crossing or forced commutation in DC circuits using capacitors/inductors).
    - Turn-off time (t_q) is 10–200 μs, during which stored charges recombine.

Additional triggering methods include high dv/dt (unwanted), temperature, or light (in LASCRs), but gate triggering is preferred for control.

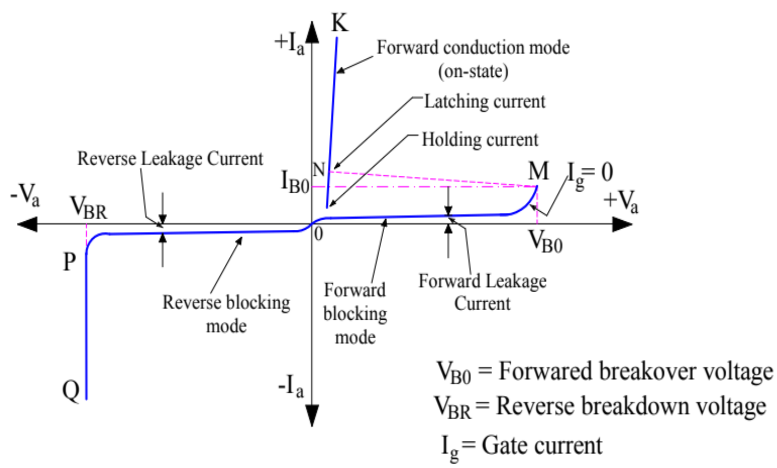
V-I Characteristics of SCR

The V-I (Voltage-Current) characteristics plot anode current (I_A) versus anode-cathode voltage (V_AK), revealing the device's switching behavior. The curve is asymmetric due to the unidirectional design.

Here is a detailed V-I characteristics diagram:

VI Characteristics of SCR - Silicon Controlled Rectifier

Another labelled V-I curve:



V-I Characteristics of SCR Explained with Circuit Diagram...

Key Regions Explained Elaborately

1. Reverse Blocking Region (Quadrant III):
    - V_AK negative, I_A negative (but very small leakage, ~μA).
    - Curve is almost flat until V_BR (reverse breakdown voltage, e.g., -400 V to -6500 V).
    - Beyond V_BR, avalanche occurs, leading to high current and potential damage. Protection like diodes or MOVs is essential.

2. Forward Blocking Region (Quadrant I, low voltage):
    - V_AK positive up to V_BO (forward breakover voltage, slightly above V_DRM).
    - I_A is minimal leakage (~μA to mA).
    - As V_AK increases, leakage rises slightly due to minority carriers.
    - If V_AK > V_BO without gate trigger, uncontrolled turn-on occurs (avoided in practice).
3. Transition/Negative Resistance Region:
    - Upon gate trigger or exceeding V_BO, the curve shows a sharp drop in voltage as current rises.
    - This "negative resistance" is due to regenerative feedback, where increasing current reduces effective resistance.
    - Latching current (I_L, 20–1000 mA) is the point where full latching occurs.
4. Forward Conduction Region:
    - After latching, V_AK drops to V_T (1–2 V), and I_A can be very high.
    - The curve is nearly vertical, indicating low on-state resistance.
    - Holding current (I_H) is the minimum I_A to sustain conduction.
    - Multiple curves for different I_G show that higher gate current lowers V_BO.
5. Other Parameters:
    - dv/dt rating: Max voltage rise rate without false triggering (200–2000 V/μs).
    - di/dt rating: Max current rise rate to avoid local hot spots.
    - Temperature effects: Higher temps reduce V_BO and increase leakage.

Applications, Advantages, and Limitations

Applications:

- AC phase control (e.g., dimmers, heaters).
- Rectifiers and inverters in power supplies.
- Motor drives, HVDC transmission, and welding equipment.
- Protection circuits (crowbar for overvoltage).

Advantages:

- High power handling with low control power.
- Low on-state losses (efficient).
- Rugged and long lifespan.
- Cost-effective for high-voltage apps.

Limitations:

- No gate turn-off (requires commutation).
- Sensitive to dv/dt and temperature.
- Unidirectional (use TRIAC for bidirectional).
- Slower switching than IGBTs (up to 1–10 kHz).

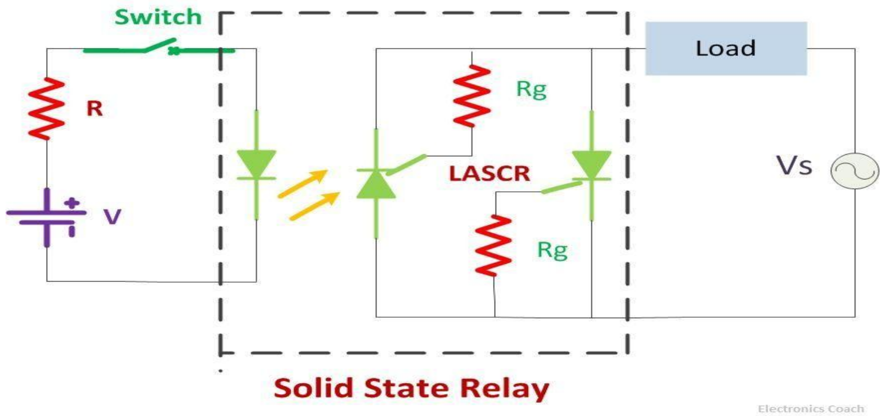
2. **Discuss various thyristor family devices (LASCR, SCS, GTO, UJT, PUT, DIAC, TRIAC) including symbols, principles, and V-I characteristics. Also, explain protection circuits.**

Ans- Thyristor Family Devices

The thyristor family encompasses a group of semiconductor devices based on the basic four-layer PNPN structure of the Silicon Controlled Rectifier (SCR). These devices are widely used in power electronics for switching, control, and protection due to their high voltage and current handling capabilities, low on-state losses, and latching behavior. The family includes variations that offer different triggering mechanisms, bidirectional conduction, or enhanced control features. Below, I discuss each specified device (LASCR, SCS, GTO, UJT, PUT, DIAC, TRIAC) with their symbols, operating principles, and V-I characteristics. Symbols and V-I curves are illustrated with diagrams where available.

1. LASCR (Light-Activated SCR)

- Symbol: The LASCR symbol is similar to an SCR but with an arrow indicating light input to the gate. It has three terminals: Anode (A), Cathode (K), and Gate (G, though often not used as light triggers it).

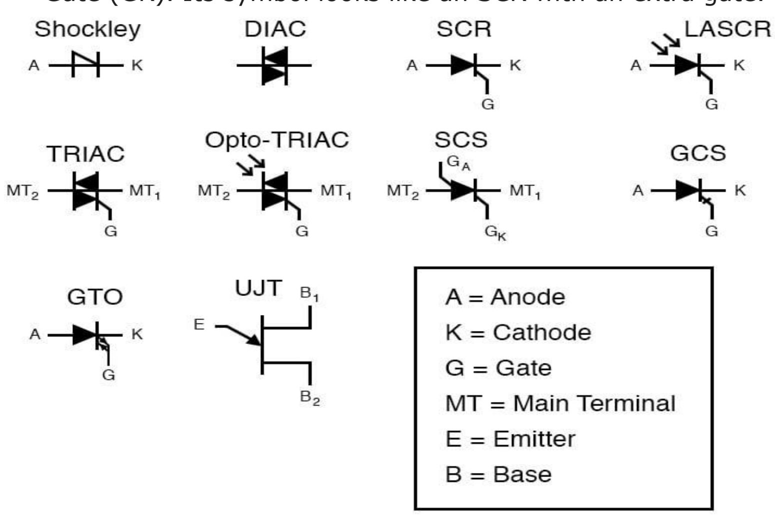


What is Light Activated SCR? - Construction, Working and...
(Note: This diagram shows the LASCR in a circuit context, highlighting its symbol.)

- Principle: LASCR is a photosensitive SCR triggered by light (e.g., from LEDs or lasers) instead of electrical gate current. It has a PNPN structure with a light-sensitive gate region. When light of sufficient intensity (typically infrared) falls on the junction, it generates electron-hole pairs, injecting carriers that initiate regenerative feedback, latching the device ON. Turn-off requires reducing anode current below holding current (IH). It provides electrical isolation between control and power circuits, making it ideal for opto-isolation.
- V-I Characteristics: Similar to SCR, with forward blocking, breakover (reduced by light intensity), and conduction regions. Higher light intensity lowers the breakover voltage (VBO). Reverse blocking shows small leakage.

2. SCS (Silicon Controlled Switch)

- Symbol: The SCS has four terminals: Anode (A), Cathode (K), Anode Gate (GA), and Cathode Gate (GK). Its symbol looks like an SCR with an extra gate.



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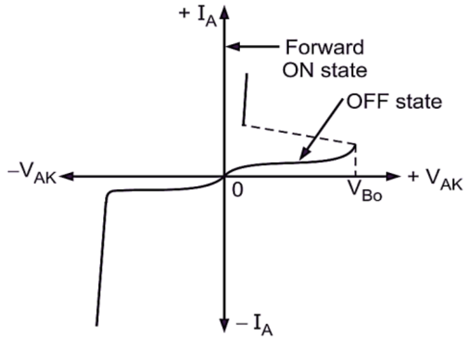
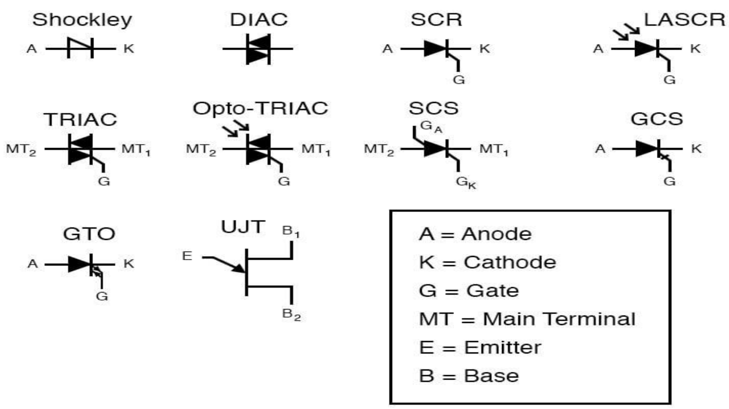
- Principle: SCS is a four-terminal PNPN device that can be turned ON or OFF using either gate. Positive pulse to cathode gate or negative to anode gate turns it ON via regenerative action. For turn-off, reverse the gate pulses to extract carriers and break the latch. It offers more control than standard SCR but has lower power ratings.
- V-I Characteristics: Bidirectional in some views, but typically shows SCR-like forward conduction with latching/holding currents. The curve includes forward/reverse blocking and conduction, with gate control affecting breakover.



What is Silicon Controlled Switch (SCS)? Working, Symbol...

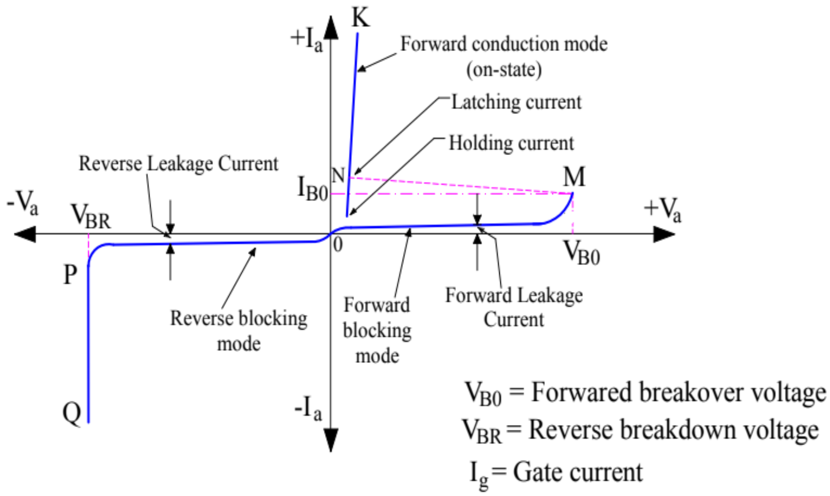
3. GTO (Gate Turn-Off Thyristor)

- Symbol: Similar to SCR, but the gate is often shown with a double arrow or circle to indicate turn-off capability. Terminals: Anode (A), Cathode (K), Gate (G).



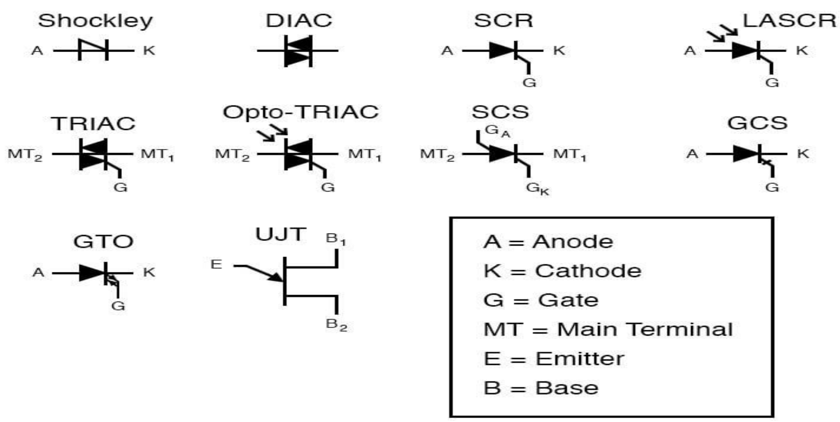
- Principle: GTO is a high-power thyristor with gate-controlled turn-on (positive pulse) and turn-off (strong negative pulse, up to 1/3 of anode current). Its interdigitated structure allows the negative gate current to divert holes from the base, breaking regeneration. It combines SCR's power handling with transistor-like control, though turn-off requires high gate drive power.

- V-I Characteristics: Similar to SCR, with forward blocking, breakover, and low on-state drop (~2-3 V). Unique turn-off region shows current drop to zero upon negative gate application. No quasi-saturation; better safe operating area (SOA).



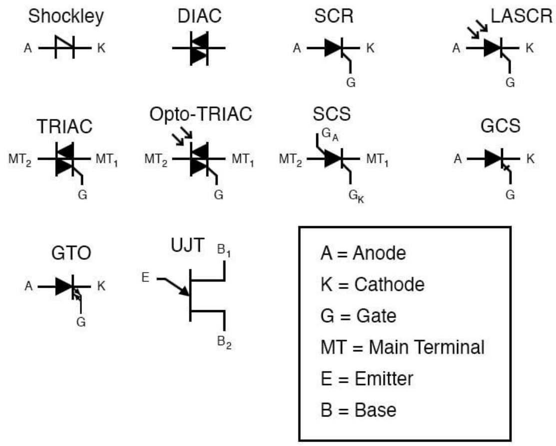
Gate Turn off Thyristor (GTO) Explained - Electrical Concepts
4. UJT (Unijunction Transistor)

- Symbol: Features an emitter (E) arrow pointing to a bar with two bases (B1, B2). It's a three-terminal device.



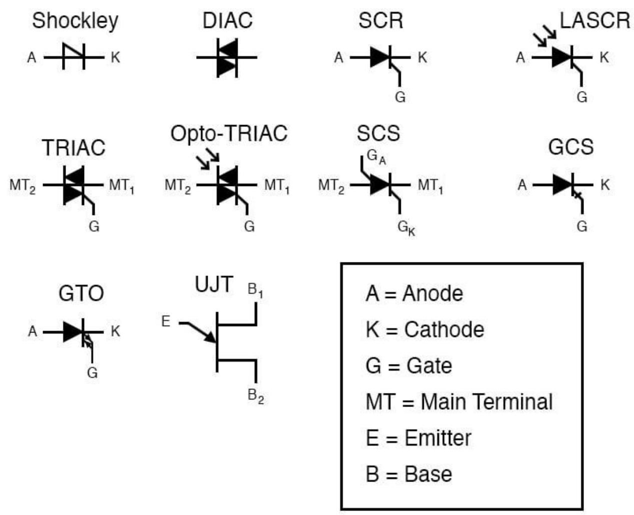
The Thyristor | Circuit Schematic Symbols |
(Included in the thyristor symbols diagram.)

- Principle: UJT is a three-layer NPN device (though called unijunction due to one PN junction). It operates on negative resistance: Voltage at emitter (VE) rises until peak point (Vp = η VBB + 0.7V, η = intrinsic standoff ratio ~0.5-0.8), then holes inject, modulating base resistance and causing a voltage drop (valley point VV). Used for relaxation oscillators and SCR triggering.
- V-I Characteristics: Shows cut-off (low current), negative resistance (sharp drop after Vp), and saturation. Emitter current vs. voltage between emitter and B1.



5. PUT (Programmable Unijunction Transistor)

- Symbol: Resembles a small SCR with terminals: Anode (A), Cathode (K), Gate (G).

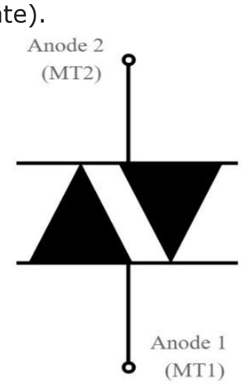


Principle: PUT is a four-layer PNPN device mimicking UJT but with programmable Vp via external gate voltage (Vp ≈ VG + 0.7V). Triggered when anode voltage exceeds gate-set threshold, entering negative resistance. Better stability and adjustability than UJT for timing circuits.

- V-I Characteristics: Negative resistance like UJT, with adjustable peak/valley points based on gate bias. Shows blocking, negative slope, and saturation regions.

6. DIAC (Diode for Alternating Current)

- Symbol: Two back-to-back diodes or a bidirectional trigger diode symbol. Terminals: MT1 and MT2 (no gate).



What Is DIAC? Symbol, Operating Principle, Structure, Uses

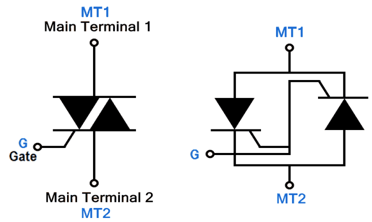
- Principle: DIAC is a bidirectional, gateless thyristor (NPNPN or equivalent two-transistor model). It blocks until voltage exceeds breakover (VBO ~20-40V in either direction), then conducts with low drop until current drops below IH. Used for symmetric triggering of TRIACs in AC circuits.

- V-I Characteristics: Symmetrical S-shaped curve in quadrants I and III. Blocking regions (±VBO) lead to sharp conduction; no latching—turns off at zero current.

Diac Symbol, Construction, VI Characteristics and Applications

7. TRIAC (Triode for Alternating Current)

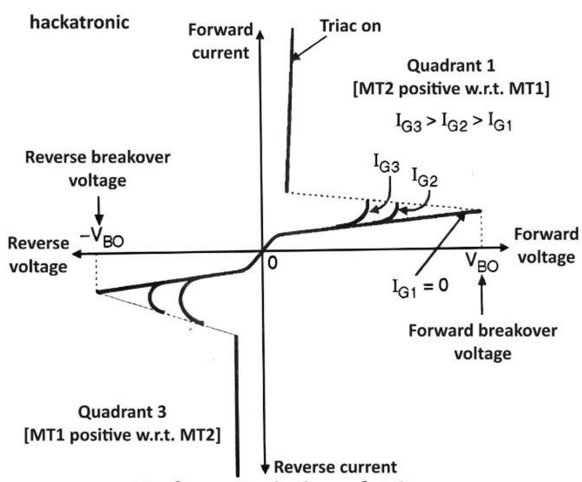
- Symbol: Bidirectional SCR-like with gate. Terminals: MT1, MT2 (main terminals), Gate (G).



TRIAC Symbol

What is TRIAC? Symbol, Construction, Working and Applications

- Principle: TRIAC is two antiparallel SCRs in one package, allowing bidirectional AC conduction. Triggered by gate pulse (positive/negative) in any quadrant, latching ON until current zero-crossing. Sensitive to gate polarity; used for AC power control.
- V-I Characteristics: Symmetrical in quadrants I and III, with breakover voltages and holding currents. Gate current shifts curves; shows blocking, triggering, and conduction in both directions.



VI characteristics of Triac

TRIAC Full Form, Symbol, Working, VI Characteristic & Application

Protection Circuits for Thyristors

Thyristors are sensitive to over-voltage, over-current, high dv/dt, and di/dt. Protection ensures reliability:

1. Over-Current Protection:
   - Fast-Acting Fuses: Melt to open circuit on faults (I^2t matched to device).
   - Current Limiting Reactors: Series inductors limit di/dt.
   - Circuit Breakers/Relays: For overloads; slower but resettable.
2. Over-Voltage/Snubber Protection:
   - RC Snubber: Across device to suppress dv/dt and transients (C=0.1-1μF, R=10-100Ω).
   - RCD Snubber: Adds diode for better energy handling.
   - MOV (Metal Oxide Varistor): Clamps spikes (rated 1.5x operating voltage).
3. dv/dt and di/dt Protection:
   - Snubbers for dv/dt; inductors for di/dt.
   - Gate circuit resistors to prevent false triggering.
4. Thermal Protection:
   - Heat sinks and thermal fuses to prevent overheating.

Unit III: Turn-on and Turn-off Methods of Thyristors

2 Marks Questions

1. What is high voltage thermal triggering of SCR?

ANS-☐ High **Voltage Triggering:** If the forward voltage exceeds the **breakover voltage (V_{BO})**, the junction J_2 collapses due to avalanche breakdown, turning the SCR ON.
☐ Thermal **Triggering:** High temperatures increase the flow of leakage current (minority carriers). When this internal current reaches a critical level, the SCR triggers without a gate signal.

2. Define dv/dt triggering.

ANS- dv/dt triggering occurs when a rapid increase in anode-to-cathode voltage acts on the internal junction capacitance (C_j). This creates a charging current $i = C_j \cdot (dv/dt)$. If this current is high enough, it triggers the SCR.

3. What is gate triggering?

ANS- Gate triggering is the process of turning an SCR ON by applying a positive pulse to the **Gate** terminal relative to the Cathode. This is the most reliable and common method used in power control.

4. Explain resistance gate trigger circuit.

ANS- This circuit uses a variable resistor to control the gate current. It is simple and inexpensive but is limited to a firing angle (alpha) range of **0° to 90°** because the trigger signal is in phase with the anode voltage.

5. What is UJT triggering?

ANS- UJT (Uni-Junction Transistor) triggering uses the device as a **relaxation oscillator** to generate sharp, consistent pulses. It provides a wide firing angle range (0° to 180°) and is highly stable against temperature changes.

6. Describe PUT relaxation oscillator.

ANS- A **Programmable Uni-Junction Transistor (PUT)** functions as an oscillator where a capacitor charges through a resistor and discharges through the PUT once the "programmed" peak voltage is reached. This creates the periodic pulses needed for SCR triggering.

7. What is opto-coupler based triggering?

ANS- This method uses light to trigger a thyristor. An LED in the control circuit sends light to a photo-thyristor. It provides **galvanic isolation**, ensuring that high-voltage power surges do not damage low-voltage control electronics.

8. Define Class A commutation.

ANS- Also called **Self or Load Commutation**, it uses an L-C resonant circuit. The current naturally oscillates and drops to zero, allowing the SCR to turn off. It is typically used in high-frequency applications.

9. What is natural commutation?

ANS- Natural commutation occurs in **AC circuits** where the supply voltage periodically reverses. When the AC cycle passes through zero and becomes negative, the SCR is naturally reverse-biased and turns off without extra circuitry.

10. Explain Class C commutation.

ANS- Also known as **Complementary Commutation**, it uses two SCRs (Main and Auxiliary) and a capacitor. Turning ON the auxiliary SCR uses the capacitor's stored energy to apply a reverse voltage to the main SCR, forcing it OFF.

5 Marks Questions

1. Explain SCR turn-on methods: thermal, illumination, dv/dt, gate.

Ans-**SCR Turn-on Methods**

An SCR can be turned on (triggered into conduction) by several mechanisms. The most commonly used and controlled method is **gate triggering**, while the others are usually **unwanted** or **parasitic** except in special-purpose devices.

No.	Turn-on Method	Principle / Mechanism	Controlled / Uncontrolled	Typical Use / Situation	Advantages / Disadvantages
1	**Gate Triggering**	Applying a positive gate current or voltage pulse	**Controlled**	Almost all practical SCR applications	Precise, reliable, widely used
2	**Thermal Triggering**	Excessive junction temperature reduces forward breakover voltage	**Uncontrolled**	Fault condition, overheating	Dangerous – usually leads to failure
3	**Illumination / Light Triggering**	Light (photon) generates electron-hole pairs in the gate region	**Controlled** (in LASCR) **Uncontrolled** (in normal SCR)	LASCR, optical triggering circuits	Provides electrical isolation (in LASCR)
4	**dv/dt Triggering**	High rate of rise of forward voltage causes capacitive current through junction J2	**Uncontrolled**	Inductive loads, sudden voltage application	Most common unwanted triggering cause – prevented by snubber

1. Gate Triggering (Most Important & Controlled Method)

Principle A small positive current (IGT) or voltage pulse is applied to the gate terminal relative to the cathode. This current injects holes into the P-base layer → forward biases the cathode junction → initiates regenerative feedback between the internal PNP and NPN transistors → SCR latches ON.

Key parameters

- Gate trigger current (IGT): typically 10 mA – 200 mA (depends on device rating)
- Gate trigger voltage (VGT): 0.8 V – 3 V
- Gate power: very low compared to load power (high gain)

Triggering modes (quadrants for AC control)

- Positive gate current with positive anode voltage (most common)
- Also possible in other quadrants for special cases (e.g., sensitive gate devices)

Advantages

- Precise control of turn-on instant
- Low control power
- Allows phase control in AC circuits

Applications Phase-controlled rectifiers, motor speed control, light dimmers, battery chargers, HVDC, etc.

2. Thermal Triggering (Over-temperature Triggering)

Principle As junction temperature increases: → Leakage current increases exponentially → Current gain (α) of internal transistors increases → Forward breakover voltage (VBO) decreases significantly → When temperature is high enough, VBO falls below the applied forward voltage → SCR turns on without any gate signal

Typical behavior

- At 25°C: VBO ≈ rated VDRM
- At 125–150°C: VBO may drop to 50–70% of rated value
- Above ~150–175°C: uncontrolled turn-on becomes very likely

Consequence This is almost always **destructive** because the device turns on under fault conditions without proper control or cooling.

Protection

- Heat sinks
- Thermal cut-outs / sensors
- Current limiting
- Proper derating of voltage and current ratings

3. Illumination / Light Triggering

Principle Light (usually infrared or visible) incident on the gate region or junction J2 generates electron-hole pairs (photo-generation). These carriers act like a small gate current → initiate regenerative action → SCR turns ON.

Two cases

- **Normal power SCR**: Very sensitive to stray light → must be kept in opaque package. Light can cause unwanted triggering.
- **LASCR (Light Activated SCR)**: Specially designed with transparent window → intentionally triggered by controlled light source (LED, laser, optical fiber).

Advantages of LASCR

- Complete electrical isolation between control and power circuit
- Immune to electrical noise
- Useful in high-voltage or hazardous environments

Disadvantages

- Lower power ratings than normal SCR
- Sensitive to ambient light (needs shielding)

4. dv/dt Triggering (Rate of Rise of Voltage Triggering)

Principle When a high rate of rise of forward voltage (dv/dt) is applied across the SCR in the off state: → The middle junction J2 (which is reverse biased) has junction capacitance Cj → Capacitive current = Cj × dv/dt flows through the device → This current acts like a small gate current → can trigger the regenerative action → SCR turns ON without any gate pulse

Critical dv/dt rating Typical values: 200 V/μs to 2000 V/μs (depends on device) Modern power SCRs usually have 1000 V/μs or higher.

Common situations where dv/dt triggering occurs

- Switching inductive loads
- Sudden application of voltage after zero-crossing in AC circuits
- Commutation in inverters/choppers
- Voltage transients / spikes

Protection against dv/dt triggering

- **RC snubber circuit** across the SCR
    - Capacitor slows down dv/dt
    - Resistor damps oscillations and limits discharge current
- Typical values: C = 0.1–1 μF, R = 10–100 Ω
- Sometimes combined with MOV for voltage clamping
-

2. Describe gate trigger circuits: R and RC.

Ans- **. R Triggering Circuit (Resistance Firing Circuit)**

The R triggering circuit is the simplest and most basic method to trigger an SCR using the gate.

Circuit Description

In this circuit, the gate of the SCR is connected to the anode through a current-limiting resistor (R) and a potentiometer (variable resistor) in series. The load (resistive or inductive) is connected in series with the SCR across the AC or DC supply.

Typical components:

- R = fixed resistor (to limit maximum gate current)
- Potentiometer (variable resistor) — used to adjust the firing angle
- Sometimes a small fixed resistor in series with the gate to protect it

Working Principle

- During the positive half-cycle of the AC supply (when anode is positive with respect to cathode), a small current flows from the anode → through the potentiometer and resistor → to the gate → cathode.
- This current is the **gate current (IG)**.

- When the gate current reaches the gate trigger current (IGT) of the SCR, the device turns ON.
- The potentiometer controls the value of the resistance in the gate path → which controls how early or late in the positive half-cycle the gate current reaches IGT.
- If the resistance is low → gate current rises quickly → SCR fires early in the half-cycle (small firing angle α).
- If the resistance is high → gate current rises slowly → SCR fires late in the half-cycle (large firing angle α).

Key Features

- Very simple circuit — only resistors and potentiometer
- Provides phase control from nearly 0° to about 90° (in AC circuits)
- Cannot provide firing beyond 90° because after 90°, the supply voltage starts decreasing and may not provide enough gate current
- Suitable for low-power resistive loads
- Gate current is in phase with the anode voltage

Advantages

- Extremely simple and inexpensive
- Few components
- Easy to understand and implement

Disadvantages

- Limited control range (typically up to ~90° firing angle)
- No isolation between control circuit and power circuit
- Not suitable for inductive loads or applications requiring wide range of phase control

2. RC Triggering Circuit (Resistance-Capacitance Firing Circuit)

The RC triggering circuit is a more versatile and widely used method that extends the firing angle range significantly compared to simple R triggering.

Circuit Description

The gate of the SCR is connected to a parallel combination of resistor (R) and capacitor (C). This RC combination is then connected through a current-limiting resistor (R1) to the anode side of the SCR. A variable resistor (potentiometer) is often used in series with the capacitor or as part of the charging path to control the firing angle.

Typical configuration:

- A capacitor C is charged through a resistor or potentiometer from the supply
- When the voltage across C reaches a value sufficient to forward-bias the gate-cathode junction and provide enough current, the SCR triggers

Working Principle

- During the positive half-cycle, the capacitor C starts charging through the resistor (or potentiometer) from the supply voltage.
- The charging rate of the capacitor depends on the RC time constant.
- As the capacitor voltage rises, it applies a voltage to the gate.
- When the gate-cathode voltage reaches the gate trigger voltage (VGT) and the gate current reaches IGT, the SCR turns ON.
- The variable resistor (potentiometer) controls the charging rate of the capacitor → which controls the time taken for the gate voltage to reach the triggering level → thus controlling the firing angle.
- Because the capacitor voltage lags behind the supply voltage (due to charging), this circuit can provide firing angles from nearly 0° up to almost 180°.

3. **Discuss SCR triggering using UJT and synchronized UJT.**

Ans- **SCR Triggering Using UJT**

- UJT acts as a relaxation oscillator to generate gate pulses for SCR.
- Capacitor C charges through variable resistor Rv.
- When emitter voltage reaches peak point Vp ($\approx \eta \times V_{BB} + 0.7$ V), UJT turns on.
- Capacitor discharges quickly through B1, creating a sharp pulse across resistor R1.
- This pulse triggers the SCR gate.
- Firing angle is controlled by adjusting Rv (small Rv → early firing, large Rv → late firing).

- Simple, low-cost, good for medium-power control.
- Limitation: not synchronized with AC supply.

Synchronized UJT Triggering

- Adds synchronization with AC line zero-crossing.
- Uses a diode across capacitor C to discharge/reset it every negative half-cycle.
- Charging always starts from zero at the beginning of each positive half-cycle.
- Firing angle remains stable even if supply voltage or frequency varies slightly.
- Control range: ~0° to nearly 180°.
- Better for inductive loads and precise phase control.
- Slightly more components (rectifier diodes + sync diode).
- Still analog, low-cost, and reliable for many AC applications.

Basic UJT → simple but can drift **Synchronized UJT** → stable and accurate phase control

4**. Explain pulse transformer and opto-coupler triggering**.

Ans -**Pulse Transformer Triggering**

- Small transformer with primary and secondary windings.
- Primary connected to control circuit (UJT, IC, etc.).
- Secondary connected directly to SCR gate and cathode.
- Sends a sharp, strong current pulse to the gate.
- Provides high electrical isolation (kV level).
- Protects control side from high-voltage power side.
- Used in high-power systems (inverters, drives, HVDC).
- Reliable but more expensive and slightly larger.

Opto-Coupler Triggering

- Uses light to transfer signal (LED + photo-device).
- Input: low current drives LED (from microcontroller, IC).
- Output: photo-triac, photo-SCR or transistor turns on.
- Triggers the main SCR gate.
- Gives good isolation (5–7.5 kV typical).
- Small size, low cost, easy for digital control.
- Common in light dimmers, fan regulators, appliances.
- Limited gate current → best for low/medium power.

Quick summary

- Pulse transformer → high power, strong pulse, industrial use
- Opto-coupler → low-cost, digital-friendly, smaller applications

5. Describe Class A and Class B turn-off methods with circuits.

Ans-**Class A Turn-Off (Self-Commutation by Resonating Load)**

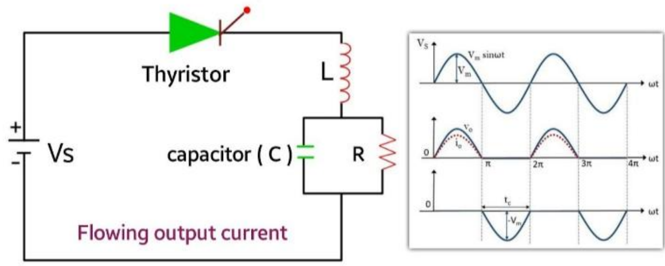
Description Class A commutation is **self-commutation** using a resonating load (usually an L-C circuit). The load itself causes the current through the SCR to become zero naturally, allowing the SCR to turn off.

Key Features

- Uses series resonant circuit (inductor L and capacitor C in series with the load).
- The current waveform is sinusoidal and naturally goes to zero.
- The SCR turns off automatically when current reverses or becomes zero.
- No external commutation circuit is needed.

Basic Circuit

Class-A Commutation of Thyristor



- Circuit diagram of class A - commutation

Working

1. When SCR is triggered, current starts flowing through L, R, C.
2. Due to L and C, the circuit is resonant → current rises sinusoidally.
3. After half-cycle of resonance, current naturally reverses or becomes zero.
4. When current tries to reverse, SCR blocks it (SCR is unidirectional).
5. Current through SCR becomes zero → SCR turns off.
6. Capacitor voltage then appears across SCR in reverse direction, helping recovery.

Applications

- High-frequency inverters
- Series resonant converters
- Some DC chopper circuits

Advantages

- Simple — no extra components for commutation
- Natural turn-off

Limitations

- Load must be highly inductive or resonant
- Limited control over turn-off instant
- Not suitable for wide range of loads

Class B Turn-Off (Self-Commutation by LC Circuit)

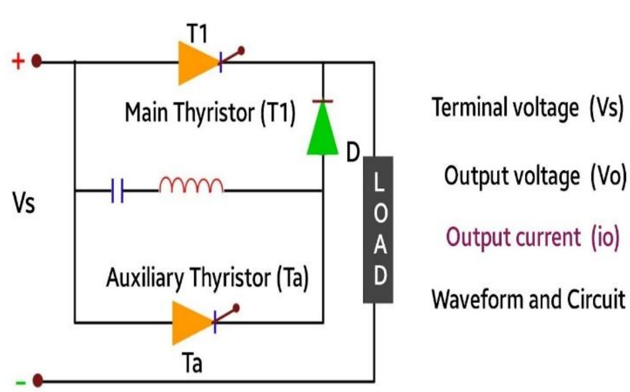
Description Class B commutation uses an **auxiliary LC circuit** connected across the SCR to force the current through the SCR to zero. It is also a type of **self-commutation**, but with an external resonant circuit.

Key Features

- Uses a pre-charged capacitor and an inductor.
- When the commutating capacitor is discharged, it sends a reverse current pulse through the SCR.
- This reverse current forces the main SCR current to zero → SCR turns off.

Basic Circuit

Class-B Commutation of Thyristor



Working

1. Capacitor C is pre-charged (with polarity such that positive plate is connected to anode side).
2. When SCR is already conducting load current.
3. To turn off: the LC circuit is triggered (either by auxiliary SCR or by design).
4. The capacitor discharges through L and SCR → produces a sinusoidal current pulse in reverse direction.
5. This reverse current opposes and cancels the main load current through SCR.
6. When net current through SCR becomes zero → SCR turns off.
7. After turn-off, capacitor recharges in opposite direction through load or supply.

Applications

- DC motor control choppers
- Some low-power inverters
- Pulse circuits

Advantages

- Simple resonant commutation
- No external power supply needed for commutation

Limitations

- Capacitor must be pre-charged
- Limited to lower power levels
- Turn-off time depends on LC values

Quick Summary

- **Class A** — Load itself is resonant → current naturally goes to zero
- **Class B** — External LC circuit forces reverse current → forces SCR current to zero

10 <u>Marks Questions</u>

1. Explain all SCR turn-on methods and gate trigger circuits including UJT, PUT, pulse transformer, and opto-coupler.

Ans- **SCR Turn-On Methods**

Silicon Controlled Rectifiers (SCRs) can be turned on through four primary methods: gate triggering, thermal triggering, illumination triggering, and dv/dt triggering. Each method initiates the regenerative feedback in the SCR's PNPN structure, latching it into conduction until the anode current drops below the holding current.

1. **Gate Triggering**: This is the most controlled and common method. A positive current or voltage pulse (typically 10-200 mA at 0.8-3 V) is applied to the gate relative to the cathode, injecting holes into the P-base layer. This forward-biases the cathode junction, starting the internal PNP-NPN feedback loop, and the SCR latches ON. It allows precise phase control in AC circuits and requires low power. Advantages include reliability and timing accuracy; it's used in nearly all applications like dimmers and motor drives.
2. **Thermal Triggering**: This uncontrolled method occurs when excessive junction temperature (often above 125-150°C) increases leakage current and transistor gains, reducing the forward breakover voltage (VBO). If VBO drops below the applied voltage, the SCR turns ON without a gate signal. It's destructive and avoided through heat sinks and derating, as it signals overheating faults.
3. **Illumination (Light) Triggering**: Light incident on the gate or middle junction generates electron-hole pairs via the photoelectric effect, mimicking gate current and triggering the SCR. In standard SCRs, it's unwanted (requiring opaque packaging), but in Light-Activated SCRs (LASCRs), it's intentional for optical control, providing electrical isolation. It's useful in high-voltage or noisy environments but sensitive to ambient light.
4. **dv/dt Triggering**: A high rate of rise of forward voltage (exceeding 200-2000 V/μs) induces capacitive current through the reverse-biased middle junction ($I = C_j \times dv/dt$), acting as internal gate current and causing unwanted turn-on. Common in inductive loads or transients, it's prevented by RC snubber circuits across the SCR to slow voltage rise.

Gate Trigger Circuits

Gate trigger circuits generate the necessary pulse or current for controlled SCR turn-on. Below are the key types, including UJT, PUT, pulse transformer, and opto-coupler.

1. **R (Resistance) Triggering Circuit**: The simplest setup connects the gate to the anode via a fixed resistor and potentiometer. During the positive AC half-cycle, gate current flows through the resistors. Adjusting the potentiometer controls the firing angle (up to ~90°). It's inexpensive for resistive loads but limited in range and unsuitable for inductive ones.
2. **RC (Resistance-Capacitance) Triggering Circuit**: Adds a capacitor in parallel with a resistor, creating a phase shift. The capacitor charges through a potentiometer, and its voltage triggers the gate when it reaches VGT. This extends the firing angle to nearly 180°, making it versatile for both resistive and inductive loads like fan regulators. It's low-cost but sensitive to supply variations.
3. **UJT (Unijunction Transistor) Triggering Circuit**: UJT acts as a relaxation oscillator. A capacitor charges through a variable resistor until the emitter voltage hits the peak point ($V_p = \eta \times V_{BB} + 0.7$ V), discharging rapidly to create a sharp pulse across a base resistor. This pulse triggers the SCR gate. Basic UJT offers simple control but lacks AC synchronization; synchronized UJT adds a diode to reset the capacitor at zero-crossings, ensuring stable firing (0°-180°) even with supply fluctuations. It's reliable for medium-power phase control.
4. **PUT (Programmable Unijunction Transistor) Triggering Circuit**: Similar to UJT but with a four-layer PNPN structure and programmable peak voltage ($V_p \approx V_G + 0.7$ V) via external gate bias (set by resistors). It generates negative resistance-based pulses for SCR triggering, offering better temperature stability and adjustability. Often used in precision timing circuits like oscillators or dimmers, it's more controllable than UJT for variable loads.
5. **Pulse Transformer Triggering**: A small transformer isolates the control circuit from the power side. The primary receives a pulse from a driver (e.g., UJT or microcontroller), inducing a secondary pulse (1:1 or 1:2 ratio) directly to the SCR gate. It provides high isolation (kV level) and strong pulses for high-power SCRs in series/parallel setups, like inverters or HVDC systems. It's reliable in noisy environments but bulkier and costlier.
6. **Opto-Coupler (Opto-Isolator) Triggering**: Uses light for signal transfer: a low-current input drives an LED, whose light activates a photo-triac or photo-SCR on the output side, triggering the main SCR gate. Types like MOC3021 offer zero-crossing detection to reduce EMI. It provides 5-7.5 kV isolation, small size, and easy digital interfacing (e.g., with microcontrollers), ideal for low-medium power appliances like dimmers. Gate current is limited, so it's unsuitable for very large SCRs.

2. Discuss all classes of SCR turn-off methods (A to F) with circuit diagrams and working principles.

Ans-**SCR Turn-Off Methods (Commutation Classes A to F)**

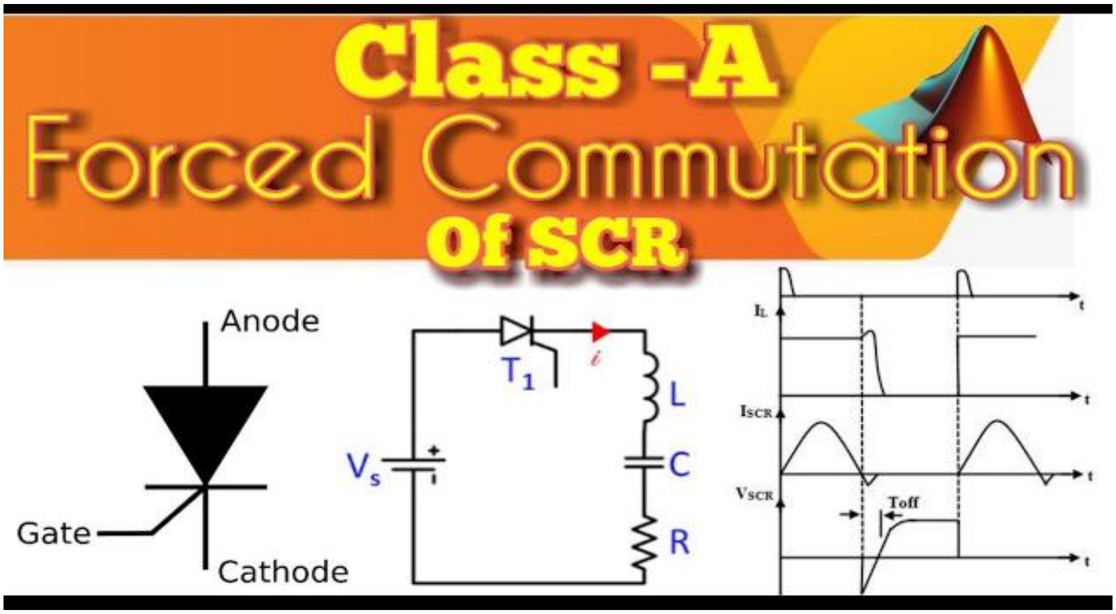
SCRs (thyristors) cannot be turned off by gate control alone; they require commutation to reduce anode current below the holding current (I_H). Commutation methods are classified into six classes (A to F), primarily for DC circuits (A-E are forced commutation) and AC circuits (F is natural). Below, I discuss each class with its working principle and a typical circuit diagram.

Class A: Self-Commutation by Resonating Load (Series Resonant Commutation)

This method uses a series resonant load (R-L-C) to naturally bring the SCR current to zero. It's simple and self-commutated, ideal for loads with inherent resonance.

Working Principle: When the SCR is triggered, current flows through the series L-C-R load, creating a sinusoidal waveform due to resonance. The current peaks and then decreases to zero after a half-cycle. At zero current, the SCR turns off naturally as it cannot conduct reverse current. The capacitor then charges in reverse, applying reverse bias to aid recovery. Turn-off time depends on resonant frequency ($f = 1/(2\pi\sqrt{LC})$).

Circuit diagram:



Class A Commutation of Thyristor | LC Load Resonance | MATLAB Simulation

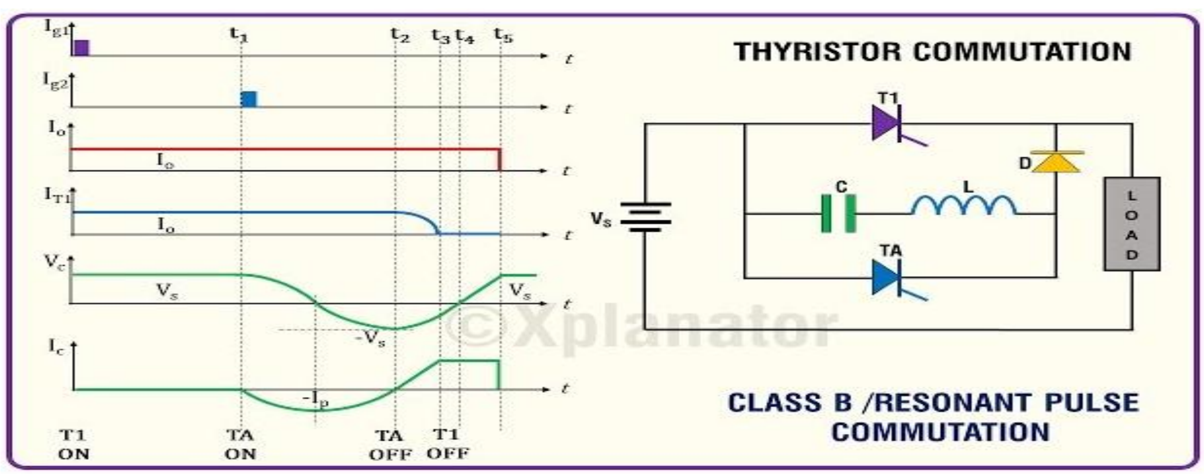
Applications: High-frequency inverters, ultrasonic generators. Advantages: No extra components; limitations: Load must be underdamped resonant.

Class B: Self-Commutation by Parallel Resonant Circuit (Resonant Pulse Commutation)

This uses a parallel LC circuit across the SCR to force reverse current, canceling the load current.

Working Principle: The capacitor C is pre-charged. When commutation is needed, the LC resonates, sending a sinusoidal reverse current pulse through the SCR via L. This pulse opposes the load current, reducing net SCR current to zero, turning it off. The diode or auxiliary path recharges C for the next cycle. Turn-off is fast (10-50 µs) but requires precise LC values.

Circuit diagram:



Waveforms/Graphs] Class B commutation circuit for thyristor(SCR ...

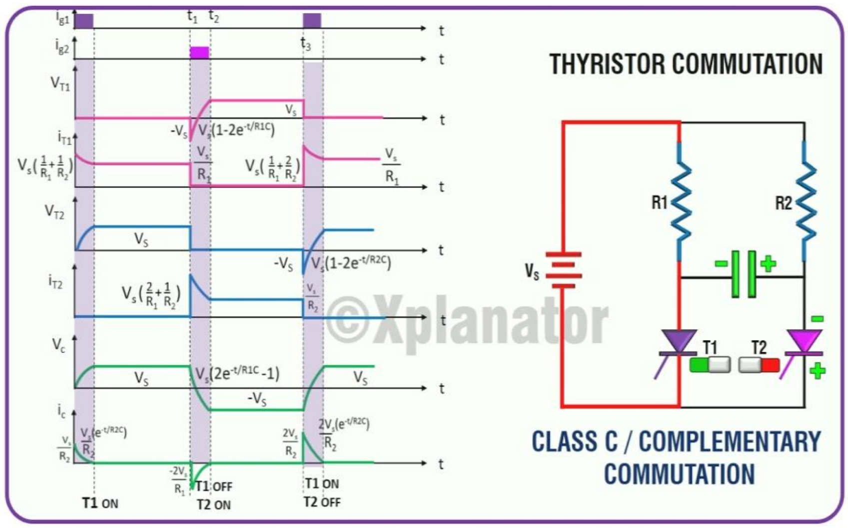
Applications: Choppers, low-power inverters. Advantages: Reliable for inductive loads; limitations: Needs pre-charging and higher component ratings.

Class C: Complementary Commutation (Auxiliary SCR Commutation)

This uses two SCRs (main and auxiliary) in a complementary setup to commutate each other.

Working Principle: The main SCR (T1) conducts the load current. To turn it off, the auxiliary SCR (T2) is triggered, discharging a pre-charged capacitor through T1 in reverse. This reverse current cancels T1's load current, turning T1 off. T2 then conducts briefly until the capacitor recharges, and the process repeats. Resistors ensure proper charging/discharging.

Circuit diagram:



Waveforms for Class C/Complementary Thyristor [SCR] commutation circuit

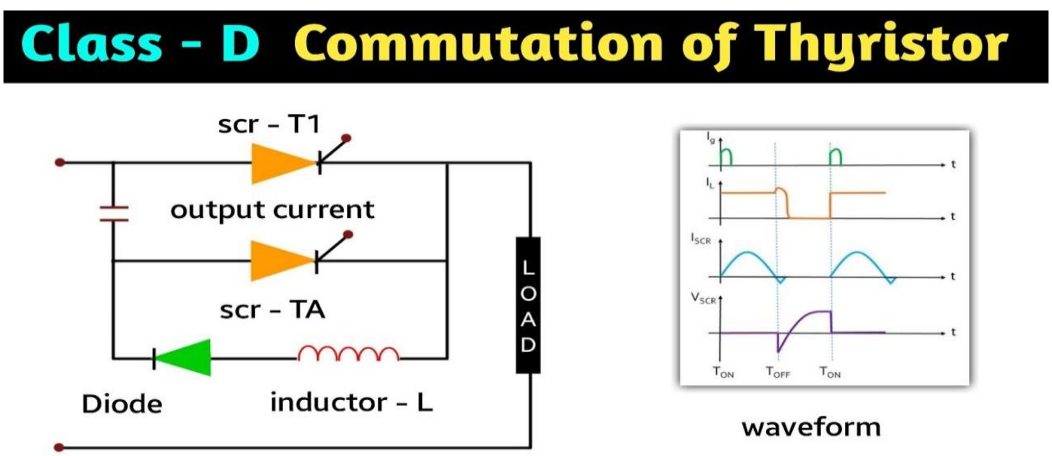
Applications: DC motor speed control, UPS systems. Advantages: Efficient for continuous operation; limitations: Requires two SCRs, increasing cost.

Class D: Auxiliary Impulse Commutation (Line Impulse Commutation)

This method uses an auxiliary SCR and inductor to create a commutation impulse.

Working Principle: The main SCR (T1) conducts. Triggering the auxiliary SCR (TA) connects a pre-charged capacitor to the inductor L, generating a high di/dt impulse. This impulse reverse-biases T1, forcing its current to zero. A diode prevents ringing, and the capacitor recharges via the load. Turn-off is impulse-based, suitable for high currents.

Circuit diagram:



class d commutation of thyristor | class d commutation of scr | scr commutation power electronics

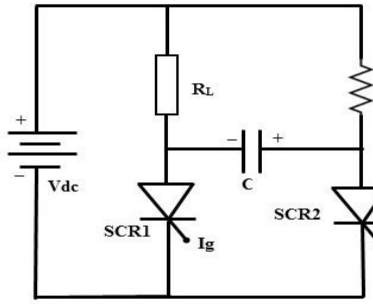
Applications: High-power choppers, traction systems. Advantages: Fast and reliable; limitations: Complex with auxiliary components.

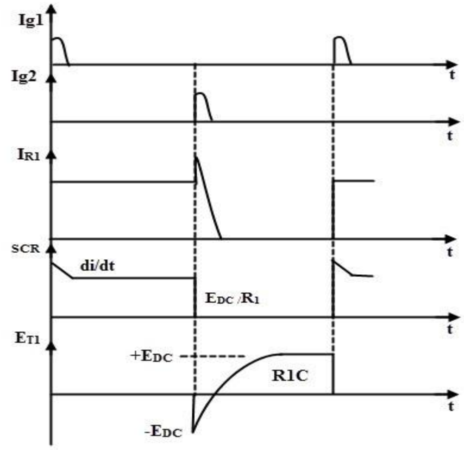
Class E: External Pulse Commutation

This uses an external pulse source (often a transformer or oscillator) to inject reverse current.

Working Principle: An external circuit generates a high-frequency pulse, coupled via a transformer or directly to the SCR. The pulse creates a reverse voltage/current across the SCR, reducing its current to zero. Capacitors and inductors shape the pulse for effective commutation. It's flexible but requires an independent pulse generator.

Circuit diagram:





Education: Industrial Electronics 5th unit: COMMUTATION TECHNIQUES

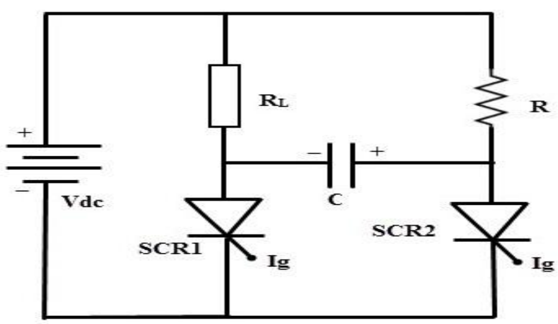
Applications: Specialized inverters, pulse power supplies. Advantages: Precise control; limitations: Needs external power source, higher complexity.

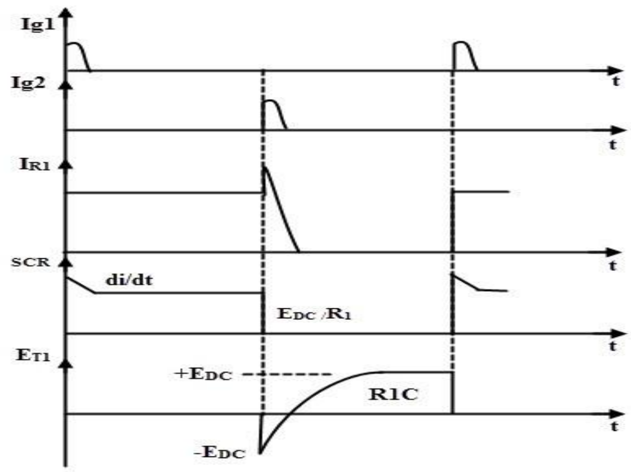
Class F: Line Commutation (Natural Commutation)

This is natural turn-off in AC circuits, where the supply voltage reverses periodically.

Working Principle: In AC, the SCR conducts during the positive half-cycle after triggering. At the end of the half-cycle (zero-crossing), the current naturally drops to zero, and the reverse voltage from the next half-cycle keeps it off. No extra circuit is needed; turn-off occurs at line frequency (50/60 Hz).

Circuit diagram:





Education: Industrial Electronics 5th unit: COMMUTATION TECHNIQUES

Applications: AC phase control, rectifiers, cycloconverters. Advantages: Simplest, no added components; limitations: Only for AC, slow (mains frequency-dependent).

Unit IV: Phase Controlled Rectifiers

2 Marks Questions

1. Define firing angle in phase control.

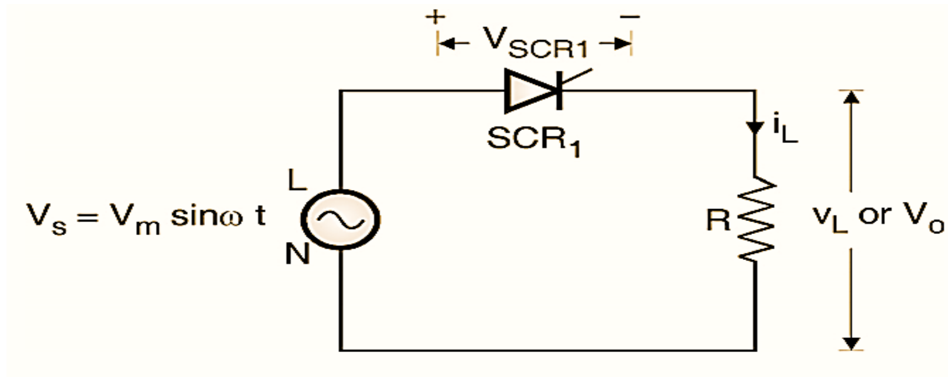
ANS- The **firing angle** is the angle (measured in degrees or radians) from the instant the SCR becomes forward-biased to the instant the gate pulse is applied to trigger it. It determines when the SCR starts conducting during the AC cycle.

2. What is conduction angle?

ANS- The **conduction angle** is the duration for which the SCR remains in the ON state. For a resistive load, it is calculated as sigamma = 180 - alpha.

3. Draw circuit for single-phase half-controlled rectifier with R load.

ANS- This circuit uses one SCR and one diode (or two SCRs and two diodes in a bridge) to provide a variable DC output.



4. What is the effect of freewheeling diode?

ANS- A freewheeling diode is connected across an inductive (RL) load to:

- Prevent the output voltage from becoming negative.
- Provide a path for the stored inductive energy to dissipate, ensuring continuous load current.
- Improve the **input power factor** and efficiency.
-

5. Explain midpoint-controlled rectifier.

ANS- This rectifier uses a **center-tapped transformer** and two SCRs. Each SCR conducts for one-half cycle of the AC input. The load is connected between the center tap and the cathodes of the SCRs.

6. List configurations of bridge controlled rectifiers.

ANS-

Half-Controlled Bridge (Semi-converter): Uses a mix of SCRs and diodes.
Full-Controlled Bridge (Full-converter): Uses only SCRs (four for single-phase).
Dual Converter: Two bridges connected back-to-back to allow four-quadrant operation.

7. What is full-controlled rectifier?

ANS- A full-controlled rectifier uses **SCRs for all switching elements** (no diodes). It can operate in two quadrants, meaning it can provide variable DC voltage and can also return power from the load back to the AC source (inversion).

8. Draw input-output waveforms for half-wave rectifier with RL load.

ANS- In an RL load, the current lags the voltage. The SCR continues to conduct even after the input voltage crosses zero due to the stored energy in the inductor, causing a small negative "spike" in the output voltage.

***9*. Equation for DC output in single-phase full-wave controlled rectifier.**

ANS- The average DC output voltage of a single-phase full-wave controlled rectifier is:

$V_{dc} = (V_m / \pi) \times (1 + \cos \alpha)$

10. What is half-bridge with common cathode?

ANS- This is a configuration where the **cathodes** of two or more SCRs are connected to a single common point. This setup simplifies the triggering circuit because all gate signals can be referenced to the same common cathode potential.

5 Marks Questions

1. Explain phase control concepts: firing and conduction angles.

Ans- **What is Phase Control?**

Phase control (also called phase-angle control) is a technique used to control the amount of power delivered from an AC supply to a load by **delaying the turn-on** of a thyristor (SCR or TRIAC) during each half-cycle of the AC waveform. This allows smooth, continuous control of output power — commonly used in light dimmers, fan regulators, heater control, motor speed control, etc.

Key Concepts

1. **Firing Angle (α) – Triggering Delay Angle**

- **Definition**: The angle (measured in degrees or radians) from the **zero-crossing point** of the AC voltage waveform to the instant when the gate pulse is applied to trigger the SCR.

- **Range**: 0° to 180° in each half-cycle.
- **What it controls**: The point in the AC cycle at which the SCR starts conducting.
  - $\alpha = 0°$ → SCR turns on immediately at zero-crossing → full power (maximum output)
  - $\alpha = 90°$ → SCR turns on at the peak of the waveform → half power (approximately)
  - $\alpha = 180°$ → SCR never turns on → zero power

Visual explanation:
- The AC sine wave starts at 0° (zero-crossing).
- If no delay → firing at 0° → full half-cycle conducts.
- If delayed by α → firing at α → only the portion from α to 180° conducts.

2. **Conduction Angle (β) – Extinction Angle**

- **Definition**: The angle over which the SCR actually conducts current during one half-cycle.
- **Relation to firing angle**: **$\beta = 180° - \alpha$** (for purely resistive loads in single-phase AC control)

Examples:
- If $\alpha = 0°$ → conduction angle $\beta = 180°$ → full half-cycle → maximum power
- If $\alpha = 60°$ → conduction angle $\beta = 120°$ → conducts for 120° of the half-cycle
- If $\alpha = 90°$ → conduction angle $\beta = 90°$ → conducts only for the second quarter of the half-cycle
- If $\alpha = 120°$ → conduction angle $\beta = 60°$ → very little conduction → low power

Important Relationships (for Resistive Loads)

Firing Angle (α)	Conduction Angle (β)	Output Power Level	Typical Application Effect
0°	180°	100% (maximum)	Full brightness / full speed
30°	150°	~93%	Slightly dimmed / reduced speed
60°	120°	~75%	Medium brightness / medium speed
90°	90°	~50%	Half power
120°	60°	~25%	Very dim / very slow
180°	0°	0% (minimum)	Off

Average Output Voltage (DC equivalent) in Phase-Controlled Rectifier

For a **single-phase full-wave controlled rectifier** (bridge with 4 SCRs): **$V_{dc} = (V_m / \pi) \times (1 + \cos\alpha)$**

Where:
- V_m = peak AC voltage
- α = firing angle in radians

This shows how increasing the firing angle α reduces the average DC output voltage (and thus power).

2.Describe single-phase half-controlled rectifier with R, RL load.

Ans-**Circuit Structure**

A single-phase half-controlled rectifier consists of:
- **2 SCRs** (thyristors) → controllable devices
- **2 ordinary diodes** → uncontrolled devices
- Arranged in a bridge configuration

Typical arrangement (most common version):
- Two SCRs in one pair of opposite arms
- Two diodes in the remaining opposite arms
- Load connected across the DC output terminals

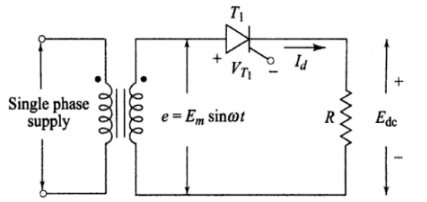


Fig.1 (a) Halfwave-controlled rectifier with resistive load

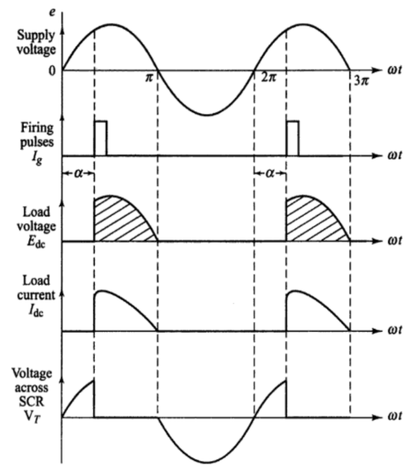
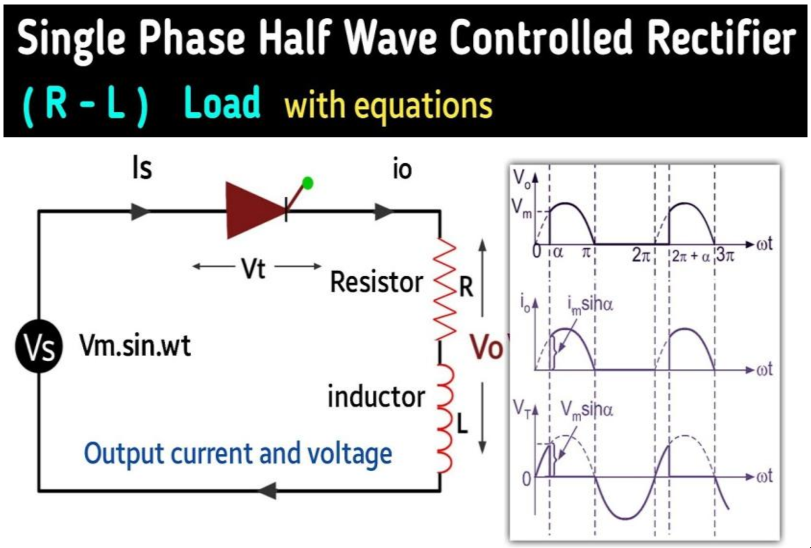


Fig.1 (b) Waveforms for a half-wave circuit



Operation with Pure Resistive Load (R Load)

Behavior:

- During positive half-cycle of AC supply → SCR1 is triggered at firing angle α → current flows through SCR1 → Load → D2
- During negative half-cycle → SCR2 is triggered at firing angle α → current flows through SCR2 → Load → D1
- The output voltage waveform is the same as a fully controlled bridge, but only two devices are gated.
- Current is in phase with voltage (no phase shift).
- Conduction starts at α and continues until the end of the half-cycle (180°).

Average DC output voltage: $V_{dc} = (V_m / \pi) \times (1 + \cos\alpha)$

Where:

- V_m = peak value of AC input voltage
- α = firing angle (in radians)

Key points:

- Same voltage equation as single-phase fully controlled rectifier
- Continuous conduction
- No freewheeling path needed
- Ripple frequency = 2 × supply frequency

2. Operation with Resistive-Inductive Load (RL Load)

Behavior:

- Due to inductance, load current does not go to zero immediately when supply voltage crosses zero.
- When supply voltage becomes negative, the inductor tries to maintain current flow.

- The corresponding freewheeling diode (D1 or D2) starts conducting → provides a path for inductor current to continue flowing.

Important modes:

A. Continuous conduction mode (most common with RL load):

- Load current never becomes zero.
- Freewheeling diodes conduct during the period when supply voltage is negative.
- The output voltage waveform has:
    - Positive portion from α to 180° (when SCR conducts)
    - Zero voltage portion when freewheeling diode conducts (inductor current circulates)
- Average voltage is still:

Vdc = (Vm / π) × (1 + cos α)

B. Discontinuous conduction mode (possible at large α or small inductance):

- Load current reaches zero before the next triggering.
- Output voltage has zero periods even during supply positive half-cycle.
- Average voltage is lower than the continuous case.

Waveform characteristics:

- Voltage waveform: chopped sine wave + flat zero periods during freewheeling
- Current waveform: smoother due to inductance, may be continuous or discontinuous

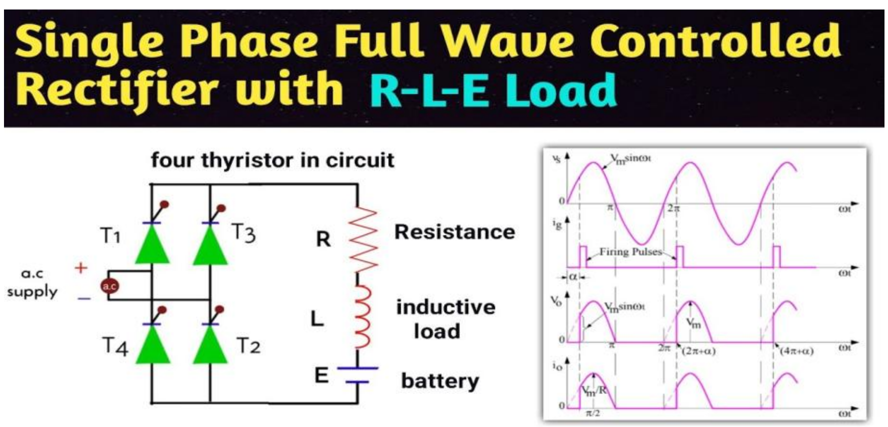
3.Discuss full-controlled rectifier operation with waveforms.

Ans-Circuit Overview

- Configuration: 4 SCRs (thyristors) arranged in a bridge.
- All four devices are controllable → full control over output voltage.
- Most common topology for single-phase DC power control.

Typical labeling:

- SCR1 and SCR2 conduct during positive half-cycle
- SCR3 and SCR4 conduct during negative half-cycle



Basic circuit

Operation Principle

- Each SCR is triggered at a specific firing angle **α** (measured from the natural commutation point, i.e., zero-crossing).
- Two SCRs conduct in each half-cycle:
    - Positive half: T1 and T2
    - Negative half: T3 and T4
- The output voltage follows the AC input waveform only from the firing instant (α) until the next zero-crossing (180°).
- By varying α from 0° to 180°, we control the average output DC voltage from maximum to zero.

Important Equations (Resistive Load)

Average DC output voltage: **Vdc = (Vm / π) × (1 + cos α)**

Where:

- **Vm** = peak value of AC input voltage
- **α** = firing angle in radians

Maximum value ($\alpha = 0°$): **$V_{dc(max)} = 2V_m / \pi \approx 0.637 V_m$** (same as uncontrolled full-wave rectifier)

At α = 90°: $V_{dc} = V_m / \pi \approx 0.318 V_m$ (half of maximum)

At α = 180°: $V_{dc} = 0$ V

Waveforms – Step-by-Step

1. **Input AC voltage waveform** (sinusoidal):

$$v = V_m \sin(\omega t)$$

2. **Gate pulses**:
   - Applied to SCR pair (T1,T2) at angle α in positive half
   - Applied to SCR pair (T3,T4) at angle α + 180° in negative half
3. **Output voltage waveform** (across load):
   - From 0° to α: zero (SCRs not triggered yet)
   - From α to 180°: follows positive half of input sine wave
   - From 180° to 180° + α: zero again
   - From 180° + α to 360°: follows negative half (appears positive due to bridge)

→ Result = full-wave rectified waveform, but **chopped** at the beginning of each half-cycle

4. **Load current waveform**:
   - **Pure R load** → same shape as voltage (in phase, discontinuous at large α)
   - **RL load** → current is smoother and may become continuous (especially at small α or large inductance)

Typical Waveforms Summary (Resistive Load)

```
Input AC voltage:    /‾‾‾\____/‾‾‾\____/‾‾‾\____
                   0°   180°   360°

Gate pulse to T1,T2:      ↑           ↑
                      α        α+180°

Output voltage:      ____/‾‾‾‾‾‾‾‾‾‾\____/‾‾‾‾‾‾‾‾‾‾\____
                     α         180°   α+180°   360°
```

Key Points at Different Firing Angles

- **α = 0°** → full conduction → maximum DC output (like uncontrolled rectifier)
- **α = 90°** → conduction only in second quarter of each half-cycle → ~50% voltage
- **α > 90°** → output voltage still positive but significantly reduced
- **α = 180°** → no conduction → zero output

Additional Notes for RL Load

- Inductance causes current to continue flowing even after voltage zero-crossing.
- May result in **continuous conduction** (current never goes to zero).
- Freewheeling does **not** occur naturally (unlike half-controlled bridge) → current flows only when SCRs are conducting.
- At large α, discontinuous conduction may appear.

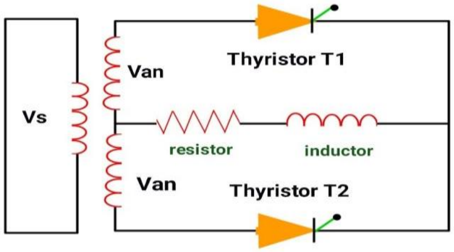
4.Explain midpoint-controlled rectifier with equations.

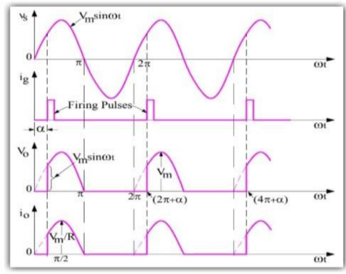
Ans-**single-phase midpoint-controlled rectifier** (also known as **center-tapped controlled rectifier** or **midpoint thyristor rectifier**) with its key equations.

Circuit Description

- It uses a **center-tapped transformer** with two secondary windings.
- Each half of the secondary is connected to one **SCR** (thyristor).
- The two SCRs are connected to the load in series with their cathodes.
- The center tap of the transformer is connected to the other end of the load (return path).

Single Phase Full wave Mid Point Controlled Rectifier with RL - Load





- Only **two SCRs** are used (unlike 4 in bridge).
- Each SCR conducts only during its corresponding half-cycle.

Operation

- During **positive half-cycle** of one secondary winding → SCR1 (T1) is triggered at firing angle α → conducts through T1 → load → center tap.
- During **negative half-cycle** of the other secondary winding → SCR2 (T2) is triggered at firing angle α → conducts through T2 → load → center tap.
- The output voltage is **full-wave rectified** but controlled by the firing angle.

Important Equations

Let:

- **Vm** = peak voltage across **each half** of the secondary winding (i.e., peak voltage from center tap to one end of the secondary)

1. Average DC Output Voltage (Vdc)

$V_{dc} = (V_m / \pi) \times (1 + \cos \alpha)$

Where:

- α = firing angle (in radians)
- Range: $0 \le \alpha \le \pi$ (0° to 180°)

This is the **same equation** as for single-phase full-wave controlled bridge rectifier.

Maximum value (α = 0°): **$V_{dc(max)} = 2V_m / \pi \approx 0.637\, V_m$**

2. RMS Output Voltage (Vrms)

$V_{rms} = V_m \times \sqrt{[(1/\pi) \times (\pi - \alpha + (1/2) \sin 2\alpha)]}$

3. Ripple Factor

Ripple factor = $\sqrt{[(V_{rms} / V_{dc})^2 - 1]}$

It varies with firing angle α (higher ripple at larger α).

4. Form Factor

Form factor = V_{rms} / V_{dc}

Typical value ≈ 1.11 at α = 0° (same as uncontrolled case), increases with α.

Waveforms Summary

- **Input voltage** (each half secondary): $V_m \sin(\omega t)$ and $V_m \sin(\omega t + 180°)$
- **Output voltage** across load:
  - From α to π → follows positive half of one secondary
  - From $\pi + \alpha$ to 2π → follows positive half of the other secondary
  - Zero voltage from 0 to α and π to $\pi + \alpha$

5. **Describe different bridge configurations: full, half, mixed.**

Ans- **1. Full-Controlled Bridge Rectifier (Fully Controlled Bridge)**

- **Number of devices**: 4 SCRs (thyristors)
- **Configuration**: All four arms of the bridge contain SCRs (T1, T2, T3, T4)
- **Control**: Complete control over both positive and negative half-cycles
- **Operation**:
  - Positive half-cycle: T1 and T2 conduct when triggered
  - Negative half-cycle: T3 and T4 conduct when triggered
  - Firing angle α controls the output from 0° to 180° in both halves
- **Average DC output voltage**: **$V_{dc} = (V_m / \pi) \times (1 + \cos \alpha)$** ($V_m$ = peak AC voltage)

- **Maximum Vdc** ($\alpha = 0°$): 2Vm / π ≈ 0.637 Vm
- **Output polarity**: Always positive DC (due to bridge)
- **Freewheeling**: No inherent freewheeling path (current flows only when SCRs conduct)
- **Typical load behavior**:
    - R load → discontinuous at large α
    - RL load → usually continuous conduction
- **Applications**: High-power DC motor drives, battery chargers, industrial power supplies
- **Advantages**: Full control, wide voltage range (maximum to zero)
- **Disadvantages**: More SCRs → higher cost, more complex gate drive, lower power factor at large α

2. Half-Controlled Bridge Rectifier (Semi-Controlled Bridge)

- **Number of devices**: 2 SCRs + 2 diodes
- **Configuration**: Two opposite arms have SCRs, the other two have ordinary diodes
- **Control**: Only half-controlled (SCRs control one direction, diodes conduct naturally)
- **Operation**:
    - Positive half-cycle: SCR1 + diode D2 conduct when SCR1 is triggered
    - Negative half-cycle: SCR2 + diode D1 conduct when SCR2 is triggered
    - Diodes provide freewheeling path for inductive current
- **Average DC output voltage**: **$V_{dc} = (V_m / \pi) \times (1 + \cos\alpha)$** (same equation as full-controlled)
- **Maximum Vdc** ($\alpha = 0°$): 2Vm / π ≈ 0.637 Vm
- **Freewheeling**: Yes — diodes naturally provide freewheeling path for RL loads
- **Typical load behavior**:
    - R load → same as full-controlled
    - RL load → continuous conduction with freewheeling periods (better current smoothness)
- **Applications**: Low-cost DC motor drives, battery chargers, small industrial applications
- **Advantages**:
    - Only 2 SCRs → lower cost
    - Inherent freewheeling (no extra diode needed)
    - Better power factor than full-controlled at large α
- **Disadvantages**: Less control flexibility than full-controlled

3. Mixed Bridge Rectifier (Asymmetric / Hybrid Bridge)

- **Number of devices**: Usually 3 SCRs + 1 diode (or sometimes other combinations)
- **Configuration**: Not fully standardized — common version has 3 SCRs and 1 diode
- **Purpose**: Attempts to combine advantages of full and half-controlled types
- **Operation**:
    - Different conduction paths depending on which devices are SCRs
    - Can allow bidirectional current or asymmetric control
    - Often used to reduce number of thyristors while retaining some control
- **Average DC output voltage**: Varies depending on exact configuration Commonly similar to half-controlled but with different ripple or control range
- **Applications**:
    - Some special-purpose rectifiers
    - Low-cost variable speed drives
    - Circuits where full control is not needed but better performance than half-controlled is desired
- **Advantages**: Fewer thyristors than full bridge, better than simple half-controlled in some cases
- **Disadvantages**:
    - Non-standard
    - Uneven voltage stress on devices
    - More complex analysis and gate control
    - Less commonly used in modern designs

Quick Comparison Table

Feature	Full-Controlled (4 SCRs)	Half-Controlled (2 SCRs + 2 Diodes)	Mixed (3 SCRs + 1 Diode etc.)
Number of thyristors	4	2	3
Control range	Full (0°–180°)	Half (but effective)	Partial
Freewheeling	No	Yes (inherent)	Depends on design
Average Vdc equation	Vdc = (Vm/π)(1 + cos α)	Same	Similar / modified
Cost	Higher	Lower	Medium
Common use	High-power drives	Low-cost drives, chargers	Special / legacy applications
Power factor at large α	Poor	Better	Varies

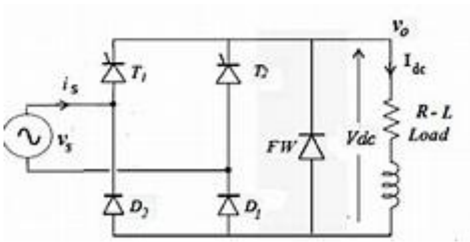
Most widely used today:

- **Full-controlled bridge** → for high-performance industrial applications
- **Half-controlled bridge** → for cost-sensitive and medium-power applications

<u>**10 Marks Questions**</u>

1. **With circuit diagrams, waveforms, and equations, explain single-phase half-controlled, full-controlled, and midpoint rectifiers with R/RL loads, including freewheeling diode effect.**

Ans- **1. Single-Phase Half-Controlled Rectifier (Semi-Controlled Bridge)**



Operation summary:

- 2 SCRs + 2 diodes
- Controls only one direction; diodes conduct naturally
- Inherent freewheeling through diodes for RL load

With R load:

- Conduction starts at firing angle α and continues to 180° in each half-cycle
- Continuous conduction, no freewheeling needed

With RL load:

- Freewheeling occurs through diodes when supply voltage reverses
- Load current continues smoothly → no negative voltage across load
- Improves power factor and current smoothness

Average DC output voltage (continuous conduction): **Vdc = (Vm / π) × (1 + cos α)**

Google Images search terms (copy-paste):

- "single phase half controlled bridge rectifier circuit diagram"
- "single phase semi controlled rectifier with RL load waveform"
- "half controlled rectifier freewheeling action diagram"

2. Single-Phase Full-Controlled Rectifier (Fully Controlled Bridge)

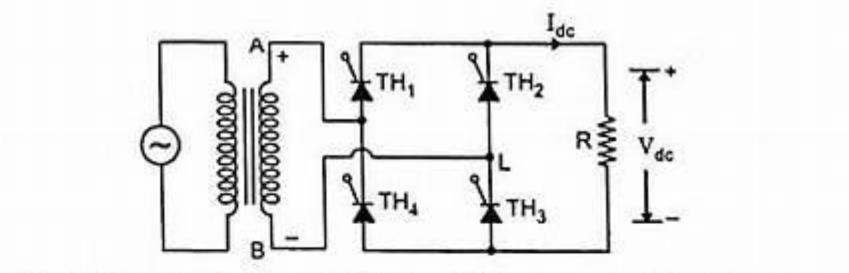


Fig. 27.13 *Single Phase Full-Wave Fully Controlled Rectifier (or Full Converter) With Resistive Load*

Operation summary:
- 4 SCRs (T1–T4)
- Full control over both half-cycles
- No inherent freewheeling (external freewheeling diode often added for RL load)

With R load:
- Conduction from α to 180° in each half-cycle
- Discontinuous conduction possible at large α

With RL load:
- Usually continuous conduction
- Current may continue after voltage zero-crossing
- Without freewheeling diode → possible negative instantaneous voltage
- With freewheeling diode across load → current circulates, voltage stays non-negative

Average DC output voltage (continuous conduction): **Vdc = (Vm / π) × (1 + cos α)**

3. Single-Phase Midpoint-Controlled Rectifier (Center-Tapped)

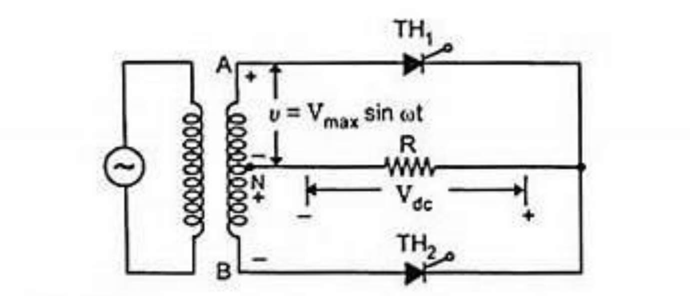


Fig. 27.7 *Mid-Point Converter With Resistive Load*

Operation summary:
- 2 SCRs + center-tapped transformer
- Each SCR conducts during its corresponding half-cycle
- Freewheeling not inherent → external diode usually added for RL load

With R load:
- Conduction from α to 180° per half-cycle
- Full-wave output, controlled by firing angle

With RL load:
- Continuous or discontinuous depending on inductance
- External freewheeling diode across load prevents negative voltage and improves current smoothness

Average DC output voltage (continuous conduction): **Vdc = (Vm / π) × (1 + cos α)** (Vm = peak voltage per half-secondary)

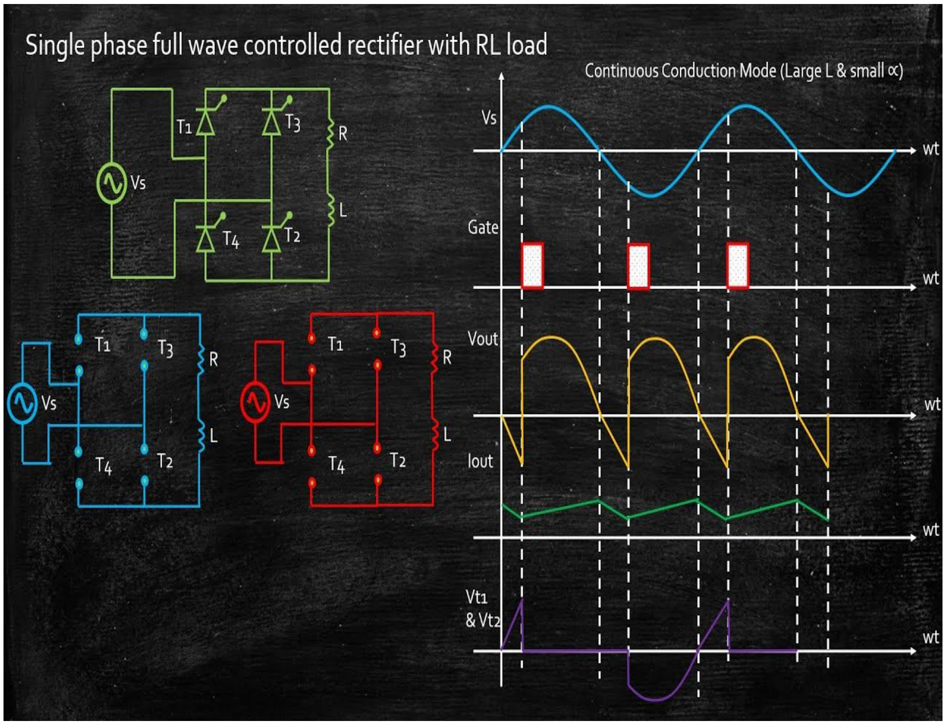
2. **Discuss various configurations of bridge-controlled rectifiers (full, half with common anode/cathode, mixed SCR-diode) with working, waveforms, and applications.**

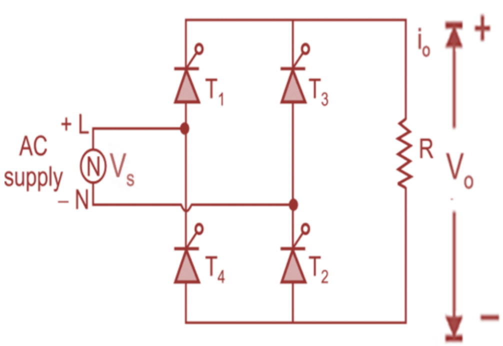
   Ans- **Various Configurations of Bridge Controlled Rectifiers**

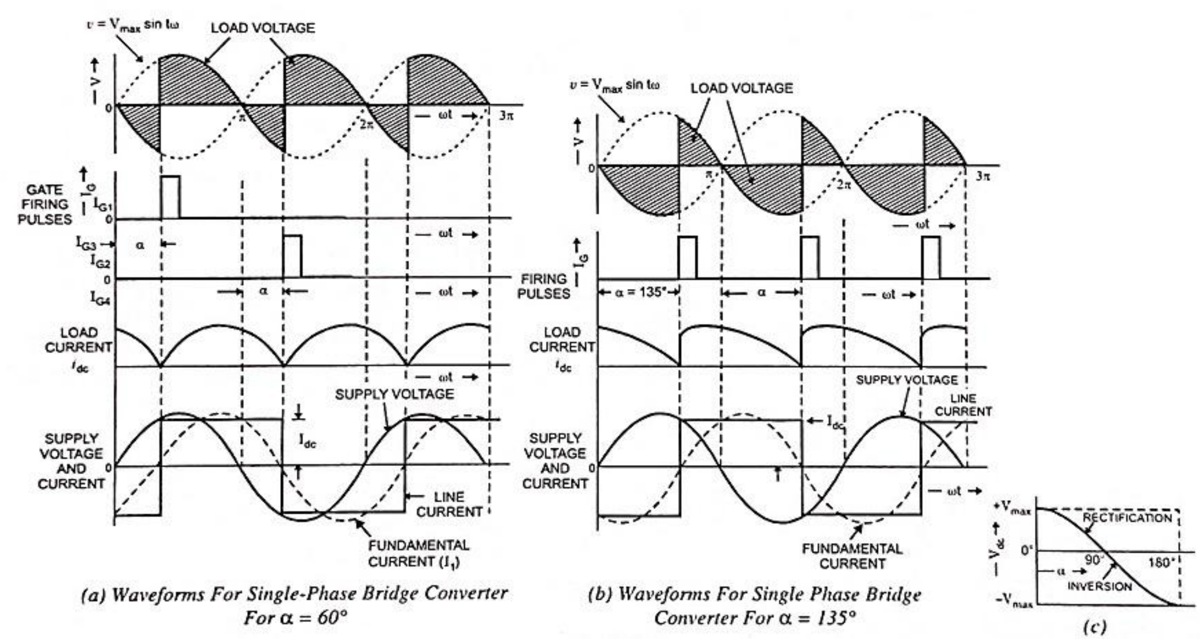
   Bridge controlled rectifiers are widely used in power electronics for converting AC to DC with variable output voltage control using thyristors (SCRs). Below, I discuss the main configurations: full-controlled (4 SCRs), half-controlled (2 SCRs + 2 diodes, including common anode/cathode symmetrical and asymmetrical types), and mixed SCR-diode (e.g., 3 SCRs + 1 diode or hybrid). For each, I'll cover working, waveforms, and applications. All are single-phase for simplicity, with typical equations for average DC voltage $V_{dc} = (V_m/\pi)(1 + \cos \alpha)$, where V_m is peak AC voltage and α is firing angle.

Full-Controlled Bridge Rectifier (4 SCRs)

This is the most versatile configuration, allowing full positive and negative half-cycle control. **Working**: Four SCRs form the bridge arms. In the positive half-cycle, SCR1 and SCR2 are triggered at α, conducting until the current falls to zero. In the negative half-cycle, SCR3 and SCR4 are triggered at α + 180°. Output is full-wave rectified but chopped at α. For R load, conduction is discontinuous at large α; for RL load, it's continuous due to inductance, but no inherent freewheeling—external diode may be added to prevent negative voltage spikes.
Waveforms: Input sine wave; output voltage chopped from α to 180°/360°; current follows voltage for R, smoother and continuous for RL. Ripple frequency = 2 × supply frequency.







Applications: High-power DC motor drives, battery chargers, HVDC converters, UPS systems. Advantages: Precise control (Vdc from 0 to max); disadvantages: Higher cost (4 SCRs), complex gating.

Half-Controlled Bridge Rectifier (2 SCRs + 2 Diodes)

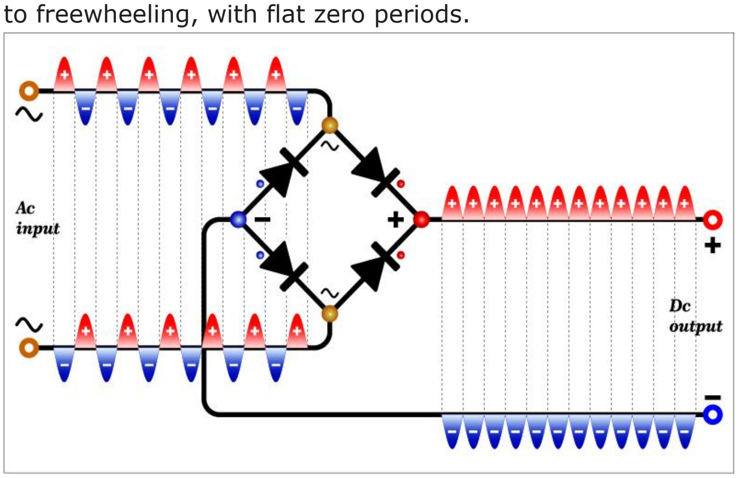
This semi-controlled type replaces two SCRs with diodes, reducing cost while retaining partial control. It has symmetrical (common anode/cathode) and asymmetrical variants.

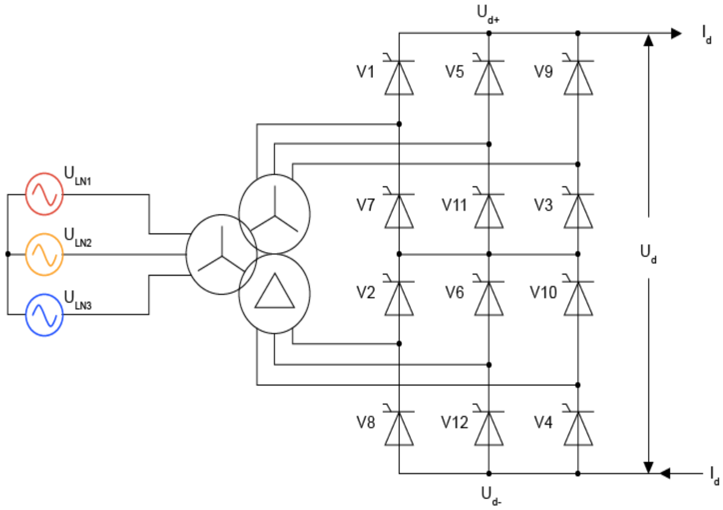
Working (General): SCRs control one polarity; diodes conduct naturally in the other. For positive half, SCR1 + diode D2 conduct after α; for negative, SCR2 + diode D1. Inherent freewheeling through diodes for RL loads prevents negative voltage.

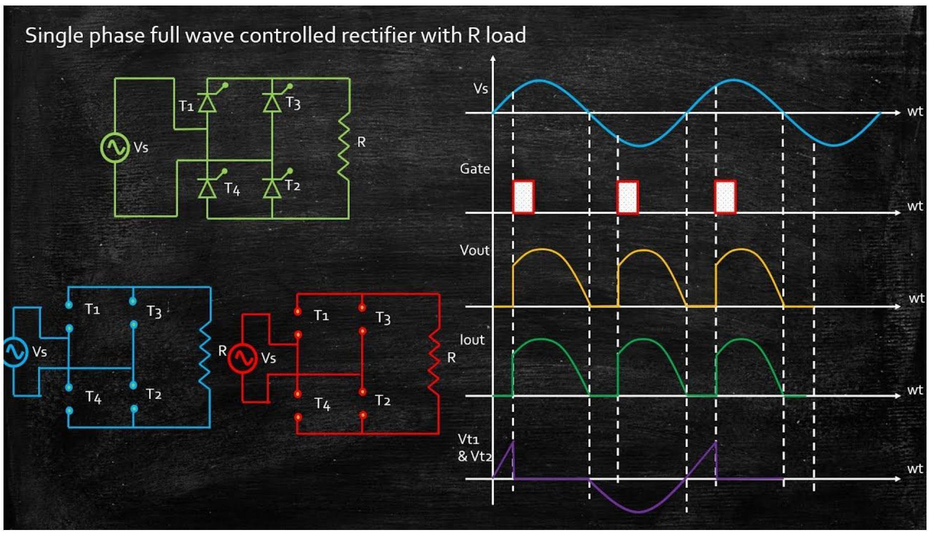
Symmetrical Common Cathode/Anode: SCRs share common cathode (or anode) point, simplifying gating (single trigger circuit). Working same as general, but optimized for isolated gate drives.

Asymmetrical: SCRs in adjacent arms; similar operation but different voltage stress on devices.

Waveforms: Output voltage chopped in one half-cycle per polarity; current continuous for RL due to freewheeling, with flat zero periods.







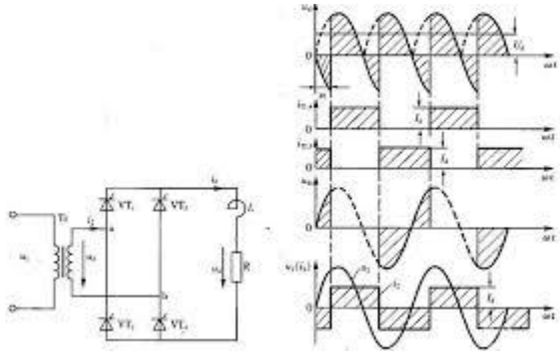
Applications: Low-cost battery chargers, DC motor speed control, heating systems. Advantages: Cheaper (fewer SCRs), inherent freewheeling; disadvantages: Limited to positive output, poorer power factor at large α.

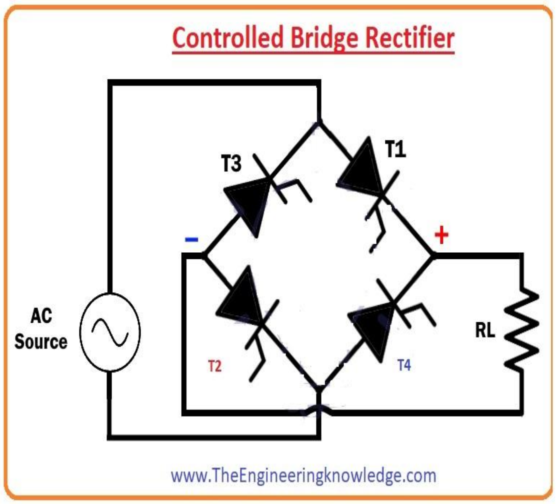
Mixed SCR-Diode Bridge Rectifier (Hybrid/Asymmetric)

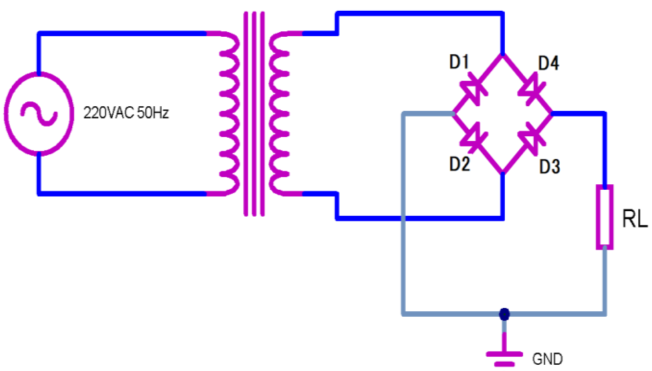
This hybrid uses 3 SCRs + 1 diode (or similar mixes) to balance cost and control, often for asymmetric operation.

Working: Three SCRs provide control in most paths; diode handles one direction. Allows bidirectional current or reduced gating complexity. For R load, conduction similar to full but with diode natural flow; for RL, may need external freewheeling diode. Voltage stress uneven across devices.

Waveforms: Similar to half-controlled but asymmetric; output chopped in controlled paths, full in diode path; current smoother in RL with possible discontinuity.







Applications: Legacy systems, low-power variable drives, specialized converters. Advantages: Reduced SCRs vs full; disadvantages: Uneven device stress, less standard, complex analysis.

Equations (All Configurations, Continuous Mode): $V_{dc} = (V_m/\pi)(1 + \cos \alpha)$; ripple higher in mixed/ half at large α.

Unit V: Industrial Control Circuits

2 Marks Questions

***1*. What is a burglar's alarm system using SCR?**
ANS- A burglar alarm uses the **latching property** of an SCR. A sensor (like a thin wire) is connected to the gate; when broken, a pulse triggers the SCR. Once triggered, the SCR remains ON (latches), keeping the alarm ringing even if the sensor is restored, until the circuit is manually reset.

2. Define SMPS.
ANS- **SMPS (Switched-Mode Power Supply)** is an electronic power supply that uses a switching

regulator to convert electrical power efficiently. It switches a power semiconductor (like a MOSFET) at high frequencies to regulate the output voltage with minimal energy loss.

3. What is offline UPS?
ANS- An **Offline UPS** powers the load directly from the AC mains under normal conditions. When the mains power fails, a static switch transfers the load to the battery-powered inverter. This transition usually involves a small **transfer time** of 5–10 milliseconds.

4. Explain emergency light system with SCR.
ANS- This system uses an SCR to switch on a backup lamp during a power failure. While AC is present, the battery charges and the SCR is kept OFF. When the AC supply fails, the gate becomes forward-biased, triggering the SCR to provide battery power to the lamp.

5. What is TRIAC in illumination control?
ANS- In lamp dimmers, a TRIAC controls light intensity by varying the **firing angle (alpha)**. By "chopping" the AC waveform in both the positive and negative half-cycles, it regulates the RMS voltage delivered to the lamp, allowing for smooth dimming.

6. Define online UPS.
ANS- An **Online UPS** always powers the load through its inverter, regardless of the AC mains status. It converts AC to DC and then back to clean AC (Double Conversion), ensuring **zero transfer time** and isolation from power line fluctuations.

7. What is temperature controller using SCR?
ANS- This circuit uses a temperature sensor (like a thermistor) to provide a trigger signal to the SCR gate. When the temperature drops below a set threshold, the SCR is triggered to turn on a heating element; it turns off once the target temperature is reached.

8. Explain SCR-based AC circuit breaker.
ANS- An SCR AC circuit breaker uses two SCRs in anti-parallel to act as a high-speed static switch. It can interrupt current within a few microseconds of a fault detection, offering much faster protection than traditional mechanical circuit breakers.

9. What is battery charger using SCR?
ANS- An SCR-based battery charger acts as a controlled rectifier. By adjusting the firing angle, the circuit regulates the DC charging voltage and current, allowing the charger to automatically reduce current as the battery reaches full charge.

10. Define fan speed control with TRIAC.
ANS- A TRIAC fan regulator controls the speed of an induction motor by varying the effective AC voltage. By changing the firing angle of the TRIAC, the amount of power delivered to the motor per cycle is adjusted, which in turn varies the motor speed.

5 6 **<u>Marks Questions</u>**

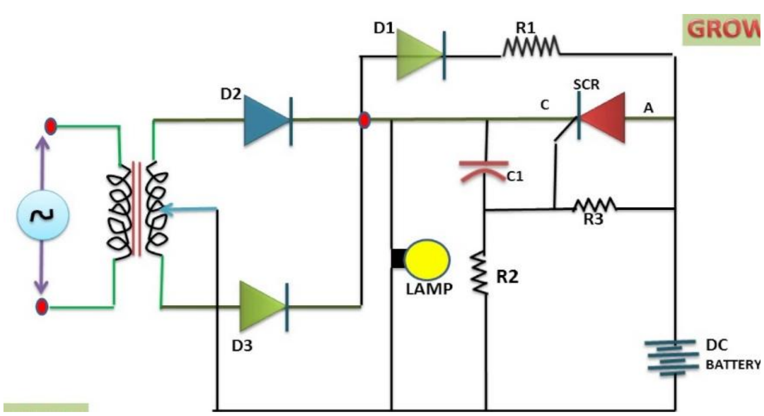
1.**Explain burglar's alarm and emergency light systems using SCR.**
Ans- **Burglar's Alarm System Using SCR**
A burglar's alarm system using SCR is a simple latching circuit that triggers an alarm (buzzer or siren) when a sensor detects intrusion and stays on until manually reset. The SCR acts as a switch that latches into conduction mode once triggered, ensuring the alarm remains active even after the sensor input is removed.
Working Principle:

- The circuit typically includes a sensor (e.g., magnetic reed switch, IR sensor, or LDR for laser-based detection) connected to the SCR's gate.
- When the sensor is activated (e.g., door opens breaking the loop or laser beam is interrupted), a small positive voltage/current is applied to the gate, forward-biasing the SCR.
- The SCR turns ON and latches, allowing continuous current from the power supply (battery or DC source) to flow through the alarm (buzzer/siren).

- The alarm sounds indefinitely due to the SCR's latching property (it stays ON as long as anode current > holding current IH).
- Reset is done by a switch that interrupts the anode current (e.g., momentary open switch in series with the SCR).
- Components: SCR (e.g., 2N5060), resistor to limit gate current, buzzer (8-12V), sensor switch, reset switch, and 9-12V DC supply.

How to make Laser Security (Theft) Alarm using SCR - 1 KM Range ...
This diagram shows a laser-based burglar alarm using SCR, where the LDR sensor triggers the gate upon beam interruption, latching the SCR to activate the buzzer.
Applications: Home security, door/window alarms; advantages: Low-cost, reliable latching; disadvantages: Requires manual reset.
Emergency Light System Using SCR
An emergency light system using SCR automatically turns on battery-powered lights during power failure and turns off when main power restores. The SCR controls the switching between AC mains and battery.
Working Principle:

- The circuit uses the SCR as a switch between the battery and the lamp (LED or bulb).
- When AC mains is present, a small DC voltage (rectified from AC) reverse-biases or keeps the SCR gate low, so SCR is OFF — lamp is off, battery charges via a diode.
- When AC fails, the gate bias changes (e.g., via a transistor or direct sensor), applying a positive trigger to the SCR gate.
- SCR turns ON and latches, connecting the battery to the lamp — light turns on.
- When AC restores, the circuit interrupts the SCR anode current (e.g., via a relay or switch) to turn it OFF.
- Components: SCR (e.g., C106D), diodes for rectification, resistor-capacitor for gate control, transistor for sensing, 6-12V battery, lamp/LEDs.



Emergency Light System Control Using SCR
These diagrams illustrate SCR-based emergency light circuits, showing how power failure triggers the SCR to latch and power the lamp from the battery until mains restore.
Applications: Home/office backup lighting; advantages: Automatic, low-power standby;

disadvantages: Battery dependency, needs reset mechanism.

2.**Describe SMPS working principle.**
Ans- SMPS is a highly efficient power supply that converts AC (or DC) input to a regulated DC output by using high-frequency switching instead of linear regulation. It is used in almost all modern electronics — laptops, mobile chargers, LED drivers, computers, TVs, etc.
Basic Working Principle
SMPS works by rapidly switching a power transistor (MOSFET or IGBT) ON and OFF at high frequency (typically 20 kHz to 1 MHz), controlling the energy flow to the output.
Main Stages of SMPS Operation:

1. **AC Input Stage**
    - Input AC voltage (e.g., 230 V, 50 Hz) is fed to the circuit.
2. **Rectification & Filtering**
    - Bridge rectifier converts AC to pulsating DC.
    - Large filter capacitor smooths it → produces high-voltage DC (≈ 310–340 V DC for 230 V AC).
3. **High-Frequency Switching (Chopper Stage)**
    - A power transistor (MOSFET) is turned ON and OFF very rapidly by a **PWM (Pulse Width Modulation)** signal from the control IC.
    - When transistor is **ON** → energy is stored in the magnetic field of the transformer/inductor.
    - When transistor is **OFF** → stored energy is transferred to the output.
4. **Isolation Transformer (in most designs)**
    - High-frequency transformer provides:
        - Galvanic isolation between input and output
        - Voltage step-down (or step-up)
    - Operates at high frequency → much smaller and lighter than 50 Hz transformers.
5. **Output Rectification & Filtering**
    - Fast recovery diodes rectify the high-frequency AC from the transformer secondary.
    - LC filter (inductor + capacitor) smooths the output to low-ripple DC.
    - Output voltage is regulated and stable.
6. **Feedback & Regulation**
    - Output voltage is sensed (usually via opto-coupler or auxiliary winding).
    - Feedback signal goes to the control IC (PWM controller).
    - PWM controller adjusts the duty cycle (ON time) of the switching transistor:
        - If output voltage is too high → reduces duty cycle
        - If output voltage is too low → increases duty cycle
    - This keeps output voltage constant despite input voltage changes or load variations.
    -

3.Compare offline and online UPS.
Ans-**1. Offline (Standby) UPS**
The Offline UPS is the most basic type. It remains at "rest" while the main power is healthy, passing utility power directly to the load through a bypass switch.

- **Working:** Under normal conditions, the UPS simply filters the power and keeps the battery charged. The **Inverter** remains OFF. When the utility power fails or fluctuates beyond limits, the transfer switch moves the load to the battery/inverter side.
- **Transfer Time:** There is a slight delay (typically **5 to 10 milliseconds**) during the switch, which most computers can handle, but sensitive medical or laboratory equipment might reset.
- **Cost:** Generally cheaper and more energy-efficient because the inverter is only used when needed.

2. Online (Double Conversion) UPS
The Online UPS is the "gold standard" for critical systems. It is called "Double Conversion" because it constantly converts AC to DC and then back to AC.

- **Working:** The load is always powered by the **Inverter**. Incoming AC is converted to DC to charge the battery and power the inverter. The inverter then regenerates a clean, perfect AC sine wave for the load.
- **Transfer Time:** There is **Zero Transfer Time**. Since the inverter is already powering the

load, there is no physical "switch-over" when the power goes out.
- **Protection:** It provides total isolation from power spikes, surges, and frequency variations.
- **Cost:** More expensive and slightly less efficient (as the inverter runs 24/7), but provides the highest level of safety.

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3. Comparison Table

Feature	Offline UPS	Online UPS
Operating Principle	Switches to battery on power failure.	Always powers load via the inverter.
Transfer Time	5ms to 10ms (delay).	**Zero** (no delay).
Voltage Regulation	Minimal (depends on input).	Excellent (output is always stable).
Isolation	No isolation from main grid.	Complete isolation from grid noise.
Battery Usage	Only used during outages.	Used as a buffer constantly.
Best For	PCs, printers, home electronics.	Servers, medical gear, lab instruments.

4.Discuss temperature controller and illumination control using SCR/TRIAC.

Ans-**1. Phase Control Principle**

In AC circuits, the SCR or TRIAC acts as a high-speed switch. By delaying the **firing angle** (α), we control how much of the AC cycle reaches the load.

- A small firing angle (early trigger) delivers **high power**.
- A large firing angle (late trigger) delivers **low power**.

2. Illumination Control (Dimmer)

For lighting, a **TRIAC** is preferred over an SCR because it can conduct in both halves of the AC cycle, providing smoother control.

- **Working:** A variable resistor (potentiometer) and a capacitor are used as a timing circuit. As the resistance increases, the capacitor takes longer to charge to the "breakover voltage" of a **DIAC** (which triggers the TRIAC).
- **Effect:** Delaying the trigger reduces the **RMS voltage** to the bulb, causing it to dim.
- **Characteristic:** This is far more efficient than using a rheostat, as the TRIAC simply "turns off" for part of the cycle rather than wasting energy as heat

3. Temperature Controller

Temperature control often uses an **SCR** (for DC heaters) or a **TRIAC** (for AC heaters) coupled with a feedback sensor.

- **Working:** A temperature sensor (like the **RTD Pt100** or **Thermistor** mentioned in your **Experiment 11**) monitors the heat.
- **Control Logic:** The sensor sends a signal to a comparator circuit. If the temperature is below the setpoint, the circuit decreases the firing angle (α), allowing more current to the heater.
- **Static Switching:** In some industrial heaters, instead of chopping every cycle, the SCR/TRIAC uses "Zero-Voltage Switching," where it stays fully ON for several cycles and then fully OFF for others to reduce electromagnetic interference (EMI).

4. Comparison for Application

Feature	Illumination Control	Temperature Control
Device Used	Typically TRIAC (for AC).	SCR or TRIAC.
Response Speed	Instantaneous.	Slow (due to thermal inertia).
Primary Goal	Change brightness/Lumen output.	Maintain stable temperature.
Feedback	Usually manual (Human eye).	Automatic (RTD/Thermistor).

5.Explain SCR-based AC and DC circuit breakers.

Ans- **1. DC SCR Circuit Breaker**

In a DC circuit, the main challenge is that the current never naturally crosses zero. Once an SCR is turned ON, it stays ON. Therefore, a "Commutation Circuit" is required to force the SCR to turn OFF during a fault.

- **Working:** Under normal conditions, the main SCR (SCR_1) is triggered and conducts power to the load. A capacitor (C) is kept charged via a secondary circuit.
- **Trip Mechanism:** When a fault (short circuit) is detected, a secondary "Auxiliary SCR" (SCR_2) is triggered. This connects the charged capacitor across SCR_1 in reverse polarity.
- **Current Interruption:** The reverse voltage from the capacitor forces the current in SCR_1 to zero, turning it OFF and successfully breaking the DC circuit.

2. AC SCR Circuit Breaker

AC breakers are simpler because the AC current naturally passes through zero twice every cycle.

- **Working:** Since an SCR conducts in only one direction, an AC breaker typically uses two SCRs connected in **Anti-Parallel** (or a single TRIAC for lower power).
- **Normal Operation:** Both SCRs receive continuous gate pulses (or pulses synchronized with the phase), allowing current to flow during both the positive and negative half-cycles.

- **Trip Mechanism:** When the control sensing circuit detects an overcurrent, it immediately stops providing trigger pulses to the gates.

- **Current Interruption:** The SCRs do not turn off instantly; they wait until the AC waveform reaches the next **natural zero-crossing**. At that point, the current drops below the "Holding Current" (I_H), and the SCRs turn OFF, isolating the fault.

3. Comparison of SCR Breakers vs. Mechanical Breakers

Feature	**SCR (Solid-State) Breaker**	**Mechanical Breaker**
Switching Speed	Extremely Fast (μs)	Slower (ms)
Arcing	**None** (No physical contacts)	High (Requires arc chutes)
Wear and Tear	Virtually zero (No moving parts)	High (Mechanical fatigue)
Power Loss	Higher (Voltage drop across SCR)	Very Low (Metal-to-metal contact)
Cost	Expensive	Economical

10 <u>Marks Questions</u>

1.Describe applications like burglar's alarm, battery charger using SCR, emergency light system, temperature controller using SCR, illumination control/fan speed control using TRIAC, SMPS, offline and online UPS, and SCR-based AC and DC circuit breakers with suitable diagrams and explanations.

Ans-1. Burglar Alarm using SCR

An SCR is ideal for alarms because of its latching property: once triggered, it stays ON even if the intruder closes the door or window again.

- Working: A thin wire or magnetic switch is placed on the door. When the door is opened (breaking the circuit) or a sensor is tripped, a small current is sent to the Gate of the SCR. The SCR fires, activating a bell or siren. Because the SCR latches, the alarm will continue to ring until the owner manually resets the power.

2. Battery Charger using SCR

SCRs are used to create "smart" chargers that prevent overcharging.

- Working: The AC mains is stepped down and rectified. The SCR sits between the charger and the battery. A sensing circuit (often using a Zener diode) monitors the battery voltage. Once the battery reaches its full target voltage, the sensing circuit stops providing gate pulses to the SCR, effectively cutting off the charging current.

3. Emergency Light System

This system automatically turns on a lamp when the main AC power fails.

- Working: Under normal conditions, AC power charges the battery and provides a reverse bias to the SCR gate, keeping it OFF. When AC power fails, the charging circuit stops, and the battery provides a forward bias to the SCR gate through a resistor. The SCR triggers, and the emergency lamp (connected to the battery) turns on instantly.

4. Temperature Controller using SCR
As discussed in your Experiment 11 (RTD/Thermistors), SCRs can regulate heaters by controlling power flow.

- Working: An SCR is used to control the current to a heating element. A sensor (like a thermistor) measures the heat. If the temperature is too low, the firing angle (α) of the SCR is decreased to allow more power. As the setpoint is reached, the firing angle is increased to reduce heat output.

5. Illumination and Fan Speed Control (TRIAC)
Since AC fans and lights need power in both directions of the sine wave, a TRIAC is used instead of a single SCR.

- Working: A DIAC and an RC (Resistor-Capacitor) network are used to trigger the TRIAC. By turning the knob (potentiometer), you change the charging time of the capacitor. This delays the TRIAC's "firing," which reduces the RMS voltage to the fan or bulb, slowing it down or dimming it.

6. Switched Mode Power Supply (SMPS)
An SMPS is a highly efficient power converter found in computers and mobile chargers.

- Working: Instead of using a heavy transformer to drop voltage, an SMPS "chops" the incoming DC at very high frequencies (kHz to MHz) using a high-speed power transistor. This high-frequency AC is then passed through a tiny transformer and rectified back to DC. A feedback loop constantly adjusts the "duty cycle" to keep the output voltage rock-solid.

7. Offline vs. Online UPS
As we compared earlier, these provide backup power:

- Offline UPS: Passes utility power directly to the load. It only switches to the battery/inverter when the power fails (5–10ms delay).
- Online UPS: Constantly converts AC to DC and back to AC. The load always runs off the inverter, providing zero transfer time and perfect isolation from grid noise.

8. SCR-based AC and DC Circuit Breakers
These are "Solid-State" breakers with no moving parts.

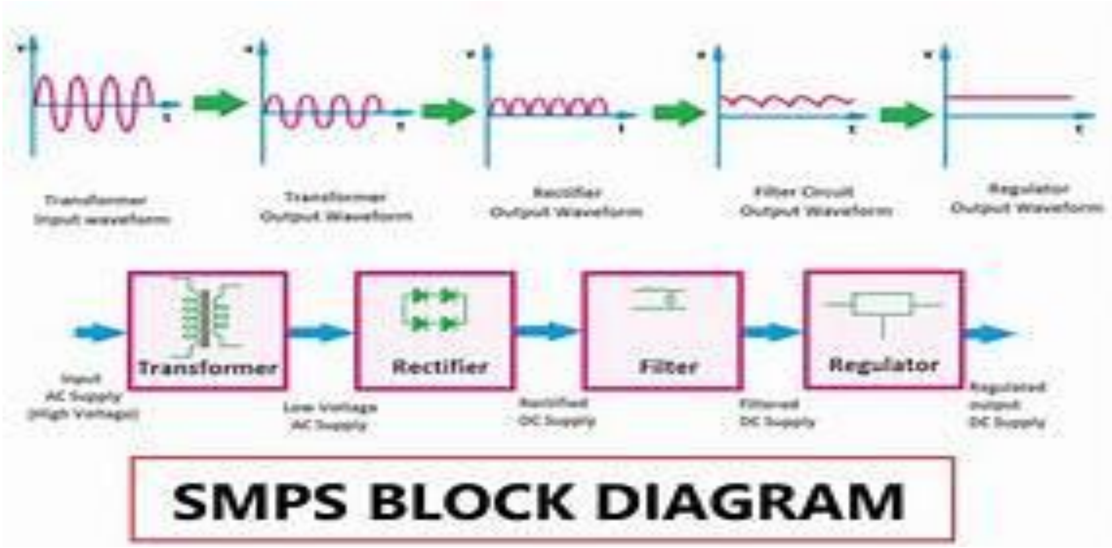
- DC Breaker: Requires a commutation capacitor to force the current to zero to turn the SCR off when a fault occurs.
- AC Breaker: Uses two SCRs in anti-parallel. It "trips" by simply stopping the gate pulses; the SCR then turns off naturally at the next zero-crossing of the AC wave.

2.Explain the working of SMPS and UPS (both offline and online types) in detail with block diagrams, advantages, and applications in industrial control.

Ans- 1. **Switched Mode Power Supply (SMPS)**

An SMPS is an electronic power supply that uses a switching regulator to convert electrical power efficiently. Unlike linear supplies, which dissipate excess voltage as heat, an SMPS "switches" high-frequency transistors between fully ON and fully OFF states.

Block Diagram & Working



1. Input Rectifier & Filter: The AC mains voltage is first rectified to unregulated DC and smoothed by a capacitor.
2. Inverter (High-Frequency Switching): A power transistor (MOSFET or IGBT) switches this DC at very high frequencies (typically 20 kHz to 1 MHz).
3. High-Frequency Transformer: This high-frequency AC is stepped down/up. Because the frequency is high, the transformer can be much smaller and lighter than a 50Hz transformer.
4. Output Rectifier & Filter: The secondary AC is rectified back to DC and filtered.
5. Feedback & Control: A controller monitors the output voltage and adjusts the Duty Cycle (the ratio of ON time to OFF time) to keep the output constant despite load changes.

Advantages:

- Efficiency: Usually 80% to 95%, as the transistor wastes little power in switching modes.
- Compact Size: High frequency allows for smaller transformers and capacitors.
- Wide Input Range: Can often handle a broad range of input voltages (85V–265V AC).

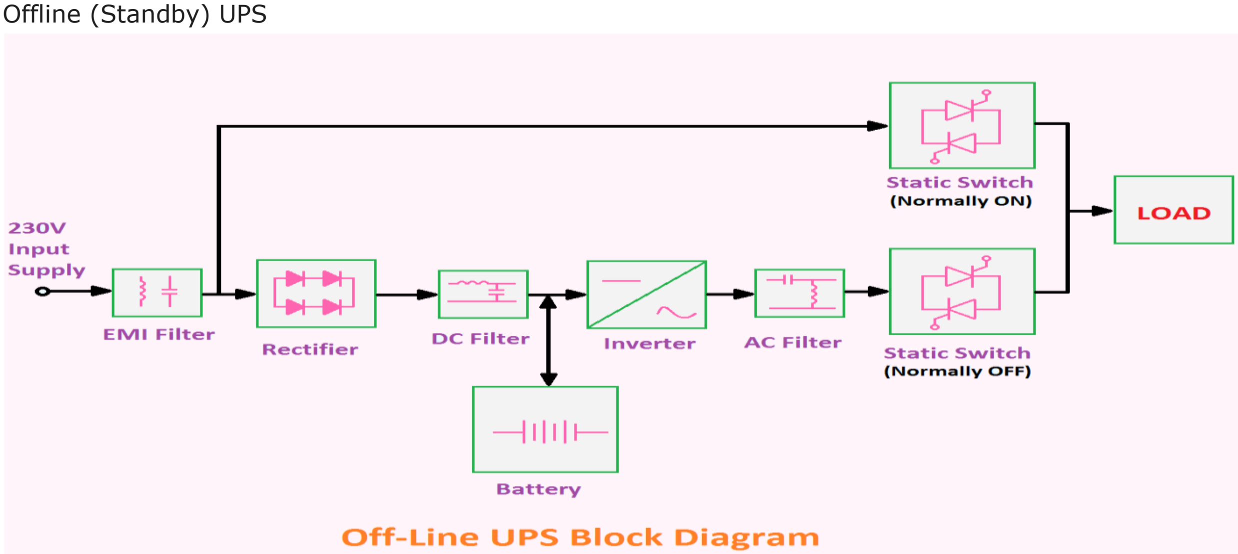
Industrial Applications:

- Powering PLC (Programmable Logic Controller) racks.
- Industrial PCs and CNC machine control units.

2. Uninterruptible Power Supply (UPS)

A UPS provides emergency power when the input source fails.

A. Offline (Standby) UPS

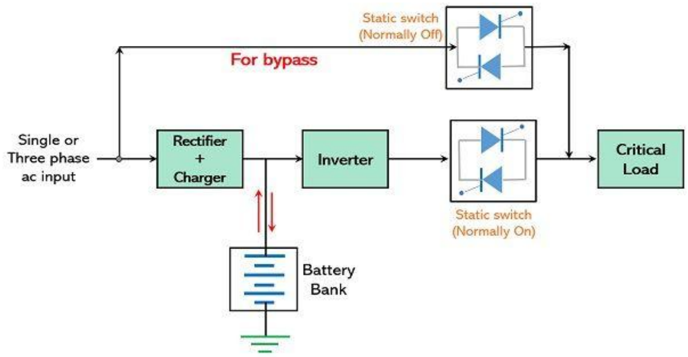


This is the simplest and most common type for non-critical loads.

- Working: Under normal conditions, utility power is filtered and passed directly to the load via a transfer switch. Meanwhile, a charger keeps the battery topped up. When power fails, the

switch moves to the Inverter position.
- Transfer Time: There is a delay of 5–10ms during the switch-over.
- Advantages: Low cost, high efficiency (inverter is usually OFF), and simple design.

B. **Online (Double Conversion) UPS**



Block Diagram of On-line UPS System

This is the standard for mission-critical industrial processes.

- Working: The load is always powered by the inverter. Incoming AC is converted to DC by the rectifier (which charges the battery) and then converted back to clean AC by the inverter.
- Transfer Time: Zero. There is no physical switch-over because the battery is already in the circuit path.
- Advantages: Total isolation from grid noise, spikes, and frequency variations. It provides the highest quality "Pure Sine Wave" output.

3. Comparison & Industrial Control Summary

Feature	SMPS	Offline UPS	Online UPS
Primary Goal	Efficient Voltage Conversion.	Basic Power Backup.	Critical Power Protection.
Output Stability	Very High.	Moderate.	Extremely High.
Industrial Use	Powering DC components within a machine.	Backing up non-critical control terminals.	Protecting main Servers and Data Centers.