

GOVT. POLY TECHNIC BHUBANESWAR

GOVT. OF ODISHA.

POWER ELECTRONICS & PLC

Semester: 5th Semester

Branch: Electrical Engineering

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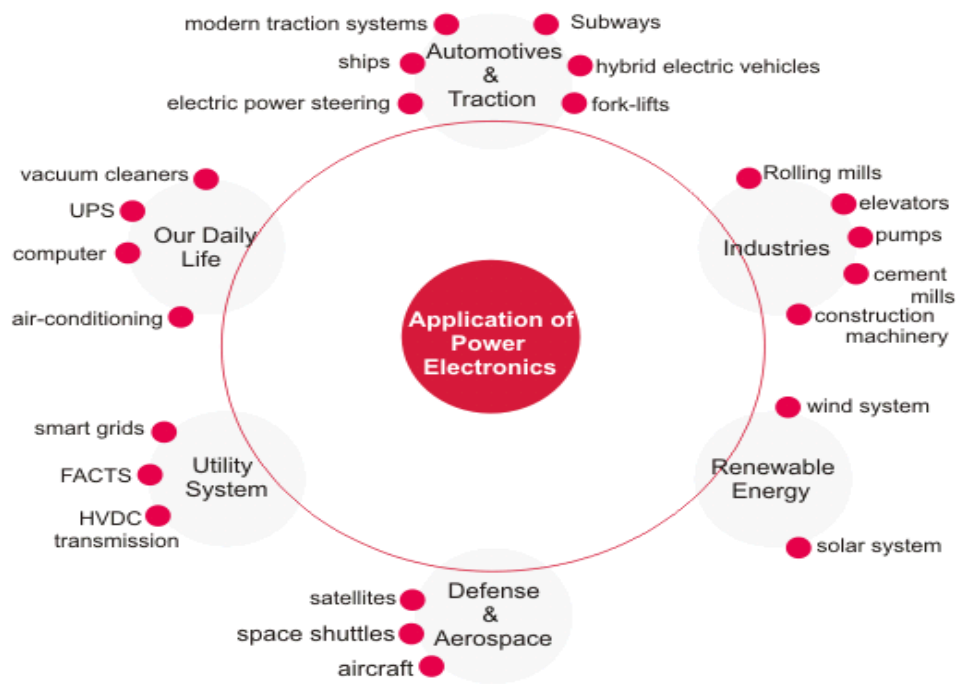
Prepared For: Diploma Students

Unit -1

UNDERSTAND THE CONSTRUCTION AND WORKING OF POWER ELECTRONIC DEVICES

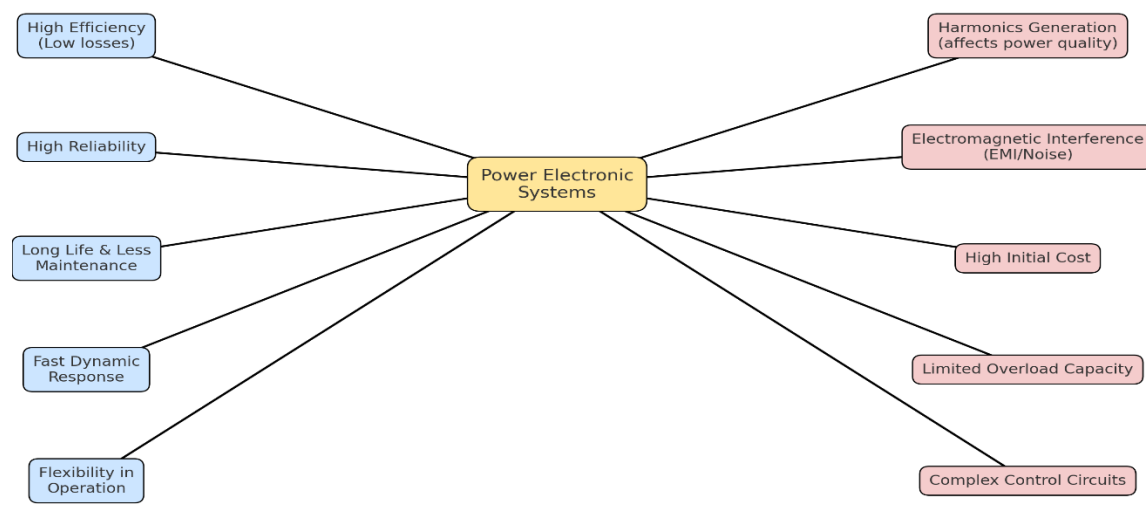
- 1.1 Construction, Operation, V-I characteristics & application of power diode, SCR, DIAC, TRIAC, Power MOSFET, GTO & IGBT
- 1.2 Two transistor analogy of SCR.
- 1.3 Gate characteristics of SCR.
- 1.4 Switching characteristic of SCR during turn on and turn off.
- 1.5 Turn on methods of SCR.
- 1.6 Turn off methods of SCR (Line commutation and Forced commutation)
 - 1.6.1 Load Commutation
 - 1.6.2 Resonant pulse commutation
- 1.7 Voltage and Current ratings of SCR.
- 1.8 Protection of SCR
 - 1.8.1 Over voltage protection
 - 1.8.2 Over current protection
 - 1.8.3 Gate protection
- 1.9 Firing Circuits
 - 1.9.1 General layout diagram of firing circuit
 - 1.9.2 R firing circuits
 - 1.9.3 R-C firing circuit
 - 1.9.4 UJT pulse trigger circuit
 - 1.9.5 Synchronous triggering (Ramp Triggering)
- 1.10 Design of Snubber Circuits

Power Electronics is the branch of electrical engineering that deals with the **control and conversion of electrical power** using **solid-state semiconductor devices** (like diodes, SCRs, MOSFETs, IGBTs, etc.). It involves converting electrical power from one form to another with **high efficiency, reliability, and flexibility**.



Advantages and Disadvantages

Power Electronic Systems: Advantages vs Disadvantages



Notes on Power Diode

1. Introduction

- A **power diode** is a semiconductor device used for **high power applications** (high current & high voltage).
- It allows current to flow **only in one direction** (forward bias).

2. Construction

- **P+ Anode (Heavily Doped)**

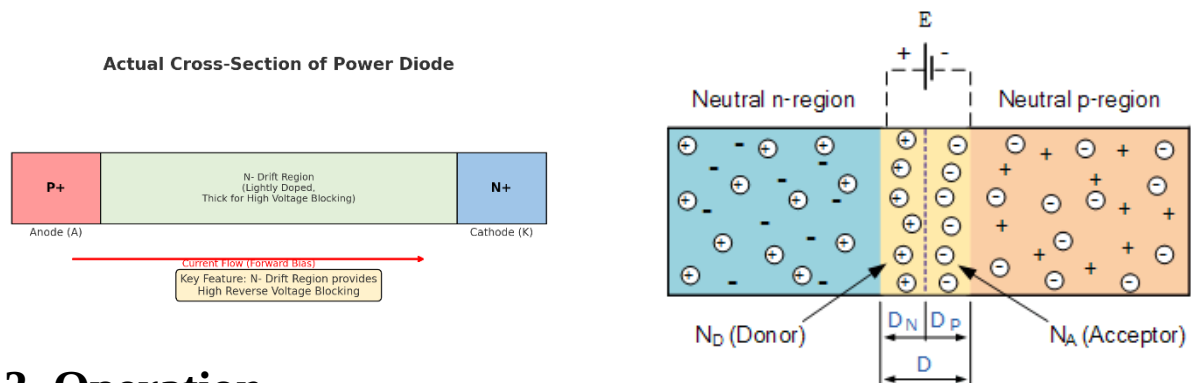
- Provides a large number of holes (majority carriers).
- Connected to the **anode terminal**.

- **N- Drift Region (Lightly Doped & Thick)**

- Supports **high reverse blocking voltage**.
- Thicker the drift region → higher the voltage withstand capacity.
- Responsible for power diode's difference from low-power diode.

- **N+ Cathode (Heavily Doped)**

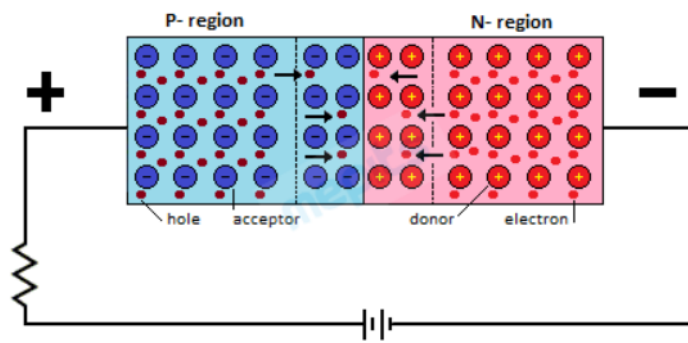
- Provides a large number of electrons.
- Connected to the **cathode terminal**.



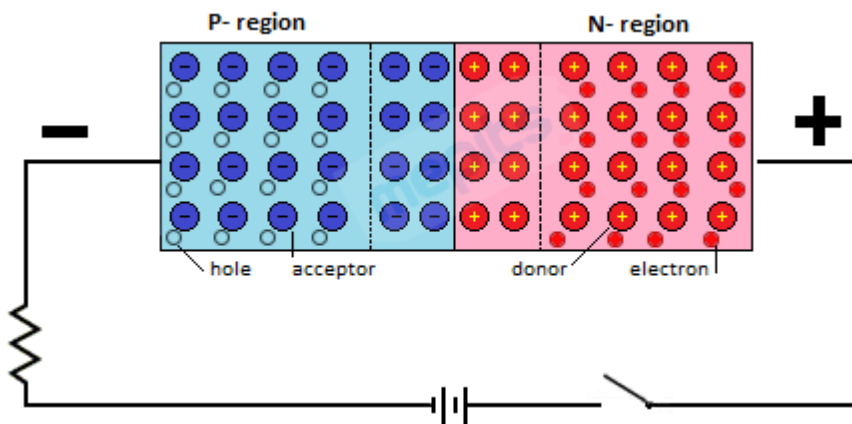
3. Operation

- **Forward Bias:**

- Anode positive, cathode negative.
- Current flows after threshold ($\sim 0.7V$ for Si diode and 0.3 for Ge diode).



- **Reverse Bias:**
 - Anode negative, cathode positive.
 - Only a small leakage current flows due to minority carrier until breakdown.



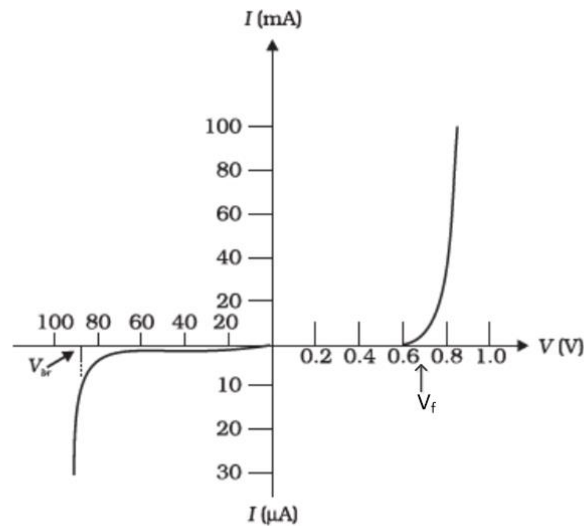
4.V–I Characteristics of a Diode

1. Forward Region

- Initially, only a **very small current** flows.
- Once the applied voltage reaches the **threshold voltage (V_f)** (≈ 0.7 V for Si, 0.3 V for Ge), conduction starts.
- After **V_f** , the **current rises rapidly** with a small increase in voltage.

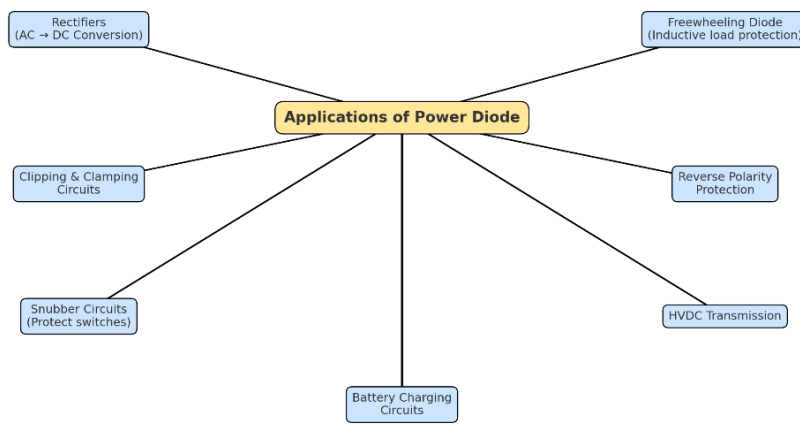
2. Reverse Region

- A **small leakage current** flows due to minority carriers.
- When the applied reverse voltage reaches the **breakdown voltage (V_{br})**, the diode starts conducting heavily in reverse direction.
- This reverse breakdown is **undesirable** (unless Zener diode is used).



V-I Char. Of Diode

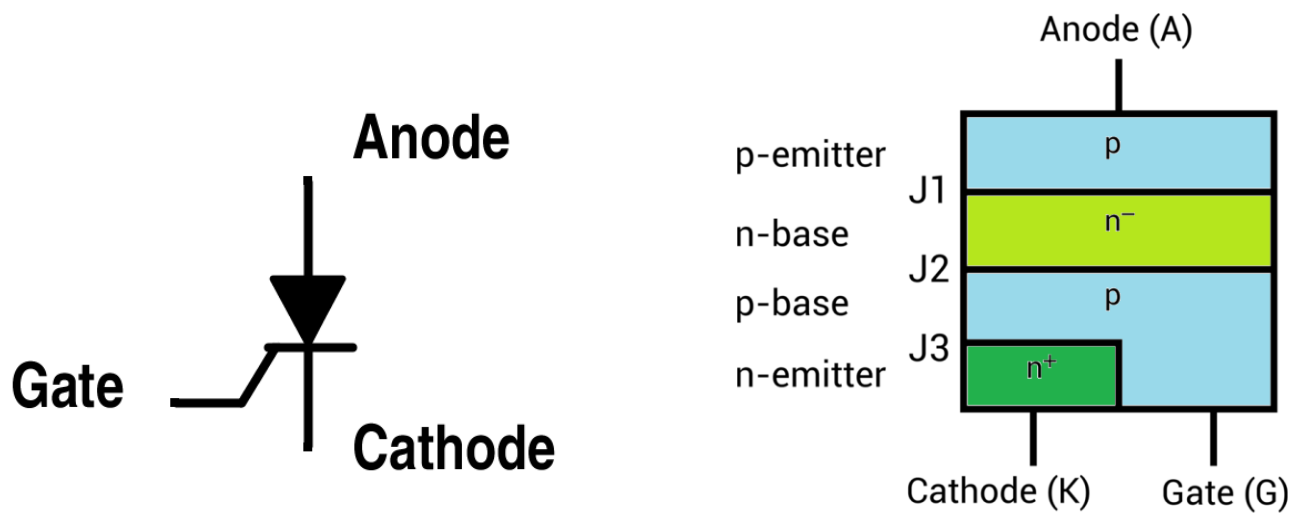
5. Application of Diode



Silicon Controlled Rectifier (SCR)

1. Construction

- **Four-layer PNP device** (like two transistors coupled) and 3 junction (J_1, J_2 and J_3) device.
- **Terminals:**
 - **Anode (A)** → connected to outer **P-layer** which is **highly doped**.
 - **Cathode (K)** → connected to outer **N-layer** which is **highly doped**.
 - **Gate (G)** → connected to inner **P-layer** (for triggering) which is **lightly doped**.
 - **J_1** - between anode and drift
 - **J_2** -between drift and gate
 - **J_3** between gate and cathode



2. Operation

Forward Blocking Mode

- Anode is positive w.r.t. cathode (no gate signal).
- Junctions **J1 and J3 are forward biased**, J2 is **reverse biased**.

Forward Conduction Mode

- Anode positive w.r.t. cathode and **positive gate current applied**.
- Junction **J1, J2, and J3 becomes forward biased** → SCR turns **ON**.

Reverse Blocking Mode

- Anode is negative w.r.t. cathode.
- Junctions **J1 and J3 are reverse biased**, J2 is **forward biased**.

3. V–I Characteristics

Reverse Blocking Region

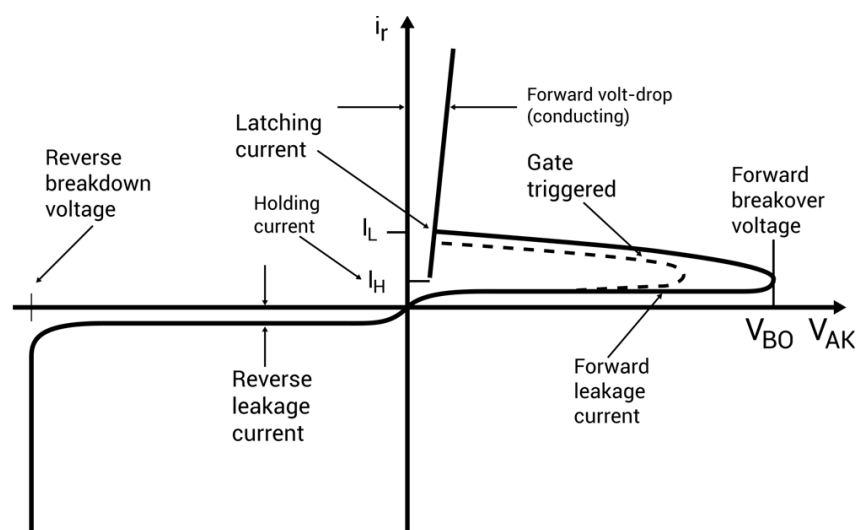
- Only a very small **leakage current** flows.
- If reverse voltage increases beyond **reverse breakdown voltage (V_{BR})** → device may be damaged.

Forward Blocking Region

- Only a **small leakage current** flows.
- SCR remains in the **OFF state** until a **gate pulse** is applied or V_{AK} **exceeds breakover voltage (V_{BO})**.

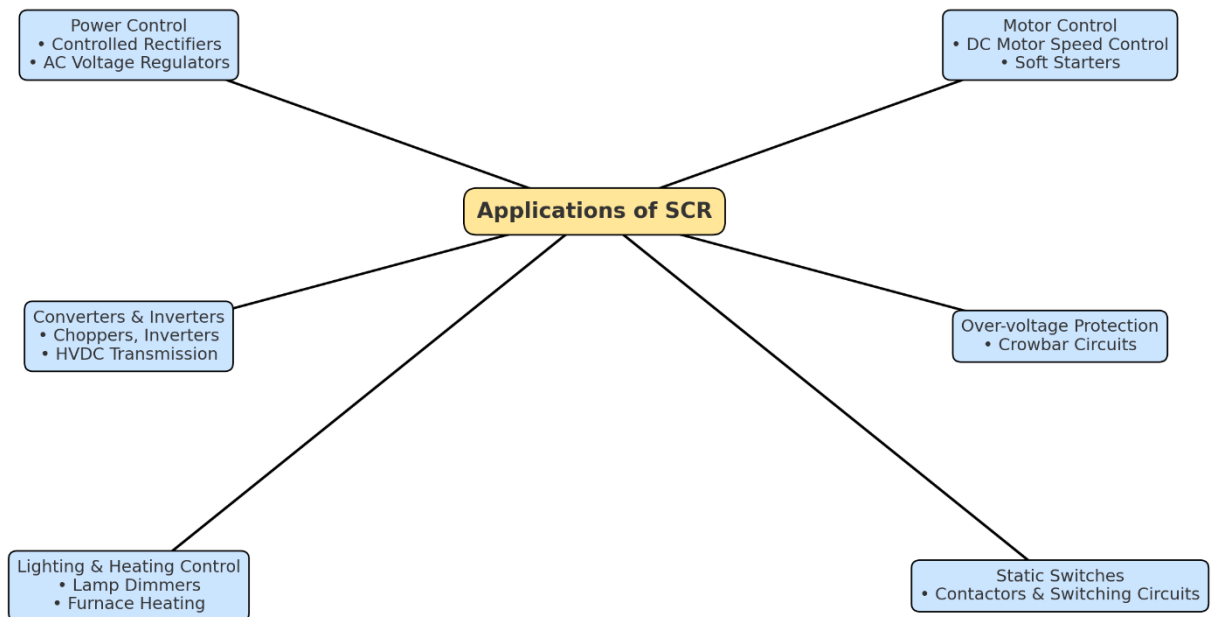
Forward Conduction Region

- Now SCR conducts with a very **small voltage drop** (~1–2 V).
- Large current flows → device in **ON state**.
- Once ON, SCR cannot be turned off by gate, only by reducing current below **holding current (I_H)**.



(V-I Char. Of SCR)

1. Application



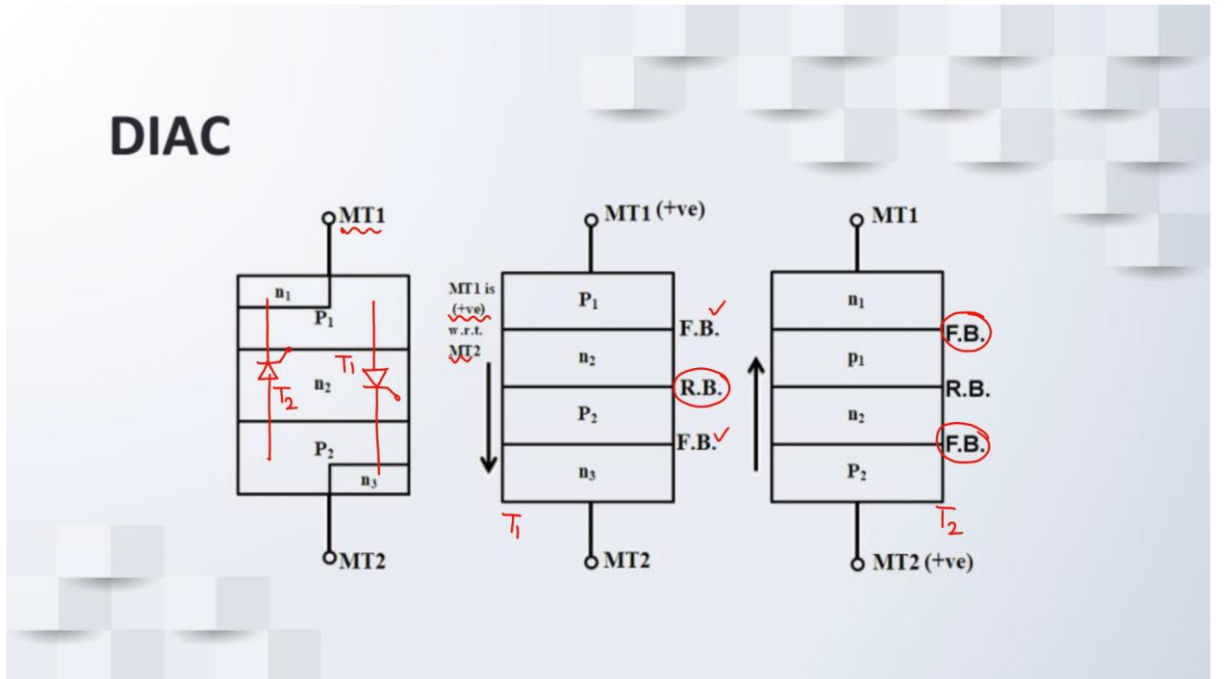
DIAC (Diode for Alternating Current)

1. Construction

- A **two-terminal, bidirectional device**.
- Can be considered as **two SCRs connected in parallel in opposite direction, but without gates**.
- Symmetrical PNPN structure.
- Terminals are called **MT1** and **MT2** (Main Terminals).



(Symbol)



2. Operation

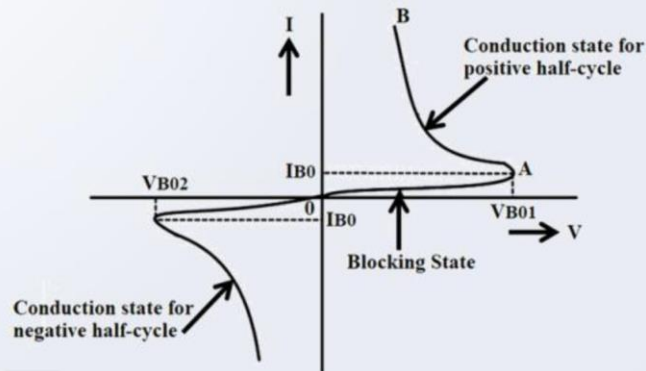
- **In both polarities**, DIAC remains OFF until the applied voltage reaches its **breakover voltage (VBO)**.
- At VBO, the device switches ON and conducts current.
- After turning ON, the voltage across DIAC drops sharply → exhibits **negative resistance characteristics**.
- Conduction continues until the current falls below the **holding current (IH)**.

3. V-I Characteristics

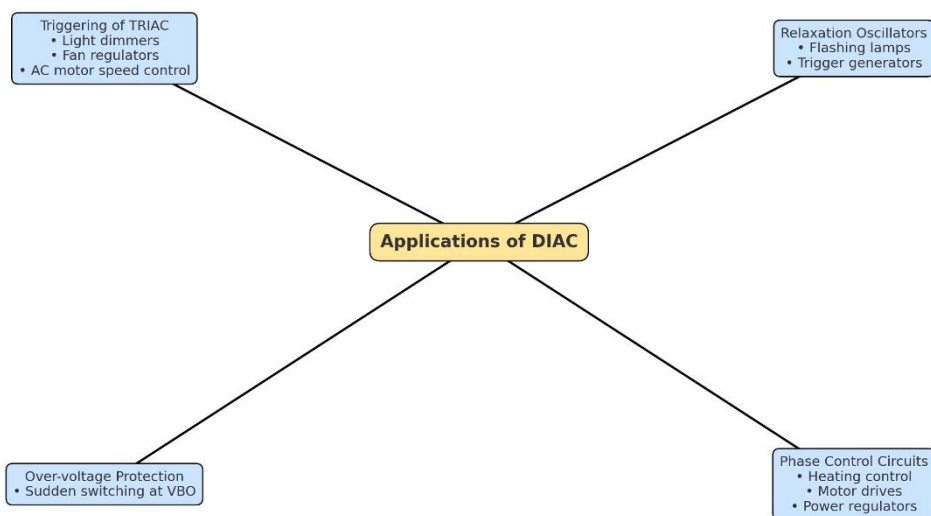
- Symmetrical about the origin (same for both positive and negative half cycles).
- **OFF state:** Almost no current flows until $\pm V_{BO}$.
- **ON state:** At breakover voltage, sudden switching occurs $\rightarrow$ current increases while voltage drops.
- **Negative resistance region** present after switching.

DIAC

used in triggering ckt of Triac.



4. Applications of DIAC

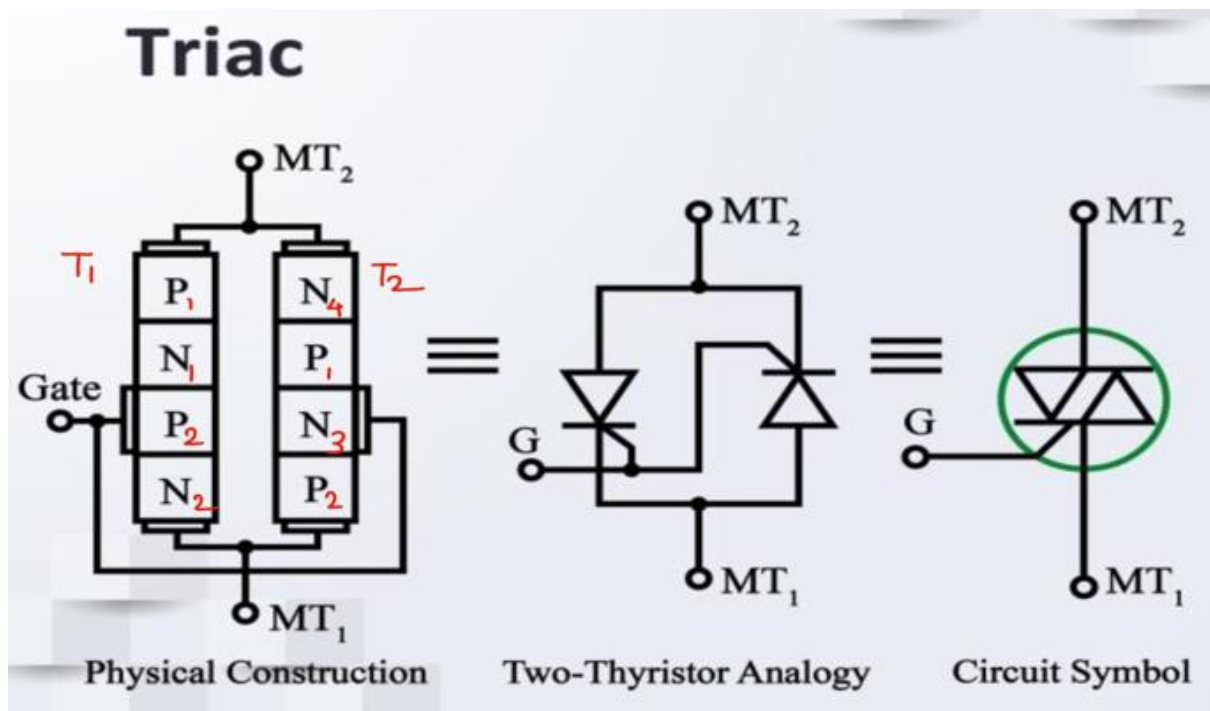


TRIAC (Triode for Alternating Current)

1. Construction

- A **bidirectional device** (can conduct current in both half cycles of AC).
- Equivalent to **two SCRs connected in parallel but opposite directions** with a **common gate**.
- Terminals:
 - **MT1 (Main Terminal 1)**
 - **MT2 (Main Terminal 2)**

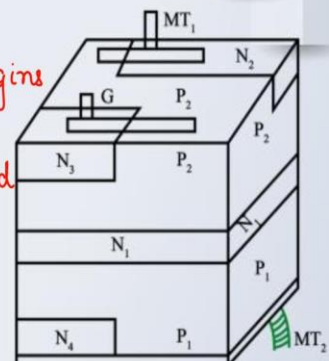
- Gate (G)

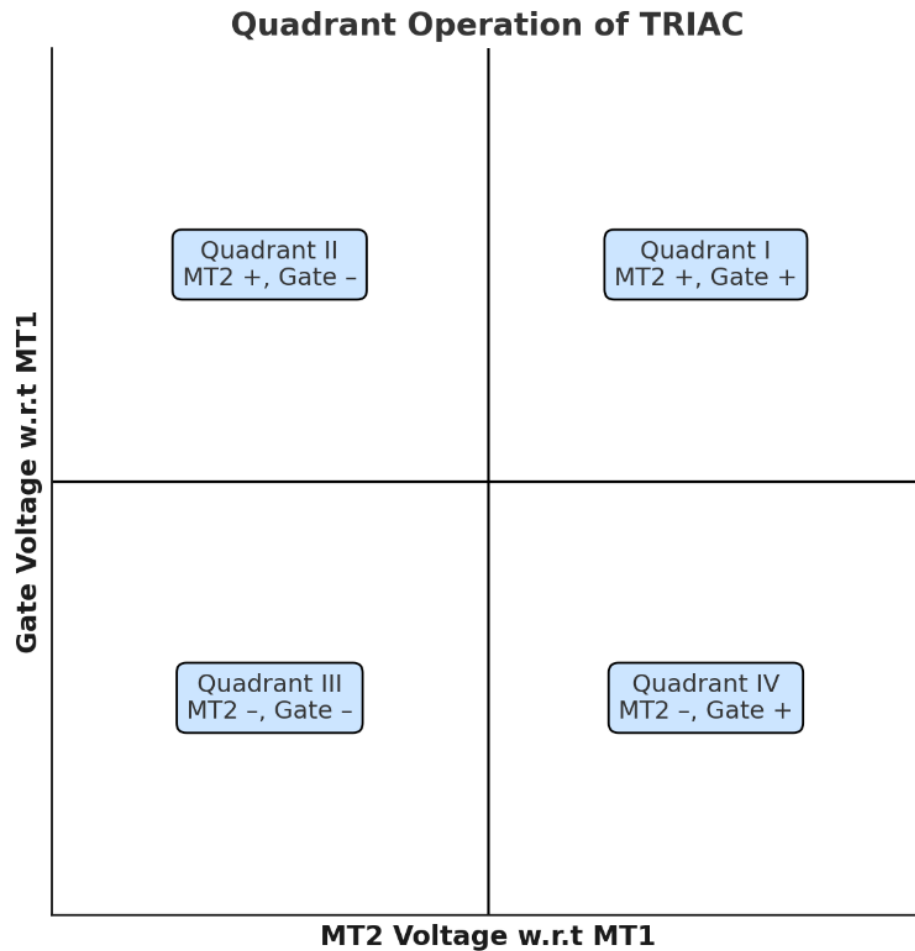


2. Operation

Triac

- When MT_1 (+ve) & MT_2 (-ve), T_2 is in forward blocking mode.
When -ve gate pulse is applied to N_3 , T_2 begins to conduct.
- When MT_1 (-ve) & MT_2 (+ve), T_1 is in forward blocking mode.
When positive pulse is applied to P_2 , T_1 begins to conduct.





3.V–I Characteristics of TRIAC

1. Symmetry

- The characteristics are **symmetrical about the origin**.
- TRIAC can operate in **both positive and negative half cycles** of AC.

2. OFF State

- In both positive and negative half cycles, **no current flows** until the voltage across MT1–MT2 reaches the **breakover voltage ($\pm V_{BO}$)**.

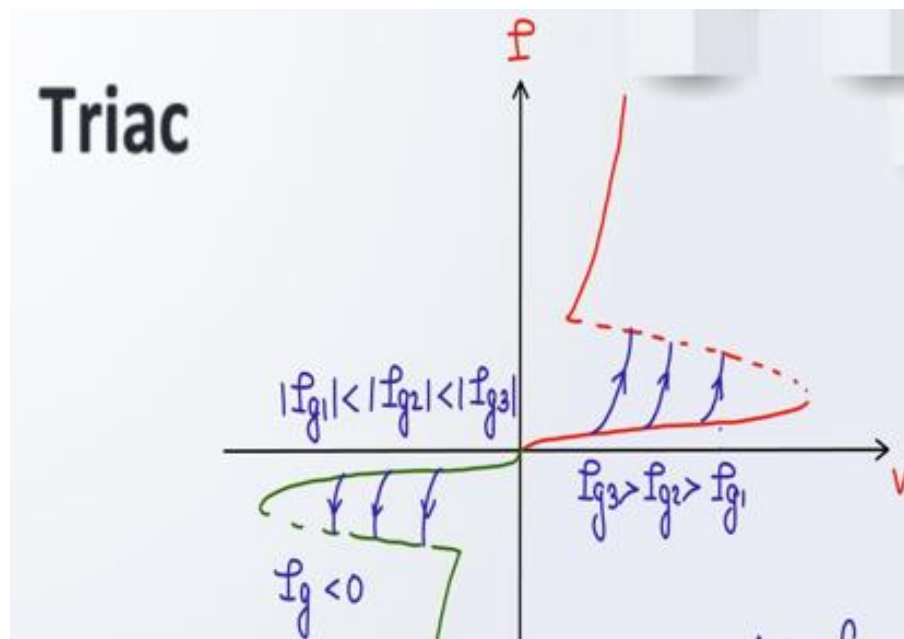
3. ON State

- Once triggered (by gate pulse or V_{BO}), the TRIAC switches ON suddenly.
- After switching, **large current flows** with only a **small voltage drop** across the device.

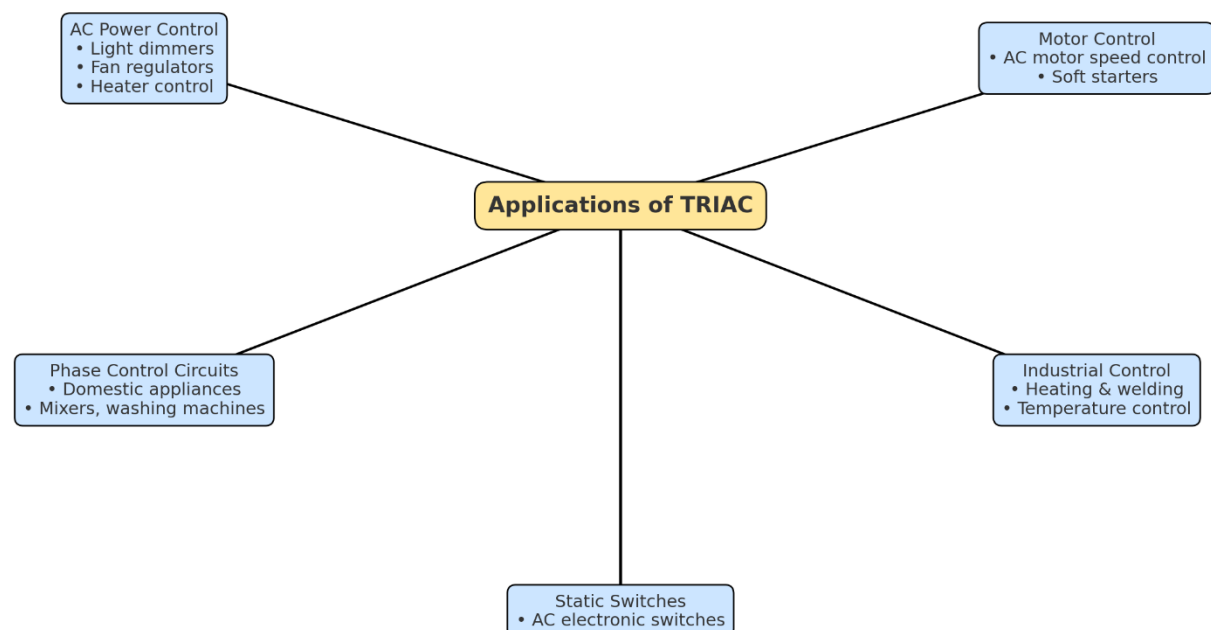
4. Bidirectional Conduction

- Conduction occurs in **both directions** (positive & negative cycles).

- Provides smooth control of AC power.



APPLICATIONS



POWER MOSFET

A. Construction of Power MOSFET

1. Substrate/Body

- Made of **p-type semiconductor**.
- Inside it, heavily doped **n^+ regions** are diffused to form **source terminals**.

2. Gate

- A **metal layer** is placed above the p-region, separated by a thin **SiO_2 insulating layer**.
- This provides **insulated gate control** (very high input impedance).

3. Source

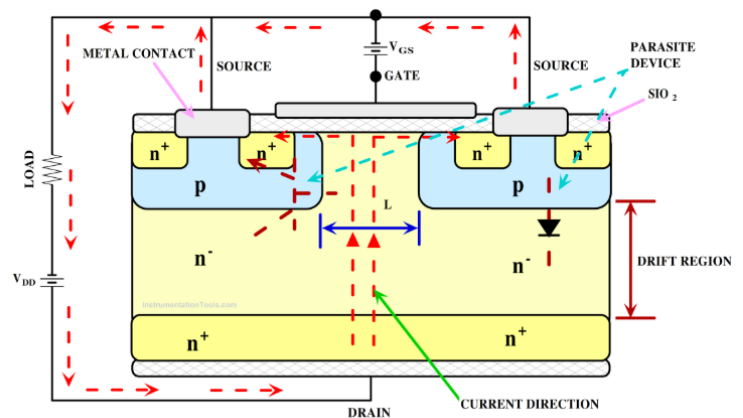
- Provides charge carriers (electrons for n-channel MOSFET).
- Consists of **n^+ regions**.

4. Drain & Drift Region

- On the other side, a heavily doped **n^+ drain contact** is formed.
- In between lies the **n^- drift region**, which supports high voltage.

5. Body Diode

- An inherent **p-n junction** exists between body and drain, forming a **parasitic diode**.
- Important for reverse current in switching applications.



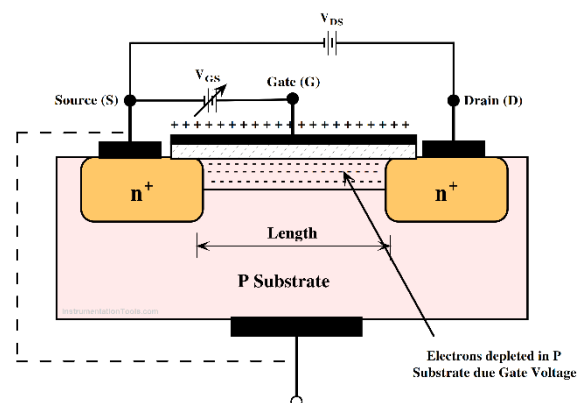
Key Point:

- Power MOSFETs use a **vertical structure** → high current from **Source** → **Drain** through drift region.
- Gate voltage **controls the channel formation** between Source & Drain.

B. Operation

1. Gate Control

- Gate controls the **ON/OFF** state of MOSFET.
- **V_{GS} (Gate-to-Source voltage)** is applied.
- Gate is separated by **SiO_2 insulation** → so no gate current flows.



2. Electric Field

- A **positive gate voltage** creates an **electric field (E-field)**.
- This field:
 - Pushes **holes away** from gate region (p-body).
 - Attracts **electrons** below the gate.

3. Channel Formation (Inversion)

- When electron concentration is higher than hole concentration → region under gate becomes **n-type**.
- This process is called **Inversion**.
- An **n-channel** forms between Source and Drain.

4. Current Flow

- Electrons move from **Source** → **n-channel** → **Drift region** → **Drain**.
- Voltage across **Drain-Source (VDS)** pulls electrons.
- Drain collects electrons → current flows.

5. Important Points

- MOSFET is a **voltage-controlled device**.
- Works with **majority carriers (electrons)** → **fast switching**.
- Has **high input impedance** (no gate current).

✓ **For SETVT Exams → Write:**

- Gate voltage controls conduction.
- Positive V_{GS} forms n-channel (Inversion).
- Current flows from Source → Drain by electrons.
- It is a **majority carrier, fast-switching device**.

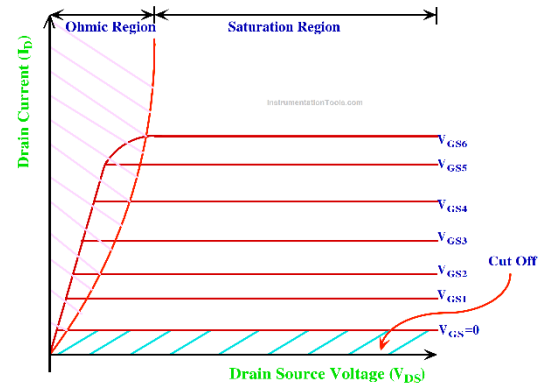
C. Symbol

Enhancement Type N Channel MOSFET	Enhancement Type N Channel MOSFET	Enhancement Type P Channel MOSFET	Enhancement Type P Channel MOSFET

D. V-I Characteristics

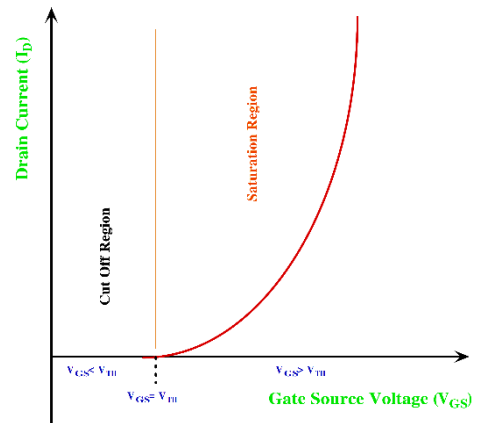
- **Output Characteristics (ID vs VDS):**

- **Cutoff Region:** $V_{GS} < V_{th} \rightarrow I_D \approx 0$.
- **Ohmic (Linear) Region:** $I_D \propto V_{DS}$ (acts like a variable resistor).
- **Saturation (Active) Region:** I_D controlled by V_{GS} , independent of V_{DS} .

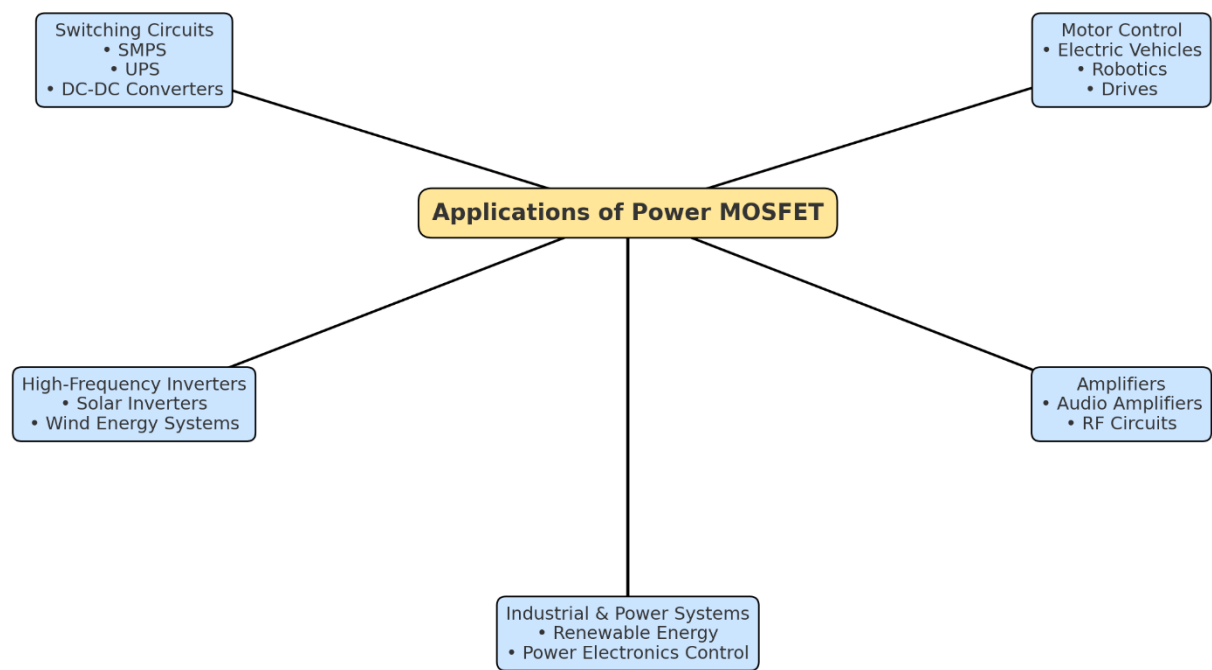


- **Transfer Characteristics (ID vs VGS):**

- $I_D \propto (V_{GS} - V_{th})^2$ in enhancement mode.



E. APPLICATION



GTO (Gate Turn-Off Thyristor)

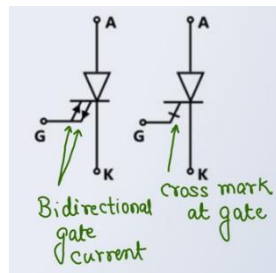
1. Definition

☞ A **GTO** is a type of **thyristor** which can be **turned ON** by a **gate pulse** and also **turned OFF** by a **negative gate pulse**.

☞ It is called **GTO** because it can be **turned OFF** by applying a negative gate pulse.

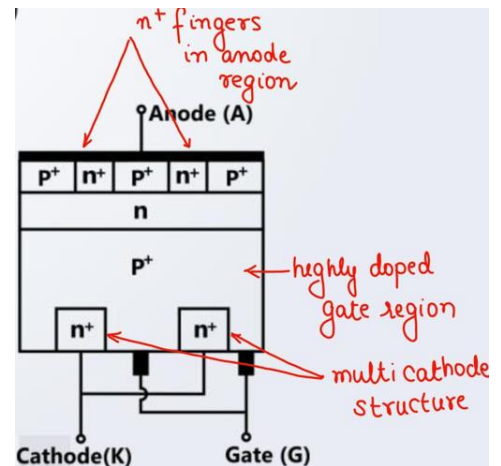
☞ Hence, it is a **fully controlled switch**.

☞ Symbol



2. Construction

- Four-layer **PNPN structure** (like an SCR).
- Terminals:
 - **Anode (A)**
 - **Cathode (K)**
 - **Gate (G)**
- Difference from SCR → GTO can be **turned OFF** by **gate**, while SCR needs current to fall below holding current.
- In GTO, the Anode is composed of p^+ layer with n^+ type fingers diffused in it. This is not the case for a conventional thyristor.

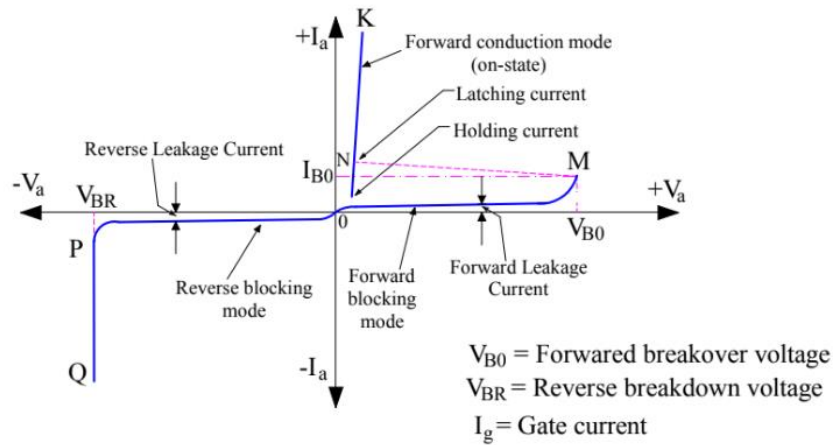


3. Operation

- **Turn ON** → Apply **positive gate pulse**.
- **Turn OFF** → Apply **negative gate pulse** (extracts carriers).
- Can switch at **high voltage & current levels**.

4. V-I Characteristics

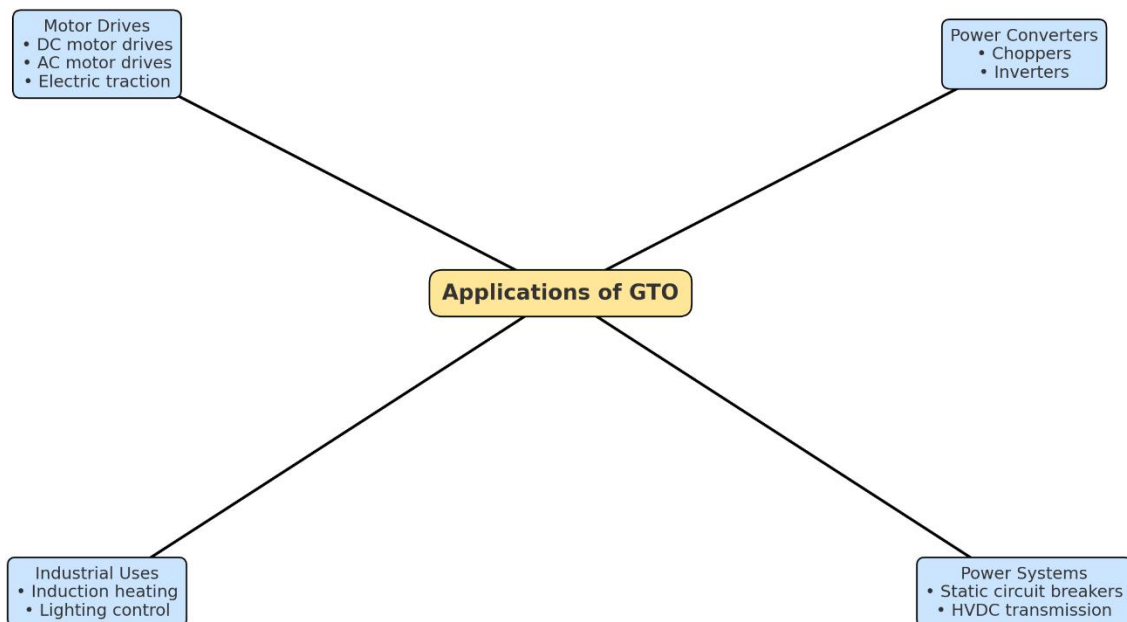
- Similar to SCR, but **gate control works for both ON and OFF**.
- Forward blocking, conduction, and reverse blocking regions are same as SCR.



SCR vs GTO (Quick Compare)

Feature	SCR	GTO
Structure	P ⁺ anode only	N ⁺ fingers in P ⁺ anode
Commutation	Needs circuit	No commutation circuit
Frequency	≤ 1 kHz	> 1 kHz
Latching Current	Low (100–500 mA)	High (~2 A)
Reverse Blocking	High	Low (20–30 V)
Gate Current	Low	High
Efficiency	Lower	Higher

5. Applications

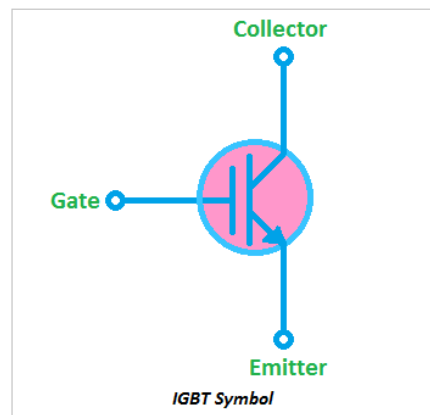


IGBT (Insulated Gate Bipolar Transistor)

1. Definition

☞ IGBT is a **three-terminal power semiconductor device** that combines the features of MOSFET (voltage control, fast switching) and BJT (low conduction losses, high current handling).

IGBT Symbol



2. Construction

◆ Basic Idea

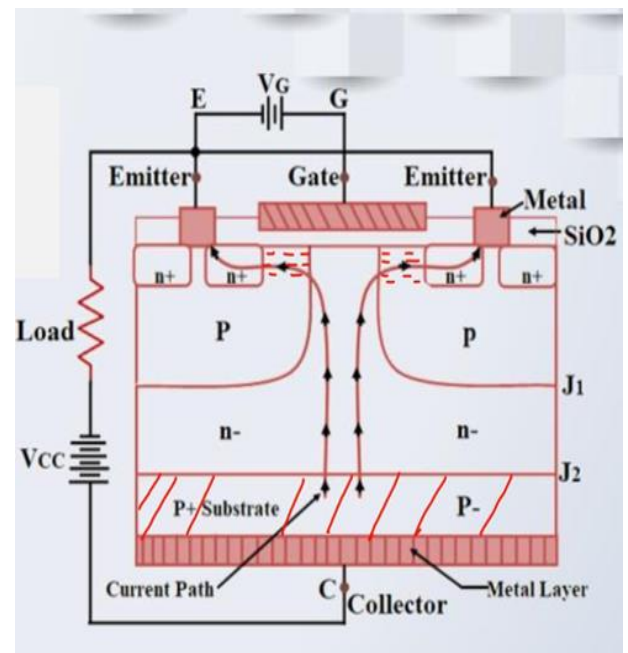
- IGBT is derived from **Power MOSFET**, but with a change:
 - ☞ In Power MOSFET → **n⁺ drain layer**
 - ☞ In IGBT → replaced by **p⁺ collector layer**

◆ Layer Structure

- **Top** → Emitter (E)
- **Gate (G)** → insulated by SiO₂ layer
- **Body** → p-layer + n⁻ drift region + p⁺ substrate
- **Bottom** → Collector (C)
- Junctions: **J1** and **J2**

◆ Terminals Mapping

- **MOSFET Source** → **IGBT Emitter (E)**
- **MOSFET Drain** → **IGBT Collector (C)**
- **MOSFET Gate** → **IGBT Gate (G)**



3. Operation

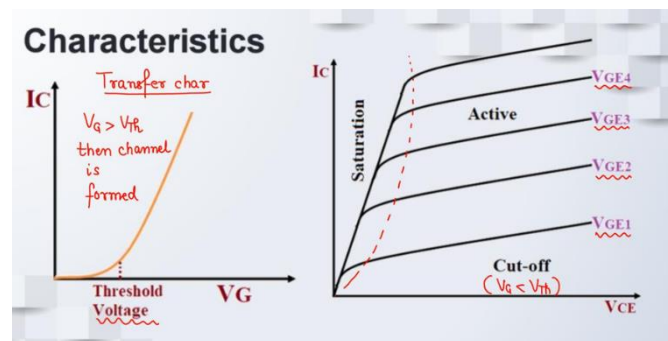
1. **Gate ON (Positive Voltage at Gate):**
 - Gate voltage creates an **inversion channel** under the gate terminal.
 - This allows **electrons** to flow from the **Emitter** → **Collector**.
 - Once the channel is created, the device behaves like a **PN junction diode** between collector & emitter.
2. **Conduction:**
 - **Electrons flow** from **Emitter** → **Collector**.
 - **Holes flow** from **Collector** → **Emitter**.
 - This makes IGBT a **bipolar device** (both majority & minority carriers take part).
 - Current mainly flows **Collector** → **Emitter** just like in an **npn transistor**.
3. **Gate OFF (Zero Voltage at Gate):**
 - Channel disappears.
 - No conduction (except leakage current).

☞.Special Points

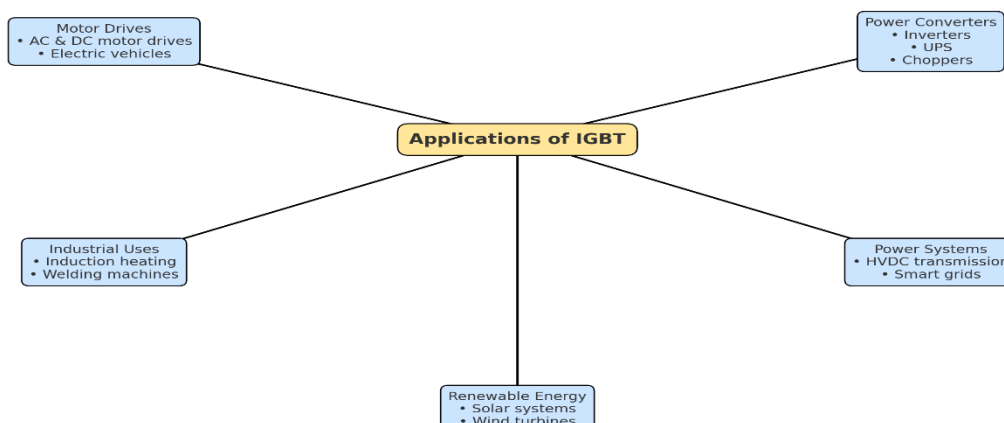
- IGBT does **not** contain any diode, but it contains a **thyristor-like structure** internally.
- Combines:
 - **MOSFET property** → Gate control (voltage controlled, high input impedance).
 - **BJT property** → Current conduction (low loss).

4. V-I Characteristics

- **Cutoff Region:** $V_{GE} < V_{th}$ → device OFF.
- **Active Region:** Current controlled by V_{GE} , like MOSFET transfer.
- **Saturation Region:** Low conduction drop, behaves like BJT.



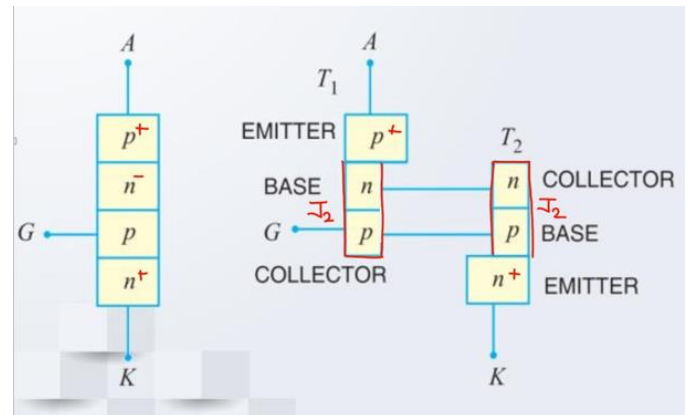
5. Applications of IGBT



1.2 Two-Transistor Analogy of SCR

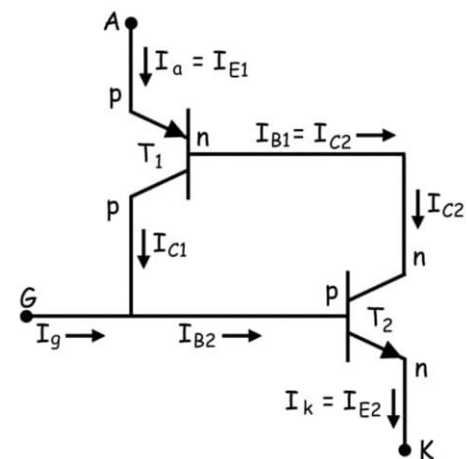
1. Concept

- An SCR has **4 layers (PNPN)** and **3 junctions (J1, J2, J3)**.
- It can be represented as a combination of **two transistors**:
 - **Q1 (PNP transistor)**
 - **Q2 (NPN transistor)**



2. Equivalent Model

- Upper half (P–N–P) → acts like **PNP transistor (Q1)**.
- Lower half (N–P–N) → acts like **NPN transistor (Q2)**.
- The **collector of Q1** is connected to the **base of Q2**.
- The **collector of Q2** is connected to the **base of Q1**.
- Thus, they form a **positive feedback loop**.



3. Working

- When a **gate pulse** is applied:
 - Q2 starts conducting → provides base current to Q1.
 - Q1 conducts → provides base current to Q2.
 - This regenerative action continues until both transistors go into **saturation**.
- Hence, SCR turns ON and conducts heavily.
- Once ON, it remains conducting even if gate pulse is removed (latching).
- When gate current (I_g) is applied:
 - The base current of transistor T2 increases, so its collector current (I_{C2}) increases.
 - Base current of transistor T1 (I_{B1}) equals collector current of T2 (I_{C2}), so I_{B1} also increases.
 - Collector current of transistor T1 (I_{C1}) increases, since $I_{C1} = \beta \times I_{B1}$.
 - The base current of transistor T2 is $I_{B2} = I_{C1} + I_g$, so I_{B2} further increases.

This creates a regenerative loop:

Gate current → $I_{B2} \uparrow \rightarrow I_{C2} \uparrow \rightarrow I_{B1} \uparrow \rightarrow I_{C1} \uparrow \rightarrow I_{B2} \uparrow$ **again.**

For transistor T1 (PNP type):

- Anode current (I_A) = $I_{C1} + I_{B1} = I_{C1} + I_{C2}$

For a general transistor:

- Collector current (I_C) = $\alpha \times \text{emitter current (IE)} + I_{CBO}$

Where:

- α = Common-base current gain, less than 1
- $\alpha \times I_E$ = Component of collector current due to charges injected from the emitter
- I_{CBO} = Reverse saturation current of collector–base junction

Derivation of Anode Current (I_A) in Two-Transistor Model

$$\begin{aligned}
 I_A &= I_{C1} + I_{C2} \\
 &= \alpha_1 I_{E1} + I_{CBO1} + \alpha_2 I_{E2} + I_{CBO2} \\
 &= \alpha_1 I_A + \alpha_2 I_g + (I_{CBO1} + I_{CBO2}) \\
 \text{By KCL, } I_A + I_g &= I_K \\
 I_A &= \alpha_1 I_A + \alpha_2 (I_A + I_g) + (I_{CBO1} + I_{CBO2}) \\
 I_A (1 - \alpha_1 - \alpha_2) &= \alpha_2 I_g + (I_{CBO1} + I_{CBO2}) \\
 I_A &= \frac{\alpha_2}{1 - (\alpha_1 + \alpha_2)} I_g + \frac{(I_{CBO1} + I_{CBO2})}{1 - (\alpha_1 + \alpha_2)}
 \end{aligned}$$

1.3 Gate Characteristics of SCR

1. Definition

- Gate characteristics show the relationship between **gate voltage (V_G)** and **gate current (I_G)** for a given junction temperature.
- They indicate how much **gate current** is needed to trigger the SCR at different gate voltages.

2. Gate Ratings of SCR (Thyristor)

At the time of manufacturing, every SCR is specified with **maximum and minimum gate ratings**.

These limits must be followed for safe and reliable operation.

1. Maximum Ratings

1. Maximum Gate Voltage (V_{g-max}):

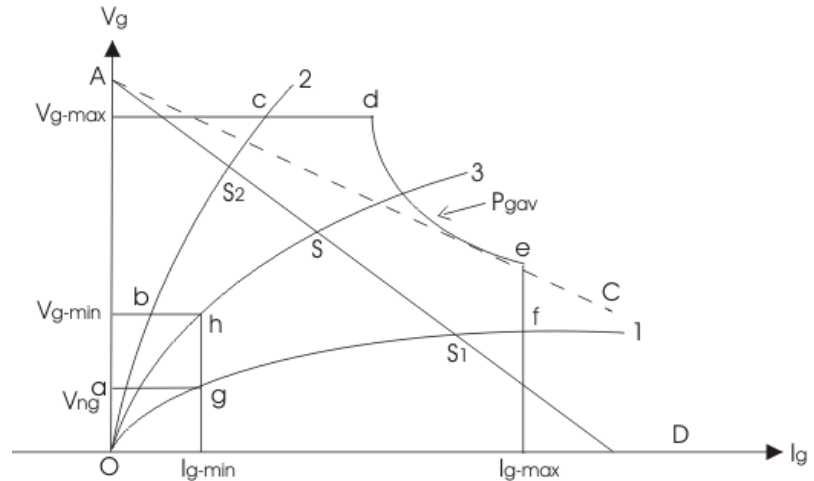
- Highest gate voltage that can be applied safely.
- Exceeding this may **damage the gate junction**.

2. Maximum Gate Current (I_{g-max}):

- Highest gate current allowed.
- Beyond this → **excessive heating & junction failure**.

3. Maximum Average Gate Power Dissipation (P_{gav}):

- Defined as $P_g = V_g \times I_g$.
- Limits the **power handled by gate**.



2. Minimum Ratings

1. Minimum Gate Voltage (V_{g-min}):

- Lowest gate voltage required to **successfully turn ON the SCR**.

2. Minimum Gate Current (I_{g-min}):

- Minimum current needed to initiate conduction.
- Also called **Gate Trigger Current (IGT)**.

- The **turn-on characteristics of an SCR** can be represented by two important curves:

1. **Curve 1** → Represents the **minimum voltage** required to turn ON the SCR.
2. **Curve 2** → Represents the **maximum safe voltage** that the SCR can handle.

- The **safe operating region** of the SCR lies **between these two curves**, i.e., within the area **bcdefgh** in the characteristic diagram.

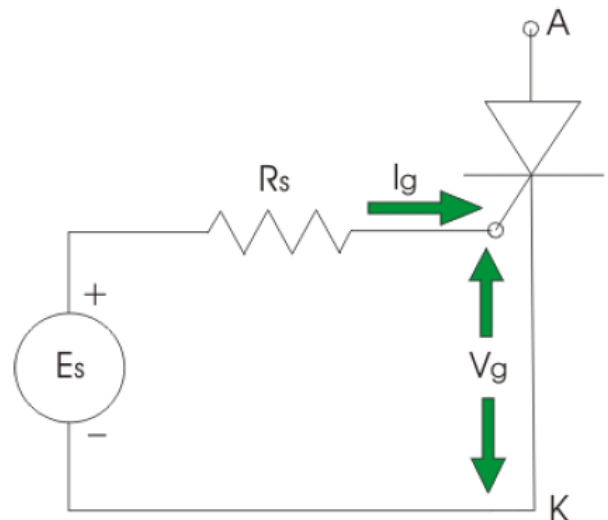
Gate Triggering Circuit of SCR

From the circuit,

$$E_s = V_g + I_g \times R_s$$

Where:

- E_s → Gate source voltage (applied DC supply)
- V_g → Gate-to-Cathode voltage drop (≈ 0.7 V for silicon)
- I_g → Gate current (controls triggering)
- R_s → Gate series resistance (used to limit current)



Working:

- A DC supply E_s is applied between **Gate** and **Cathode** through resistor R_s .
- The resistor R_s limits the **Gate current** (I_g) so it does not exceed the safe value.
- When $I_g \geq I_{g(\min)}$, the SCR turns ON.
- The relation can also be rearranged as:

$$I_g = (E_s - V_g) / R_s$$

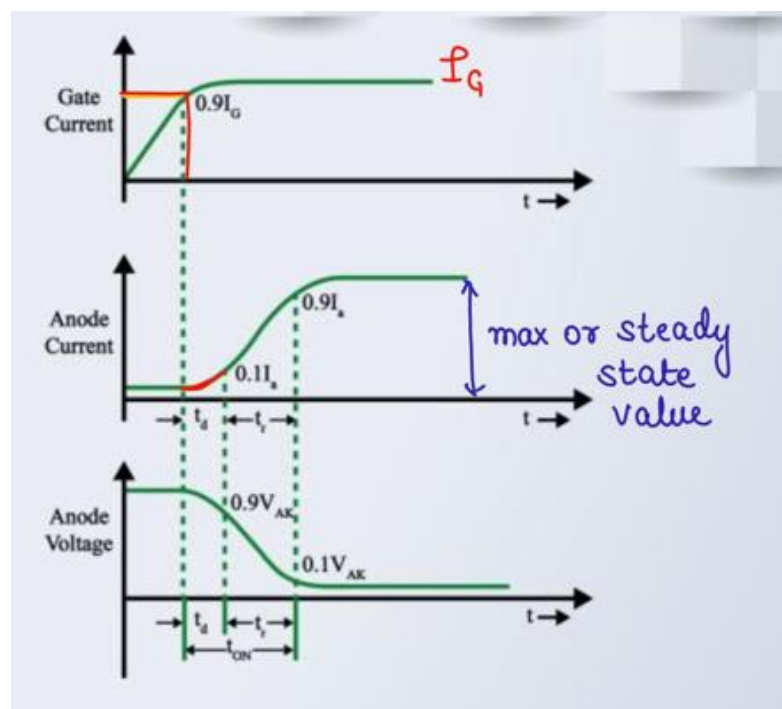
1.4 Switching Characteristics of SCR

1. Turn-ON Characteristics

When a gate pulse is applied, SCR takes a **finite time** to conduct fully. It consists of three intervals:

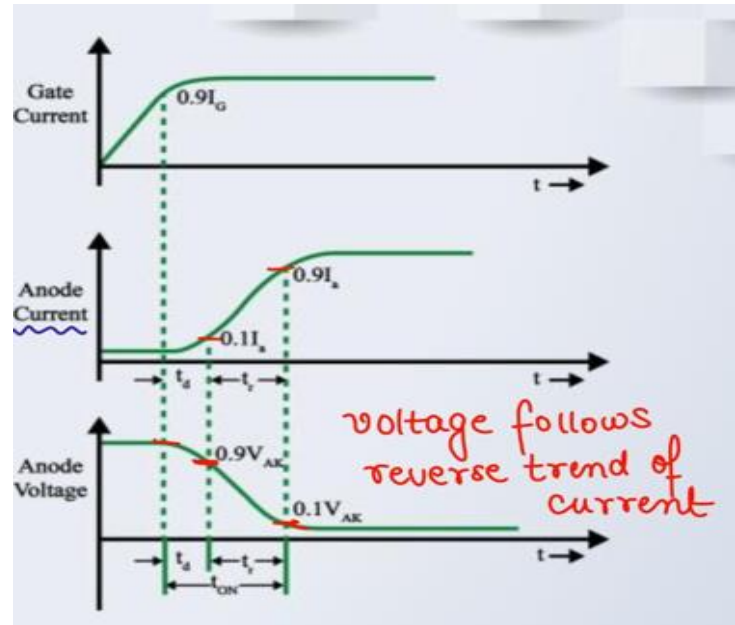
1. Delay Time (t_d)

- Time in which **anode current increases** from 0 to 10% of final value.
- At the same time, **anode voltage drops** from 100% to 90% of initial value.
- Depends on **gate current (I_g)** and **rate of rise of gate current (dI_g/dt)**.
- Higher $I_g \rightarrow$ smaller t_d .



2. Rise Time (t_r)

- Time in which **anode current rises** from **10% to 90%** of final value.
- **Anode voltage falls** from 90% to 10% of initial value.



3. Spread Time (t_s)

- Time taken for **current to spread uniformly** across the junction area.
- Anode current rises from **90% to 100%** of final value.
- Anode voltage falls from **10% to ON-state voltage drop (1–2 V)**.

✓ **Turn-ON time (t_{ON})** = $t_d + t_r + t_s$ (a few microseconds).

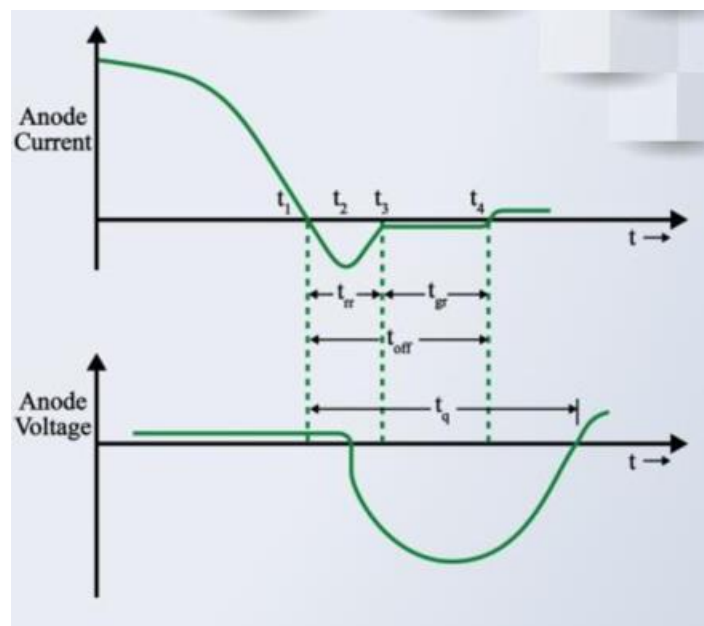
2. Turn-OFF Characteristics

When the anode current is reduced to zero (natural or forced commutation), SCR takes a **finite time** to regain its forward blocking capability.

It consists of:

1. Reverse Recovery Time (t_{rr})

- During this time, **reverse current flows** through the device.
- This removes **stored charges** from the junctions.
- Defined as the time between **current becoming negative** and reducing to **25% of its reverse maximum (IRM)**.



2. Gate Recovery Time (t_{gr})

- Time required for the **junction barriers** to be re-established.
- Device regains full **forward blocking capability** after this.

3. Turn-OFF Time (t_{off})

- Total time taken by SCR to turn OFF:

$$t_{off} = t_{rr} + t_{gr}$$

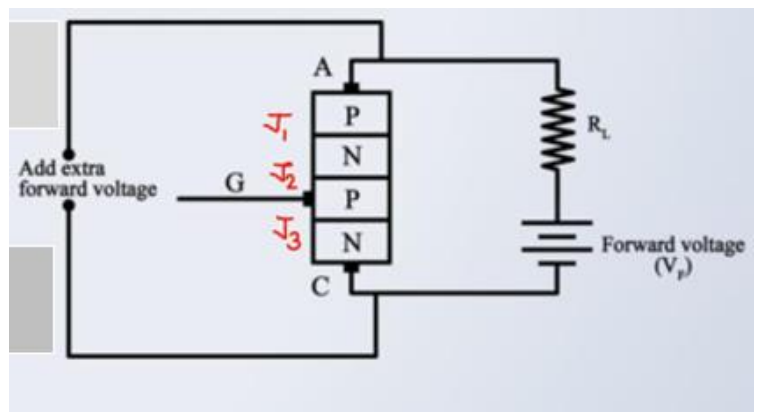
- Typically **tens of microseconds (μs)**.
- **Note:** Turn-OFF time of SCR is much **longer than Turn-ON time**.

1.5 Turn-ON Methods of SCR

SCR can be turned ON (switched to conduction) by the following methods:

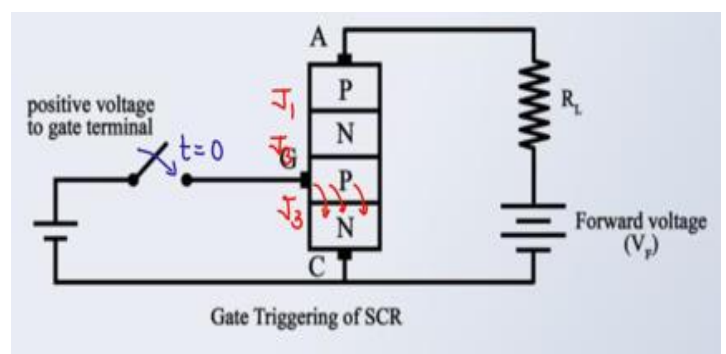
1. Forward Voltage Triggering

- As forward voltage across SCR is increased in forward blocking mode, the reverse bias across junction J_2 increases. This leads to an increase in **depletion width** (Early Effect).
- Above a certain voltage, the entire base region of the internal transistor becomes **depleted**, and the SCR turns **ON**.
- Such a voltage is called **Forward Breakover Voltage (V_{BO})**.



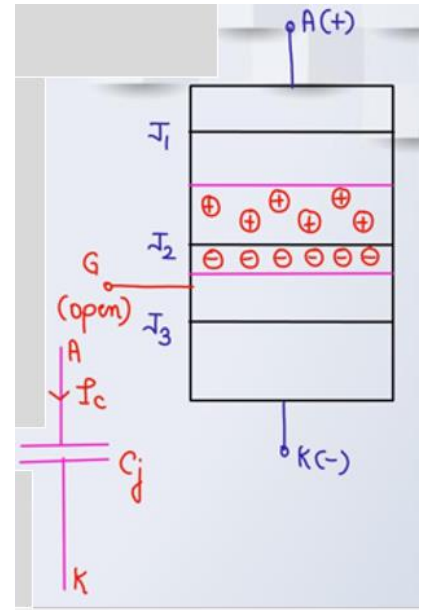
2. Gate Triggering ✓ (Most Common)

- A voltage source is connected between **gate (G)** and **cathode (C)**, which forward biases junction J_3 .
→ This establishes the flow of charges between **anode (A)** and **cathode (C)**.
- Once the **anode current** reaches above the **latching current**, the gate pulse can be removed.
- Continuous gate triggering is **not required**.



3. dv/dt Triggering

- The **depletion layer** across reverse-biased junction **J2** contains positive and negative ions, hence acts as a **capacitor**.
- Such capacitance is called **Junction Capacitance (Cj)**.
- When the applied voltage changes rapidly, a **charging current** flows:
- $$I_C = C_j \frac{dV_{AK}}{dt}$$
- If this charging current exceeds the **latching current**, the SCR turns **ON**.



★ Key Point:

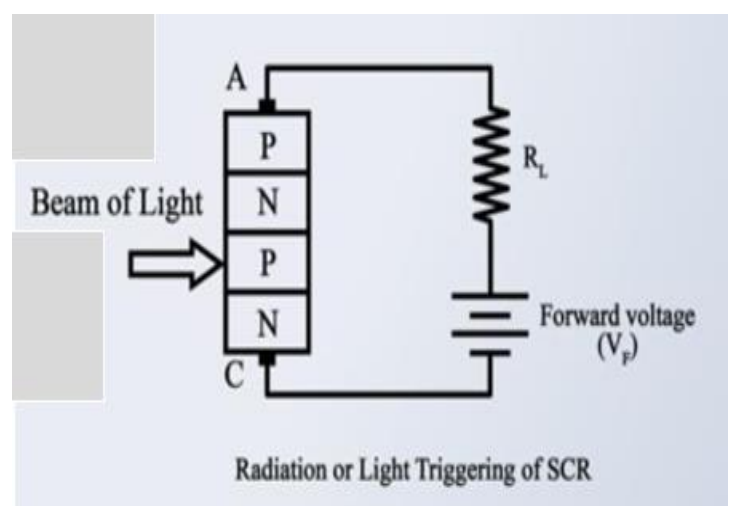
This type of triggering is **undesirable** because we cannot control the turn-on of the SCR — it depends only on the rate of rise of voltage.

4. Thermal Triggering

- If we raise the **temperature** near the **gate region** or junction **J2**, then electrons can be extracted out of atoms or ions.
- If charges are generated by means of high temperature, they can act as **gate current**.
- The depletion layer of **J2** reduces.
- Hence, the device can turn **ON** at a **lower forward voltage**.
- ⚠ **Undesirable:** High temperature can damage the device.

5. Light Triggering

- When **light of suitable frequency** is incident on junction **J2**, electrons are emitted from atoms.
- If the **energy of the photon** is greater than the energy required to emit an electron, then an electron is released.
- The generated charge carriers act like **gate current** and help in triggering the SCR.
- A **single source of light** can trigger multiple SCRs (provides **electrical isolation**).



- **Application:** Used in **Light Activated SCR (LASCR)**, especially in **HVDC systems**.

1.6 Turn-OFF Methods of SCR

Since SCR cannot be turned OFF by gate signal, it requires **commutation methods**. The process of turning OFF an SCR is called **Commutation**.

Turn-off of a thyristor means changing the device state from **forward-conduction mode** to **forward-blocking mode**.

Turn-Off Requirements

For a thyristor to turn off:

1. **Anode current** must be reduced below the **holding current**.
2. A **reverse voltage** must be applied across the device to remove excess charge carriers and regain its blocking state.

Classification of Commutation Techniques

Commutation techniques are classified based on:

1. The **manner in which anode current is reduced to zero**.
2. The **configuration of the commutating circuits**.

Types of Commutation

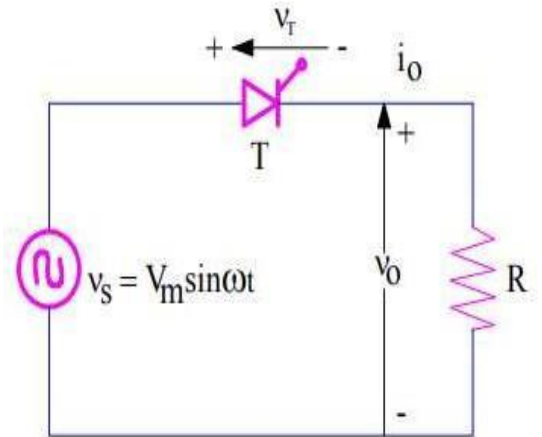
1. **Natural Commutation (Line Commutation) – (Class F)**
 - Occurs naturally in AC circuits when current passes through zero.
2. **Load Commutation (Self-Commutation) – (Class A)**
 - Energy stored in reactive components (L or C) of the load forces current to zero.
3. **Forced Commutation**

External circuit components force the current through thyristor to zero.

 - **Resonant Pulse Commutation – (Class B)**
 - **Complementary Commutation – (Class C)**
 - **Impulse Commutation – (Class D)**

1. Natural Commutation (Line Commutation)

- The SCR is turned off automatically when the **AC supply current crosses zero** at the end of every half cycle.
- For an SCR to **turn OFF successfully**, the following conditions must be satisfied:
- A: **Current through SCR must fall below the holding current.**
- B: **SCR must be reverse biased for a duration greater than its turn-off time (t_q).**



- Assume that the thyristor **T** is fired (gated) at firing angle 0° (i.e. $\omega t = 2n\pi$, where $n = 0, 1, 2, \dots$).
- Since the load is **purely resistive**, with zero firing angle, the **SCR behaves like a diode**.

Operation:

1. **Positive Half Cycle ($0 \leq \omega t \leq \pi$):**

- The SCR is forward biased and conducts.
- Output voltage v_o = source voltage v_s .
- Load current $i_o = (v_s / R)$, in phase with v_o .
- Hence, i_o has the same wave shape as the source voltage v_s .

2. **At $\omega t = \pi$:**

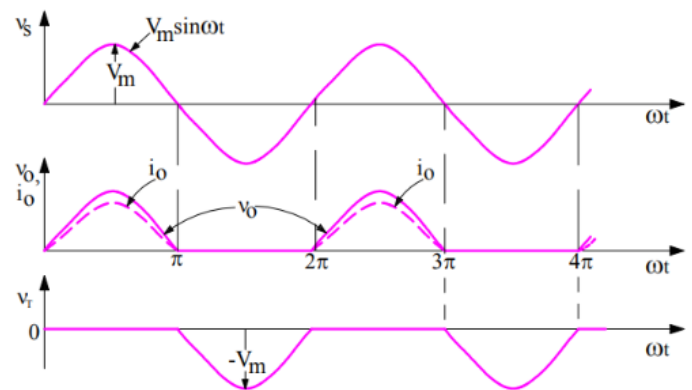
- Source voltage $v_s = 0$, load voltage $v_o = 0$, and load current $i_o = 0$.
- Current through SCR becomes zero.

3. **Negative Half Cycle ($\pi \leq \omega t \leq 2\pi$):**

- The SCR becomes **reverse biased**.
- It remains reverse biased for a duration:

$$t = \frac{\pi}{\omega}$$

- This time **t** is called the **circuit turn-off time (t_c)**.
- If $t_c > t_q$ (device turn-off time), the SCR successfully turns off (commutates).



Why is it called Natural Commutation?

- The commutation of the SCR does **not require any external circuit**.
- The device is turned off **only because of the natural reversal of AC load current and source voltage**.

- Hence, it is called **Natural Commutation** (or Line Commutation / Class-F Commutation).
- Commonly used in **AC Voltage Regulator, Phase Controlled Converter , HVDC transmission.**

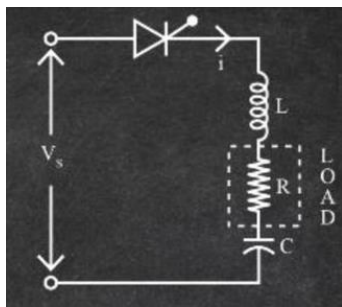
2. **Forced Commutation**

- The current through the SCR is forced to zero by an **external circuit**.
- Commonly used in **chopper circuits, inverters, DC circuits** where supply voltage is DC.

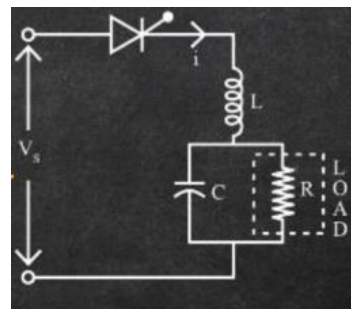
1.6.1 Load Commutation of SCR

Definition

- Load commutation is a type of **forced commutation** where the **load current itself** helps in turning OFF the SCR.
- This happens when the load has a **resonant LC circuit** (inductive + capacitive) and satisfies underdamped condition.



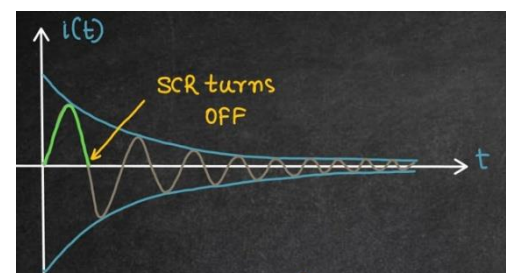
(Low R)



(High R)

Working

1. In an **RLC load**, the current is **sinusoidal/oscillatory**.
2. During part of the cycle, **load current naturally reverses** due to energy exchange between L and C .
3. This reverse current flows through the SCR → drives the **anode current to zero**.
4. Once the current remains below **holding current (I_H)** for a short time, SCR turns OFF.
5. The **voltage across capacitor** provides a reverse bias across the SCR, ensuring it regains blocking capability.



Key Points

- Load commutation is also called:
 - **Resonant Commutation**
 - **Self-Commutation**

- Occurs due to **oscillatory behavior** of LC circuit.

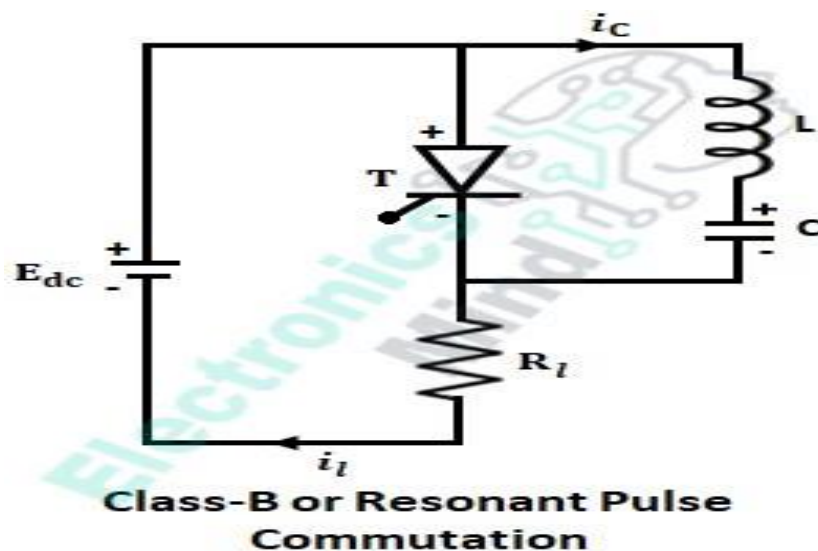
Application

- Widely used in:
 - DC Choppers
 - Inverters with resonant load
 - Induction heating circuits

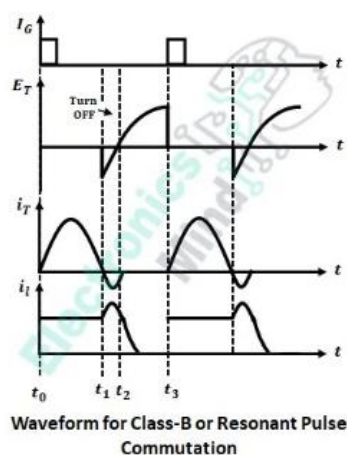
1.6.2 Resonant Pulse Commutation of SCR

Definition

- Resonant pulse commutation is a **forced commutation method** where a **resonant LC circuit** produces a **reverse current pulse** to turn OFF the SCR.
- The pulse forces the **anode current to zero** for a sufficient time so that the SCR regains forward blocking capability.



◆ Modes of Operation in Class-B Commutation



Mode-1: Capacitor Charging (SCR OFF, before t_0)

- Supply E_{dc} charges the capacitor C through the path:

$$E_{dc} \rightarrow L \rightarrow C \rightarrow R_L \rightarrow E_{dc}$$

- Capacitor charges to **slightly greater than** E_{dc} with polarity:
Top +, Bottom -.
- SCR (T) is OFF, no load current flows ($i_T = 0, i_L = 0$).
- This is the **initial condition** before triggering.

Mode-2: SCR ON, Capacitor Discharging (t_0 to t_1)

- At t_0 , a gate pulse I_G is applied $\rightarrow$ SCR turns ON.
- Two currents flow now:
 - Load current (i_L) through SCR:

$$E_{dc} \rightarrow T \rightarrow R_L \rightarrow E_{dc}$$

- Resonant capacitor current (i_C) due to capacitor discharge:

$$C^+ \rightarrow L \rightarrow T \rightarrow C^-$$

- Net SCR current:

$$i_T = i_L + i_C$$

- On waveform: i_T rises in a resonant half-sinusoidal fashion, i_L flows constant through the load.
- Capacitor voltage u_C decreases from $+E_{dc}$ toward 0.

Mode-3: Capacitor Reversed Polarity (t_1 to t_2)

- At t_1 , capacitor fully discharged and now starts charging in **reverse polarity**:
Top -, Bottom +.
- Resonant current reverses its direction:

$$C^- \rightarrow T \rightarrow L \rightarrow C^+$$

- Now, i_C is **opposite** to load current i_L .
- Net SCR current:

$$i_T = i_L - i_C$$

- As i_C grows, it cancels load current.
- On waveform: i_T reduces toward 0.
- This **reverse capacitor voltage** appears across SCR (ET negative) $\rightarrow$ providing reverse bias.

Mode-4: Thyristor Turn-OFF (at t_2)

- At t_2 , if:

$$i_T < I_H \quad (\text{holding current})$$

then SCR turns OFF.

- After SCR turns OFF, load current also reduces to zero since no path remains.
- On waveform:
 - $i_T = 0$,
 - $i_L = 0$,
 - E_T (voltage across SCR) rises to full supply E_{dc} .

Mode-5: Next Cycle (after t_3)

- Capacitor recharges again to slightly above E_{dc} with initial polarity.
- SCR remains OFF until the next gate pulse is applied at t_3 .
- Process repeats cycle by cycle.

✓ Mode Summary Table

Mode	Time	Capacitor State	Current Path	SCR Condition
Mode-1	Before t_0	Charged to $+E_{dc}$	$E_{dc} \rightarrow L \rightarrow C \rightarrow R_L \rightarrow E_{dc}$	OFF
Mode-2	$t_0 \rightarrow t_1$	Discharging	$E_{dc} \rightarrow T \rightarrow R_L$ and $C^+ \rightarrow L \rightarrow T \rightarrow C^-$	ON
Mode-3	$t_1 \rightarrow t_2$	Recharged with reverse polarity	$C^- \rightarrow T \rightarrow L \rightarrow C^+$	Reverse biased
Mode-4	At t_2	Negative voltage on C	Load & capacitor currents cancel ($i_T \rightarrow 0$)	Turns OFF
Mode-5	After t_3	Recharged to initial polarity	Idle until next trigger	OFF

[Applications](#)

- DC choppers**

- **Forced commutated inverters**
- **High-frequency converters**

★ **Quick Memory Tip for Students:**

- **DC circuits → Forced commutation**
- **AC circuits → Natural commutation**

1.7 Voltage and Current Ratings of SCR

When an SCR is manufactured, it is specified with certain **voltage and current ratings** to ensure safe operation.

A. Voltage Ratings of SCR

- **V_{RRM} : Repetitive Peak Reverse Voltage**
 - Maximum reverse voltage that the SCR can withstand **repetitively (periodically)**.
- **V_{RWM} : Peak Reverse Working Voltage**
 - Maximum reverse **DC or constant voltage** that the SCR can withstand continuously.
- **V_{RSMV} : Non-Repetitive Peak Reverse Voltage**
 - Maximum reverse surge voltage that the SCR can withstand **without repetition**.
- **V_T : On-State Voltage**
 - Voltage drop across anode and cathode at a specified forward current.

B. Current Ratings

1. **Average On-State Current (I_{Tavg})**
 - Maximum **average current** the SCR can carry in ON state.
2. **RMS Current ($I_T(rms)$)**
 - Maximum **RMS value of on-state current** allowed.
3. **Surge Current (I_{TSM})**
 - Maximum **non-repetitive peak current** the SCR can handle for a short time (e.g., during fault).
4. **Latching Current (I_L)**

- Minimum anode current required to **latch SCR ON** after gate pulse is removed.

5. Holding Current (I_H)

- Minimum Anode current below which SCR **turns OFF**.

1.8 Protection of SCR

Since SCR is a **power device**, it must be protected from **overcurrent, overvoltage, overheating, and false triggering**.

Overvoltages in SCRs

- **Main cause of SCR failure** → false turn ON or permanent damage if voltage $> V_{BR}$.
- **Sources:** commutation, chopping, lightning, switching.
- **Types:**

1. Internal Overvoltages

- Occur during operation (turn OFF).
- Due to reverse recovery current + circuit inductance.
- High di/dt → induced voltage $>$ rating → damage.

2. External Overvoltages

- From supply or load.
- Causes:
 - Transformer switching transients (several V_{BO})
 - Lightning surges in HVDC systems
 - Sudden interruption of inductive loads
 - Arc voltages due to DC side switching

Protection Methods

1. Snubber Circuit

- An **RC network** (resistor + capacitor) connected across SCR.
- The capacitor **absorbs voltage spikes** and resistor **dissipates energy**.
- Also limits **dv/dt** to avoid false triggering.

2. Voltage Clamping Devices

- Protect against **external overvoltages** (lightning & switching surges).
- Common devices:
 - **Metal Oxide Varistor (MOV)**
 - **Selenium Thyrector Diode**
 - **Avalanche Diode Suppressor**

Working Principle of Voltage Clamping Devices

- Devices (MOV, thyrector, avalanche diode) exhibit **non-linear resistance**.
- As voltage $\uparrow \rightarrow$ resistance $\downarrow$.
- During a surge, they provide a **low-resistance path**, thereby **clamping the voltage across the SCR** and protecting it from damage.

1.8.2 Overcurrent Protection of SCR

Cause of Overcurrent

- Short circuits in the circuit.
- Overloading of load.
- Fault conditions in power system.

Protection Methods

1. Fuses

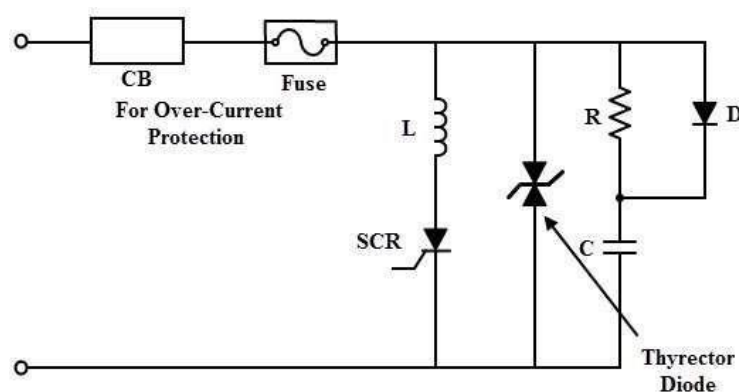
- Fast-acting fuses break the circuit during short circuit or overload.
- Protect SCR from heavy surge current.

2. Circuit Breakers (CB)

- Used in high-power applications for automatic isolation.

3. Current Limiting Reactors (Series Inductors)

- Limit the rate of rise of current (di/dt).
- Protect SCR during switching.

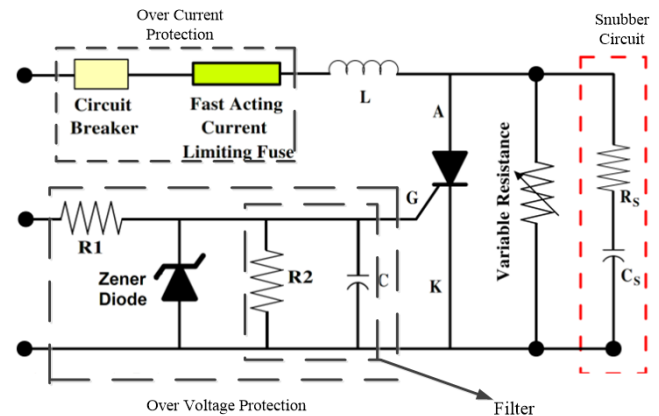


(Figure showing over voltage and over current protection)

1.8.3 Gate Protection of SCR

Cause of Gate Damage

- **Overvoltage at gate** → may break gate-cathode junction.
- **Excessive gate current** → overheats and damages gate terminal.
- **Noise / spurious signals** → may cause false triggering.



Protection Methods

1. **Series Gate Resistor (R1)**
 - Limits **gate current (I_g)** within safe value.
 - Protects against **excessive I_g** .
2. **Zener Diode Clamp**
 - Connected across gate and cathode.
 - Clamps **excessive gate voltage (V_g)** to safe value.
3. **Gate Drive Isolation**

Problem:

- Electrical **noise or spikes** in the gate circuit may cause **false triggering of SCR**.
- This happens because small unwanted gate currents can trigger SCR.

Solution:

- Use a **Resistor (R)** and **Capacitor (C)** connected **in parallel across the gate and cathode**.
- This RC network is called a **Gate Snubber Circuit**.

1.9 Firing Circuits of SCR

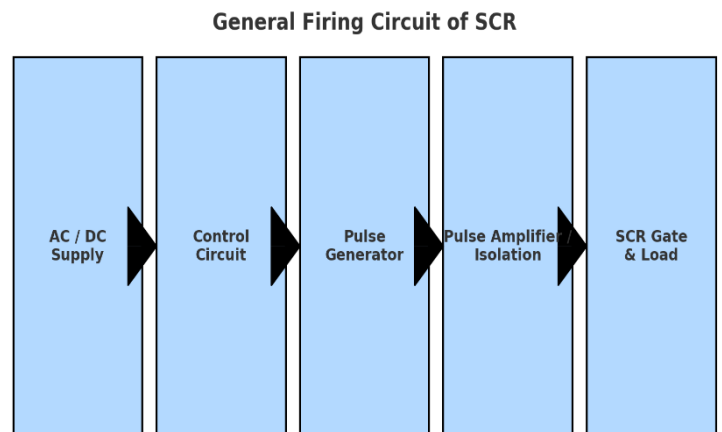
Introduction

- **Firing Circuit:** A circuit arrangement used to provide a suitable **gate pulse** to the SCR for turning it ON at the desired instant.
- SCR requires:
 - **Forward bias** (Anode +ve, Cathode -ve)
 - **Gate triggering pulse** of sufficient magnitude and duration.
- Types of firing circuits are broadly classified as:
 1. **Resistance (R) Firing Circuit**
 2. **Resistance–Capacitance (RC) Firing Circuit**
 3. **UJT Firing Circuit**
 4. **Pulse Transformer Firing Circuit**
 5. **Synchronous Triggering**

1.9.1 General Layout of Firing Circuit

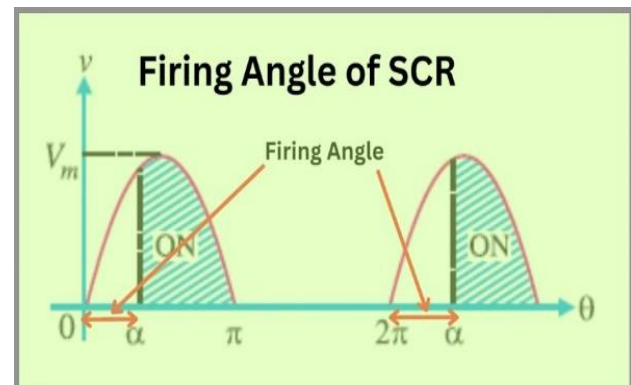
Main Blocks

1. **AC / DC Supply** → source for power circuit.
2. **Control Circuit** → decides firing angle (phase control).
3. **Pulse Generator** → produces gate triggering pulses.
4. **Pulse Amplifier / Isolation (Pulse Transformer or Opto-coupler)** → strengthens and isolates the pulse.
5. **SCR Gate** → receives pulse and turns ON at desired instant.
6. **Load** → controlled by SCR.



Firing Angle (α) / Delay Angle

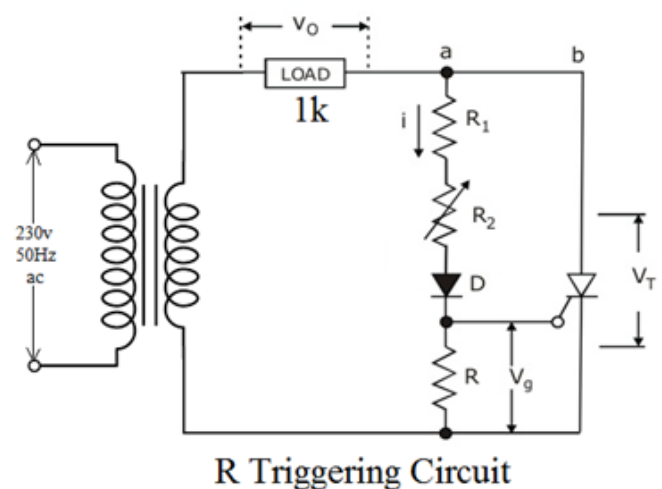
- **Definition:** The angle (measured from zero crossing of AC input) at which the SCR is triggered.
- **Range:** $0^\circ \leq \alpha \leq 180^\circ$.
- **Effect:**
 - **Small α (0° – 30°):** Early firing → More conduction → High output.
 - **Medium α (60° – 90°):** Delayed firing → Partial conduction → Medium output.
 - **Large α (120° – 180°):** Late firing → Less conduction → Low or zero output.



1.9.2 Resistance Firing Circuit of SCR

Circuit Description

- **Components:**
 - **R1** → Current limiting resistor (protects gate from high current).
 - **R2** → Variable resistor (used to adjust firing angle).
 - **D (Diode)** → Blocks reverse gate current.
 - **R** → Voltage limiting Resistor (limit the over voltage)
 - **SCR** → Main controlled rectifier.
 - **Load** → Connected in series with SCR. **230V, 50Hz AC supply** with step-down transformer.



Operation

1. The input AC supply is:
 $V_s = V_m \times \sin(\omega t)$
2. The gate current is:
 $i = (V_m \times \sin(\omega t)) / (R_1 + R_2)$
3. The gate voltage is:
 $V_g = (V_m \times \sin(\omega t) \times R) / (R_1 + R_2 + R)$
 $V_g = V_{gm} \times \sin(\omega t)$

where,

$$V_{gm} = (V_m \times R) / (R_1 + R_2 + R)$$

4. The SCR will trigger when:
 $V_g > V_{gt}$

Therefore,

$$V_{gm} \times \sin(\omega t) > V_{gt}$$

or,

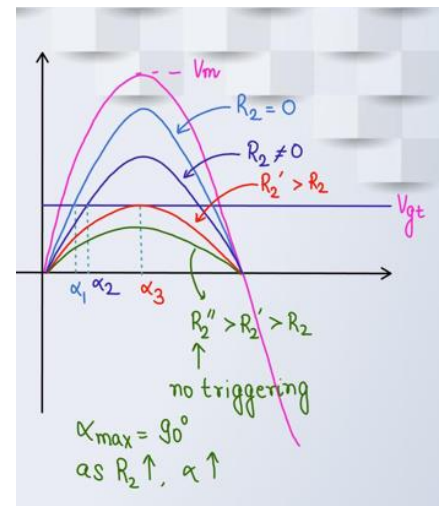
$$\omega t > \sin^{-1} (V_{gt} / V_{gm})$$

Firing Angle Control

- When $R_2 = 0 \rightarrow$ Maximum gate current flows $\rightarrow$ SCR fires at minimum angle (early in the cycle).
- When R_2 increases $\rightarrow$ Gate current reduces $\rightarrow$ Firing angle α increases (SCR fires later).
- When R_2 is too high $\rightarrow$ Gate voltage never reaches threshold $V_{gt} \rightarrow$ SCR does not trigger.
- Maximum firing angle = 90°

✓ Summary:

The resistance triggering circuit is simple and inexpensive. By adjusting R_2 , the firing angle α can be varied between 0° to 90° .



1.9.3 RC Firing Circuit of SCR

Limitations of Resistance Firing

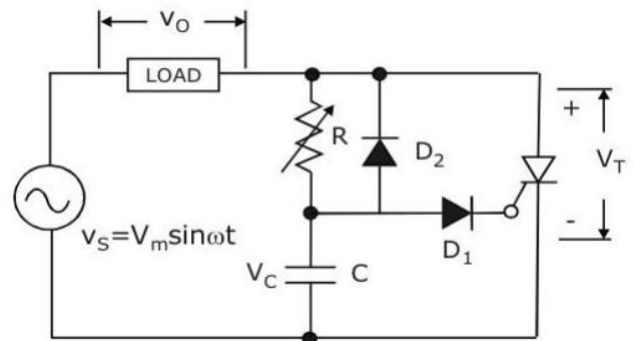
- In a simple resistance firing circuit, the maximum firing angle (α) is limited to 90° .
- To increase the firing angle beyond 90° , an **RC firing circuit** is used.

Definition

An **RC firing circuit** is a phase-control triggering method of an SCR where a **resistor (R)** and **capacitor (C)** are used to control the **firing angle (α)**. By adjusting R and C, we can delay the gate pulse, hence controlling the output power.

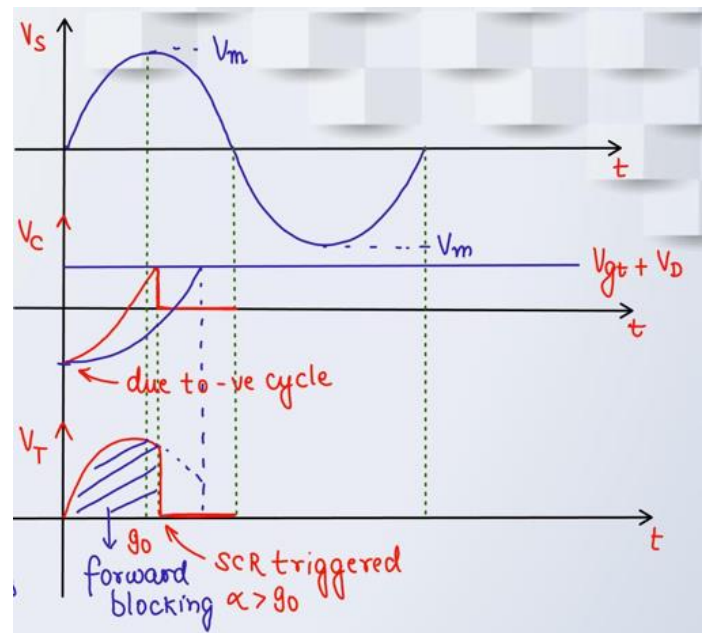
Circuit Description

- **R (variable resistor):** Controls the charging rate of the capacitor (time constant of the circuit).
- **C (capacitor):** Charges and discharges, providing gate triggering.
- **D1 (diode):** Prevents reverse flow of gate current.
- **D2 (diode):** Provides charging path for capacitor during the negative half cycle.
- **SCR:** Main controlled rectifier.



Working

1. **Negative Half Cycle:**
 - When SCR is OFF, the capacitor charges to a negative voltage through diode D2.
2. **Positive Half Cycle:**
 - Capacitor starts charging towards positive voltage through the resistor R.
 - As capacitor voltage (V_C) rises, it adds to the gate triggering voltage.
3. **Triggering Condition:**
 - As soon as the capacitor voltage (V_C) exceeds the sum of gate threshold voltage (V_{gt}) and diode drop (V_d), the SCR is triggered ON.



Condition:

$$V_s > I_g R + V_{gt} + V_d$$

Therefore,

$$R \leq (V_s - V_{gt} - V_d) / I_g$$

✓ Summary:

- RC firing circuit provides a wider range of firing angle control (0° – 180°).
- Capacitor charging controls the delay in firing.
- Diodes ensure proper capacitor charging/discharging.
- More flexible than resistance firing circuit.

1.9.4 UJT Pulse Trigger Circuit

Unijunction Transistor (UJT)

Definition

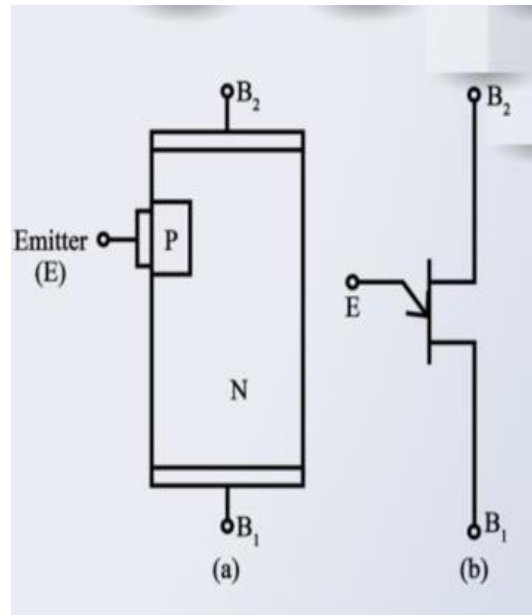
- A **Unijunction Transistor (UJT)** is a 3-terminal semiconductor device that has **only one PN junction**.
- It is mainly used as a **switching device** and as a **triggering element** for SCRs, TRIACs, etc.

Terminals

- **Emitter (E):** P-type material.
- **Base 1 (B1) and Base 2 (B2):** N-type material ends.
- Thus, it is a **3-terminal device**.

Construction

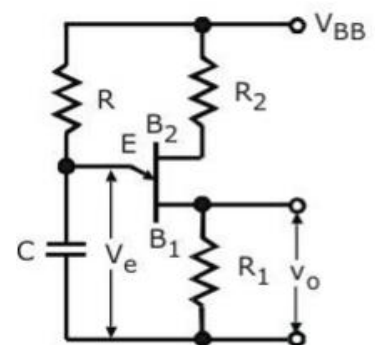
- A lightly doped **N-type silicon bar** with ohmic contacts at both ends (B1 and B2).
- A heavily doped **P-type region** is diffused near one end, forming the **emitter (E)** terminal.
- The PN junction between **emitter (P)** and **N bar** gives the name “**Unijunction**”.
- As Base is **lightly doped**, so conductivity is low and resistance is high.
- Current normally flows between **B2 and B1**.
- The emitter controls the conduction path.



UJT Pulse Trigger Circuit

Circuit Description

- **Resistor (R) and Capacitor (C):** Form the timing circuit.
- **UJT:** Provides negative resistance switching action.
- **R1 and R2:** Form the load resistors connected at bases B1 and B2.
- **V_{BB}:** Supply voltage.
- **Output (V_o):** Taken across resistor R2, used for triggering SCRs.

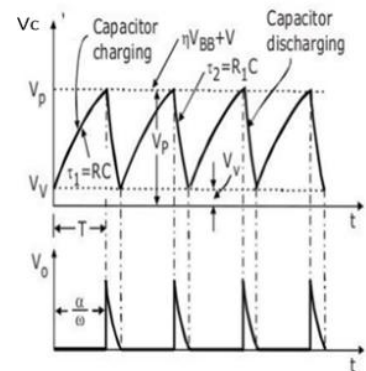


Working

1. When UJT is OFF:

- Emitter current $I_E \approx 0$.
- The capacitor C charges through resistor R towards supply voltage V_{BB} .
- The capacitor voltage V_C increases exponentially.

- **V_v = Valley Voltage** (or the minimum voltage across the capacitor after it discharges).
- When the capacitor discharges through the gate circuit at the firing instant, it does not fall to zero, but to a certain minimum value → this is called **valley voltage**.



2. Turning ON:

- As soon as capacitor voltage V_C exceeds the **peak voltage** $V_p = \eta V_{BB} + V_v$, the UJT turns ON.
- Emitter-base junction becomes forward biased.

3. Discharge Phase:

- Capacitor discharges rapidly through UJT and resistor R_1 .
- This produces a sharp pulse across R_1 .
- This output pulse (V_o) can be used to trigger the gate of an SCR.

4. Repetition:

- After discharging, the UJT turns OFF again.
- The capacitor begins to recharge, repeating the cycle.
- Hence, a **continuous train of pulses** is produced.

Key Points

- Provides **sharp, consistent gate pulses**.
- **Phase control possible** by adjusting R and C values.
- Widely used in **AC voltage controllers, motor speed control, and light dimmers**.

1.9.5 Synchronous Triggering (Ramp Triggering Method)

Definition

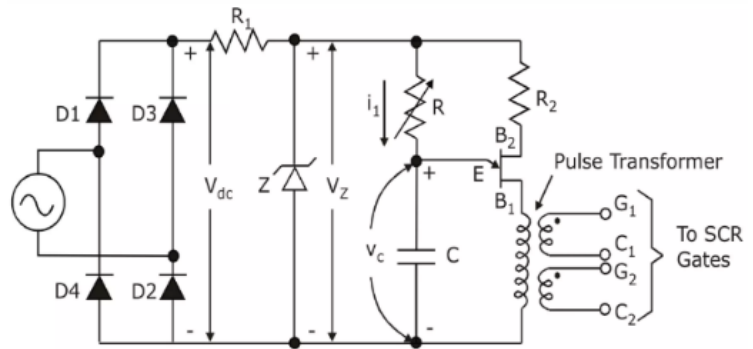
- In **synchronous triggering**, the **gate pulses** for SCR are synchronized with the AC supply waveform.
- The **Ramp Triggering Method** is one of the most common synchronous triggering techniques.
- It uses a **line-synchronized ramp voltage** compared with a DC control voltage to decide the firing instant.

purpose

- To generate **triggering pulses** for an SCR at a controlled firing angle (α) Uses **UJT relaxation oscillator** with a ramp voltage.

2. Main Parts of the Circuit

- **AC Supply (1- ϕ AC)** → Input source.
- **Bridge Rectifier (D1–D4)** → Converts AC into DC.
- **Zener Diode (Z) + Resistor R_s** → Provides constant DC voltage V_{dc} .
- **Resistor R + Capacitor C** → Produces ramp voltage (V_c).
- **UJT (Unijunction Transistor)** → Acts as a switch, generating sharp pulses.
- **Resistor R_2 + Pulse Transformer** → Delivers isolated gate pulses to the SCR.



3. Step-by-Step Working

- a) Rectification** – AC is converted to DC by diodes (D1–D4). Zener diode gives regulated voltage V_{dc} .
- (b) Ramp Generation** – Capacitor C charges through R , producing a linear ramp voltage V_c .
- (c) UJT Action** – When V_c reaches UJT peak voltage (ηV_B), UJT turns ON, discharging C and generating a sharp pulse.
- (d) Pulse Transformer** – The pulse flows through R_2 and the transformer, giving isolated gate pulses to SCR.
- (e) Firing Angle Control** – By varying R , capacitor charging rate changes → controlling firing angle α .

1.10 Design of Snubber Circuits

1. Introduction

- A **snubber circuit** is a protective circuit used with power semiconductor devices (SCR, MOSFET, IGBT, etc.).
- Purpose: To protect the device from **over-voltage, over-current, and high dv/dt or di/dt** stresses.
- Basic snubber = **Resistor + Capacitor (R–C)** or **Resistor + Inductor (R–L)** network.

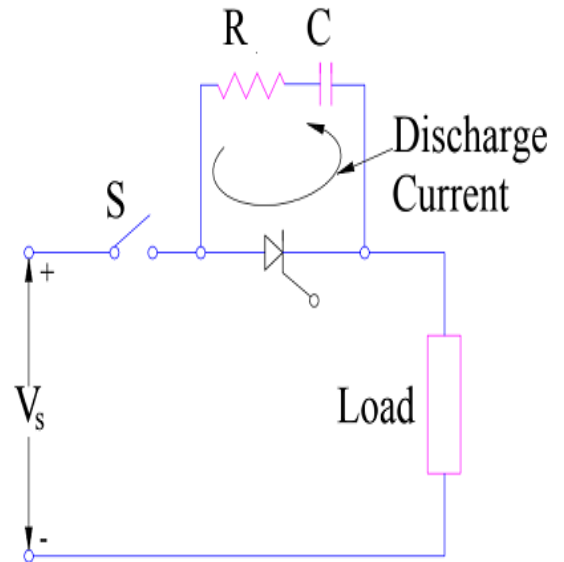
2. Types of Snubber Circuits

- A. RC Snubber (for dv/dt protection)**
- Connected across the device.
 - Capacitor absorbs sudden rise in voltage, resistor dissipates energy.
 - Limits **dv/dt** and voltage transients.
- B. RL Snubber (for di/dt protection)**
- Connected in series with the device.

- Inductor opposes sudden rise of current, resistor damps oscillations.
- Limits **di/dt**.

3. Working of RC Snubber Circuit

- When the switch is closed, a sudden voltage appears across the SCR.
- The capacitor in the snubber initially acts as a **short circuit**, bypassing this sudden voltage and reducing the voltage across the SCR to nearly zero.
- As time increases, the capacitor charges gradually, so the rate of rise of voltage (**dv/dt**) across the SCR remains very small and below the SCR's maximum dv/dt rating.
- Normally, the capacitor charges up to the supply voltage (forward blocking voltage of the SCR).
- When the SCR is turned ON, the charged capacitor discharges through it, producing a **high discharge current (di/dt)**.
- To prevent damage due to this high di/dt, a **small resistor** is connected in series with the capacitor. This resistor limits the peak discharge current and damps oscillations.
- Hence, RC snubber circuits are widely used in switching applications to protect against **high dv/dt and transient voltages**.



UNIT -2

UNDERSTAND THE WORKING OF CONVERTERS, AC REGULATORS AND CHOPPERS.

- 2.1 Controlled rectifiers Techniques(Phase Angle, Extinction Angle control), Single quadrant semi converter, two quadrant full converter and dual Converter
- 2.2 Working of single-phase half wave controlled converter with Resistive and R-L loads.
- 2.3 Understand need of freewheeling diode.
- 2.4 Working of single phase fully controlled converter with resistive and R-L loads.
- 2.5 Working of three-phase half wave controlled converter with Resistive load
- 2.6 Working of three phase fully controlled converter with resistive load.
- 2.7 Working of single phase AC regulator.
- 2.8 Working principle of step up & step down chopper.
- 2.9 Control modes of chopper
- 2.10 Operation of chopper in all four quadrants.

2.1 Controlled Rectifier Techniques

1. Controlled Rectification Techniques

There are mainly **two techniques** of controlling rectifiers:

(a) Phase Angle Control

- SCR is turned ON by delaying its firing angle (α) w.r.t. the input AC waveform.
- Output voltage is controlled by varying **firing angle α (0° – 180°)**.
- Common in **AC-DC converters**.

✓ Example: **Semi-converters & Full converters**

(b) Extinction Angle (γ) Control

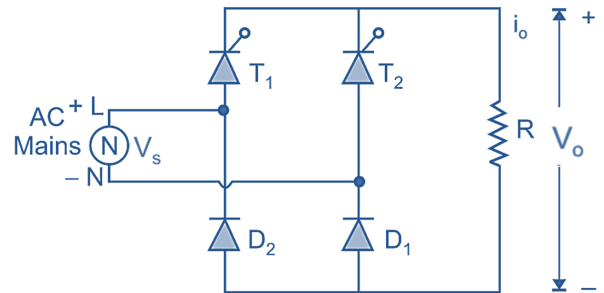
- SCR is turned OFF before the natural end of conduction.
- Used in **inverters** and **dual converters**.
- Controls output by adjusting **turn-OFF instant (γ)**.

✓ Example: **Current commutated inverters**

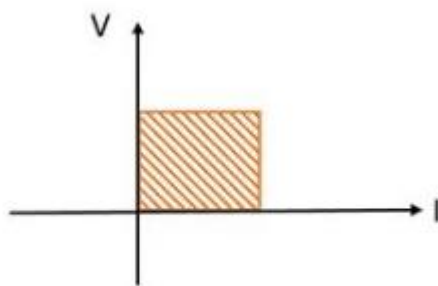
2. Types of Controlled Converters

(a) Single Quadrant Semi-Converter

- Uses **one group of SCRs + diodes**.
- Output voltage is always **positive (unidirectional)**.
- Operates in **rectifier mode only (1st quadrant)**.
- Cheaper, less control.



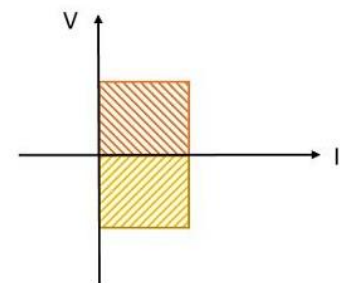
✓ Application: **DC motor drives (low power)**.



One quadrant converter

(b) Two Quadrant Full Converter

- Uses **full-bridge of SCRs**.
- Output voltage can be **positive or negative**, but current is **positive only**.
- Operates in **two quadrants (I and IV)**.
- Allows **power reversal (rectification + inversion)**.

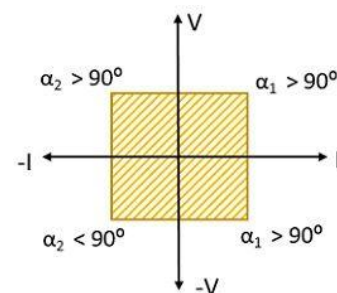


Two quadrant converter

✓ Application: **Industrial DC drives**.

(c) Dual Converter (Four Quadrant Operation)

- Consists of **two full converters connected in anti-parallel**.
- Provides **both +Vdc and -Vdc at output**.
- Current can be in both directions → operates in all **four quadrants**.
- Allows **reversible drives with regenerative braking**.



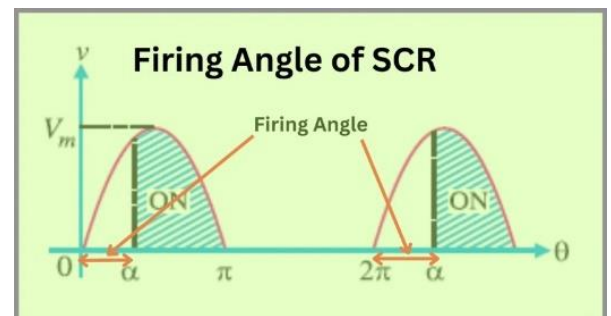
Four Quadrant Diagram

✓ Application: **DC motor speed control (forward + reverse)**.

Parameters

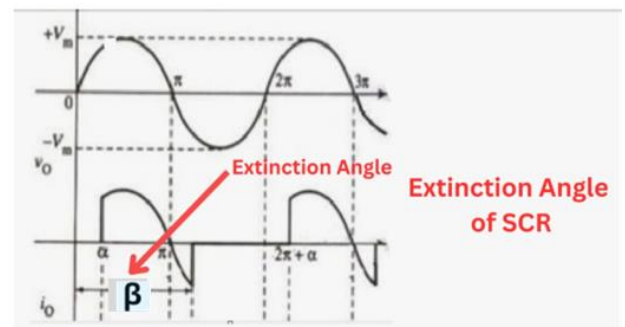
1. Firing Angle (α):

- Symbol: α
- Definition: The angle at which the gate pulse is applied to trigger the SCR.
- Range: 0° to 180°
- Controls the output voltage.



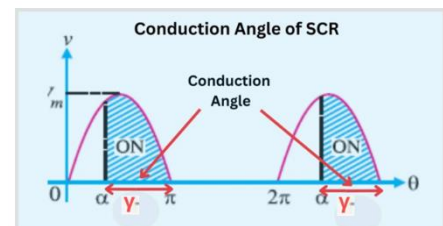
2. Extinction Angle (β):

- Symbol: β
- Definition: The angle where the current through the SCR becomes zero and it turns OFF.
- For a purely resistive load: $\beta = 180^\circ$



3. Conduction Angle (γ):

- Symbol: γ
- Definition: The total period (in degrees or radians) for which the SCR conducts.
- Formula: $\gamma = \beta - \alpha$
- For a purely resistive load: $\gamma = 180^\circ - \alpha$



4. Peak Inverse Voltage (PIV):

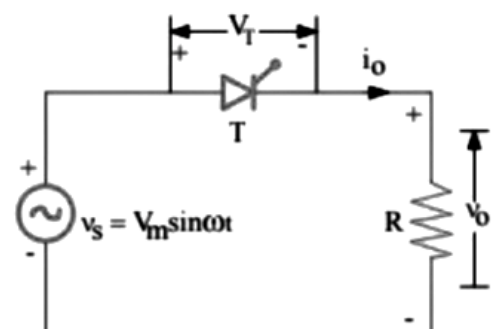
- Symbol: **PIV**
- Definition: The maximum reverse voltage across the SCR when it is in the OFF state.
- For a half-wave rectifier: **PIV** = **V_m** (where V_m is the peak input voltage).

2.2 Working of single-phase half wave controlled converter with Resistive and R-L loads.

R- LOAD

- The figure shows the circuit diagram of a **single-phase half-wave controlled rectifier** with a **resistive load (R-load)**.

- In this circuit, a **Silicon Controlled Rectifier (SCR)**, denoted as **T**, is used to rectify the input sinusoidal AC voltage.



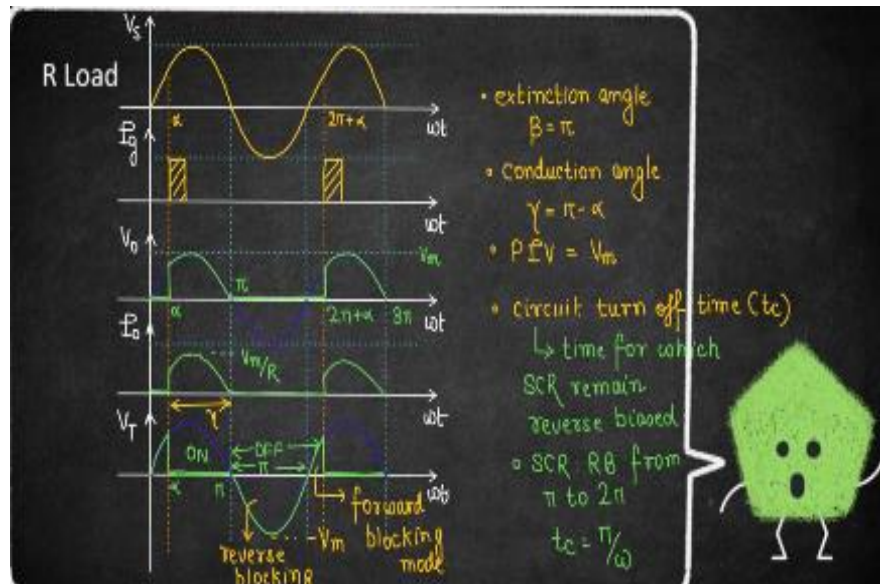
- The rectified output is then supplied to the **resistive load (R)**.

Notations:

- V_o = Load output voltage
- i_o = Load current
- V_t = Voltage across the Thyristor

Working Principle

1. The circuit has a thyristor (T), a voltage source (V_s), and a resistive load (R).
2. **Positive half cycle:**
 - The thyristor T is forward biased.
 - It will not conduct until a **gate pulse** is applied.
 - When a gate pulse is applied at angle α , the thyristor turns ON and starts conducting.
 - The input voltage appears across the load.
3. **Negative half cycle:**
 - The thyristor T becomes reverse biased.
 - It automatically turns OFF.
 - No current flows through the load.
4. **Load voltage:**
 - The load receives voltage only during the positive half cycle when the SCR is ON.
 - By varying the **firing angle α** , we can control the **average output voltage**.



Parameters

◦ Average V_o

$$V_o(\text{avg}) = \frac{1}{2\pi} \int_{\alpha}^{\pi} V_m \sin \omega t d(\omega t)$$

$$= \frac{V_m}{2\pi} (1 + \cos \alpha)$$

◦ average I_o

$$I_o(\text{avg}) = \frac{V_o(\text{avg})}{R}$$

◦ rms value of V_o

$$V_o(\text{rms}) = \left[\frac{1}{2\pi} \int_{\alpha}^{\pi} V_m^2 \sin^2 \omega t d(\omega t) \right]^{1/2}$$

$$V_o(\text{rms}) = V_m \left[\frac{1}{4\pi} \int_{\alpha}^{\pi} (1 - \cos 2\omega t) d(\omega t) \right]^{1/2}$$

$$= V_m \left[\frac{1}{4\pi} \left\{ (\pi - \alpha) + \frac{1}{2} \sin 2\alpha \right\} \right]^{1/2}$$

◦ rms I_o

$$I_o(\text{rms}) = \frac{V_o(\text{rms})}{R}$$

◦ form factor

$$FF = \frac{V_o(\text{rms})}{V_o(\text{avg})}$$

◦ voltage ripple factor

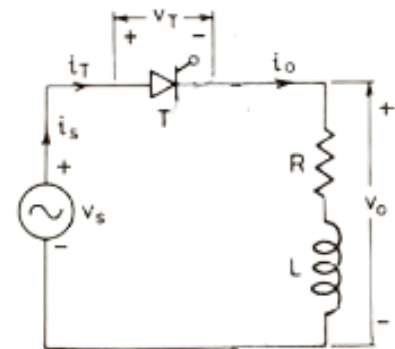
$$VRF = \sqrt{FF^2 - 1}$$

R-L LOAD

• The circuit diagram of a **single-phase half-wave controlled rectifier with RL load** is shown here.

• The circuit consists of:

- A **Thyristor (T)**
- An **AC voltage source (V_s)**
- A **series RL load** (resistor + inductor).



Operating Principle of Single-Phase Half-Wave Controlled Rectifier (RL Load)

1. The circuit consists of a thyristor (T), an AC voltage source (Vs), an inductive load (L), and a resistive load (R).

2. **Positive Half Cycle:**

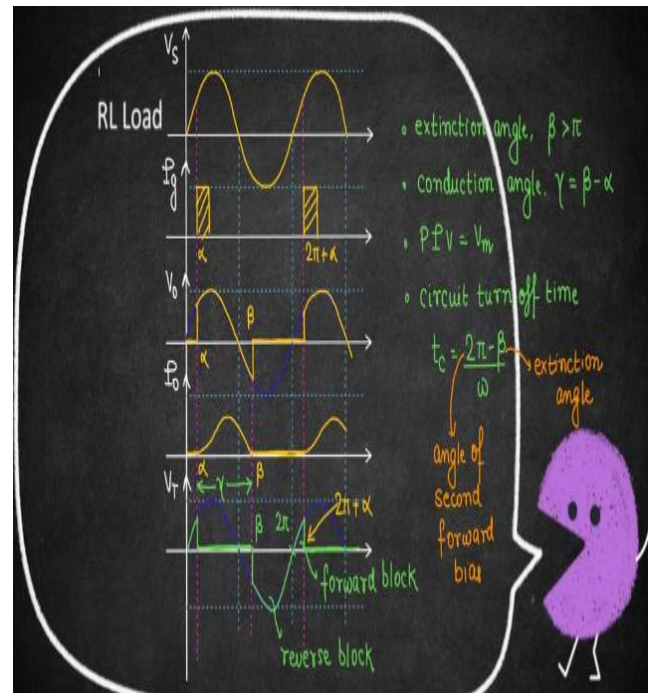
- The thyristor becomes forward biased.
- It will not conduct until a **gate pulse** is applied.
- When the gate pulse is given at angle α , the thyristor turns ON.
- The input voltage is applied to the load, and the current starts building up **gradually** due to the inductor (since an inductor opposes sudden change in current).

3. **Negative Half Cycle:**

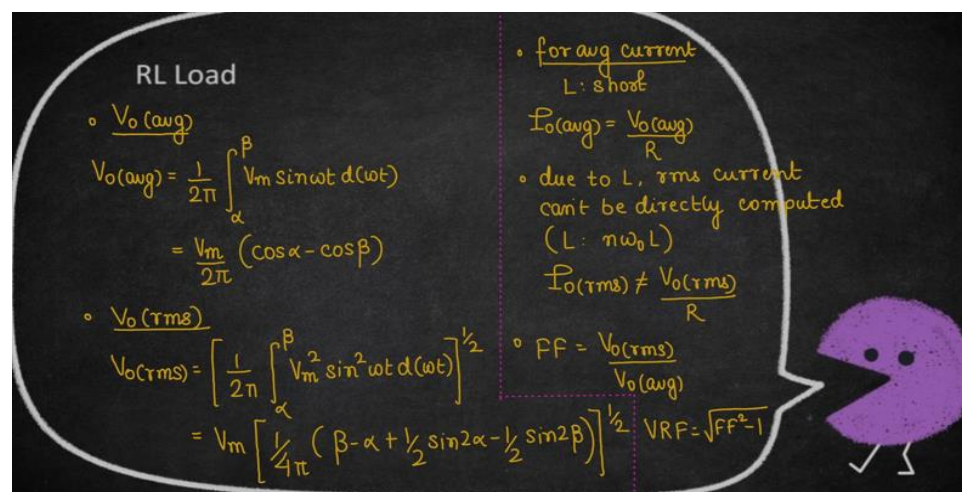
- The thyristor becomes reverse biased.
- However, due to energy stored in the inductor, the current **does not immediately fall to zero**.
- The inductor keeps supplying current, forcing the thyristor to conduct even in part of the negative half cycle.

4. Eventually, the current through the inductor decays slowly to zero.

- When the current falls below the **holding current**, the thyristor turns OFF.
- This happens at angle β , known as the **extinction angle**.



Parameters



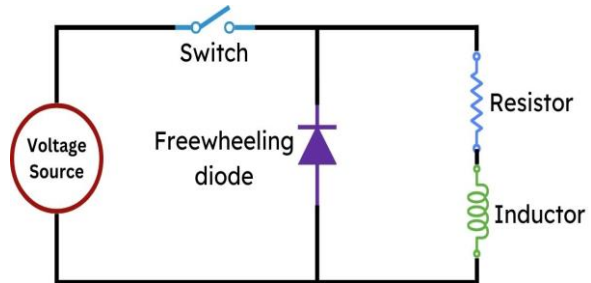
Key Difference from R-Load:

- For **R-load**, conduction stops exactly at π (180°).
- For **RL-load**, conduction extends **beyond π** because the inductor maintains current flow after the supply goes negative.

2.3 Need of Freewheeling Diode

What is a Freewheeling Diode?

- A diode connected **across the load (in parallel, reverse polarity to supply)**.
- Also called **Flywheel Diode or Commutating Diode**.
- Provides a path for load current when the SCR is OFF or AC input goes negative.



Need / Importance

1. For Inductive Loads (R-L):

- Current through an inductor cannot change suddenly.
- When SCR turns OFF, inductor tries to maintain current → causes high **negative voltage ($L \frac{di}{dt}$)** across load.
- This can damage SCR.

✓ Freewheeling diode provides a **path for inductive current**, protecting the SCR.

2. Maintains Current Flow:

- Ensures **continuous current** through load.
- Reduces **current ripple** and improves performance.

3. Improves Efficiency:

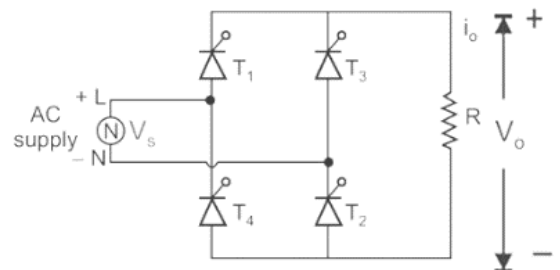
- Reduces power loss due to high reverse voltages.
- Improves load voltage waveform (more stable DC).

2.4 Working of single phase fully controlled converter with resistive and R-L loads

R- LOAD

Circuit Description

- The circuit is a **full-wave bridge rectifier** where all four devices (**T1, T2, T3, T4**) are **thyristors (SCRs)**.
- Output power can be controlled by adjusting the **firing angle (α)**.
- **Diagonally opposite thyristors** conduct in pairs:
 - **T1 & T2** conduct during the positive half cycle.
 - **T3 & T4** conduct during the negative half cycle.
- The load current always flows in the **same direction**, ensuring full-wave rectification.



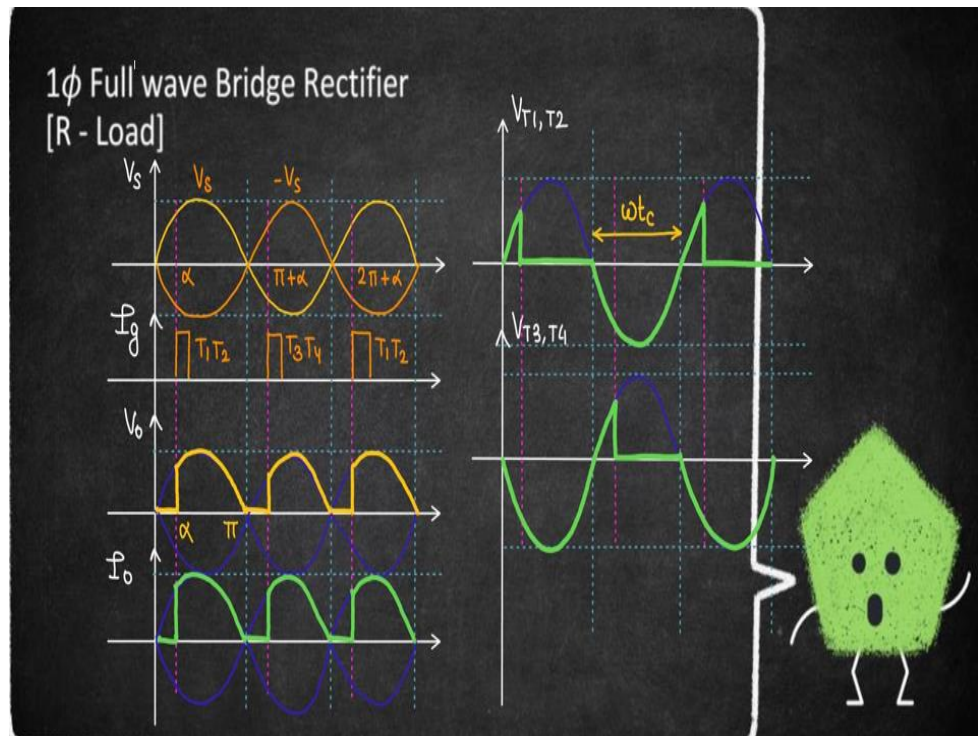
Operation of 1- Φ Full-Wave Bridge Rectifier (R-Load)

1. Supply Voltage (V_s)

- A pure sinusoidal input is applied.
- Positive half: 0 to π .
- Negative half: π to 2π .

2. Gate Pulses (I_g)

- During positive half cycle, **T1 & T2** are triggered at firing angle α .
- During negative half cycle, **T3 & T4** are triggered at firing angle α .



3. Load Voltage (V_o)

- From α to π : Output voltage = Input voltage (since T1, T2 conduct).
- From $\pi + \alpha$ to 2π : Output voltage = Input voltage (since T3, T4 conduct).
- Hence, output is **full-wave controlled**, but shifted by the firing angle α .

4. Load Current (I_o)

- For R-load, the load current (I_o) is **in phase** with load voltage (V_o).
- Current flows during both half cycles, direction is the same in load.

5. Thyristor Voltages (V_{T1} , V_{T2} and V_{T3} , V_{T4})

- When thyristors are OFF, they block the supply voltage.
- When ON, their voltage drop is nearly zero.
- V_{T1} , $T2$ block during negative half cycle; V_{T3} , $T4$ block during positive half cycle.

PARAMETERS

1 ϕ Full wave Bridge Rectifier [R - Load]

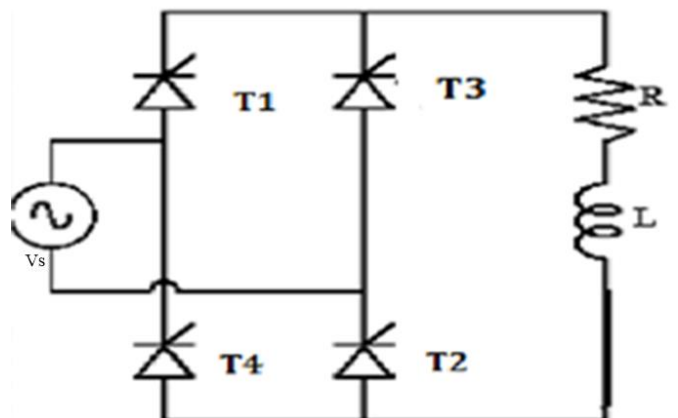
- $\gamma_T = \pi - \alpha$
- $P \cdot I_V = V_m$
- $t_c = \pi / \omega$
- $V_o(\text{avg}) = \frac{1}{\pi} \int_{\alpha}^{\pi} V_m \sin \omega t d(\omega t)$
 $= \frac{V_m}{\pi} [1 + \cos \alpha]$
- $V_o(\text{rms}) = \left[\frac{1}{\pi} \int_{\alpha}^{\pi} V_m^2 \sin^2 \omega t d(\omega t) \right]^{\frac{1}{2}}$
 $= V_m \left[\frac{1}{2\pi} \left\{ \pi - \alpha + \frac{1}{2} \sin 2\alpha \right\} \right]^{\frac{1}{2}}$
- $I_o(\text{avg}) = \frac{V_o(\text{avg})}{R}$
- $I_o(\text{rms}) = \frac{V_o(\text{rms})}{R}$



R-L LOAD

Circuit Description

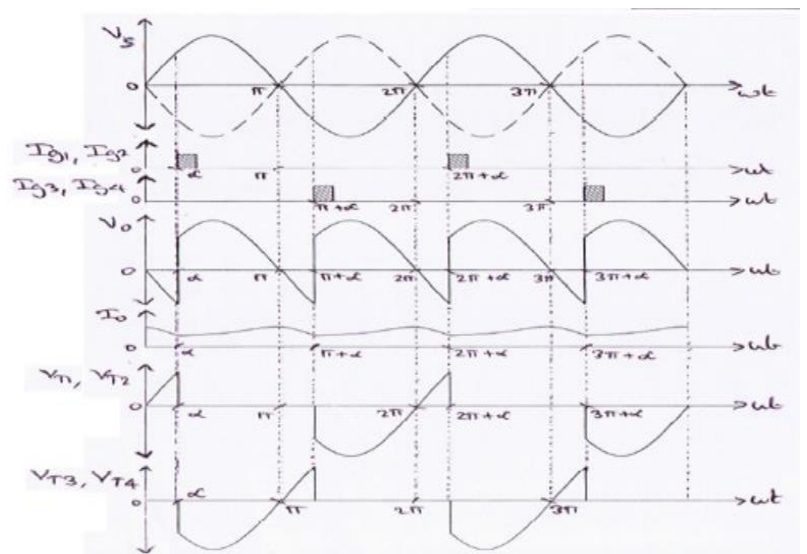
- The circuit consists of:
 - Four thyristors (**T1**, **T2**, **T3**, **T4**) connected in a bridge configuration.
 - An **AC source** as the input.
 - A load consisting of a **resistor (R)** in series with an **inductor (L)**.



Operation

1. Positive Half Cycle (0 to 180 degrees):

- T1** and **T2** are forward biased.
- When triggered at firing angle α , they start conducting.
- Current flows through the path:
Source $\rightarrow$ T1 $\rightarrow$ Load (R-L) $\rightarrow$ T2 $\rightarrow$ Source
- Load current builds up gradually because of the inductor.



- Even after 180 degrees, T1 and T2 may continue to conduct for some time due to the stored energy in L.

2. Negative Half Cycle (180 to 360 degrees):

- **T3 and T4** are forward biased.
- When triggered at firing angle $\pi + \alpha$, they conduct.
- Current path:
Source $\rightarrow$ T3 $\rightarrow$ Load (R-L) $\rightarrow$ T4 $\rightarrow$ Source
- Again, due to the inductor, current does not fall immediately to zero but continues for a while beyond 360 degrees.

3. Voltage across Thyristors (VT1, VT2 and VT3, VT4)

- When **T1 and T2** are conducting $\rightarrow$ their voltage drop is nearly zero.
- When they are OFF $\rightarrow$ they block the reverse supply voltage.
- Similarly for **T3 and T4** in the negative half cycle.

Equations with Symbols

1. Average DC Output Voltage

Symbol: **Vavg or Vdc**

Formula:

$$V_{avg} = (2 \times V_m / \pi) \times \cos(\alpha)$$

2. Average DC Load Current

Symbol: **Iavg**

Formula:

$$I_{avg} = V_{dc} / R$$

$$= (2 \times V_m / (\pi \times R)) \times \cos(\alpha)$$

3. RMS Load Voltage

Symbol: **Vrms(load)**

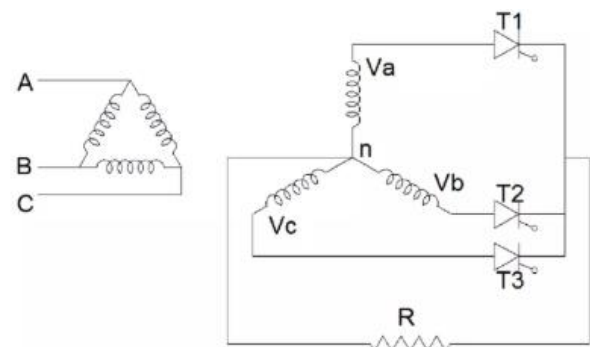
Formula:

$$V_{rms}(\text{load}) = V_m / \sqrt{2}$$

2.5 Three-Phase Half-Wave Controlled Converter with Resistive Load

Circuit Description

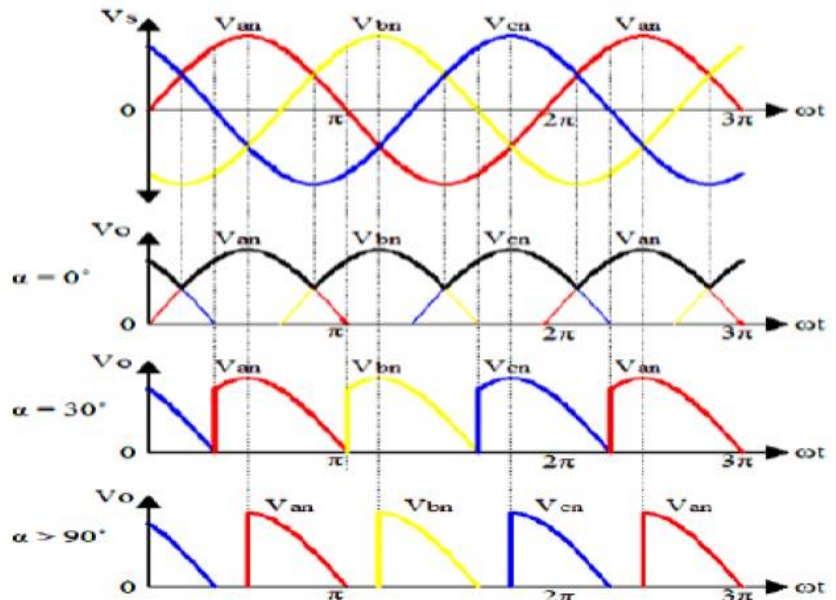
- The left side shows a **three-phase AC source** (phases A, B, C) connected in a **delta configuration**.



- A three-phase transformer is used, and the secondary side provides voltages V_a , V_b , V_c (with respect to the neutral point n).
- On the right side:
 - Three thyristors (**T1, T2, T3**) are connected.
 - A resistive load (R) is connected at the output.

Working Principle

1. Each thyristor conducts for **120° (one-third of a cycle)** when its corresponding phase voltage is the **maximum positive** among the three.
2. The firing angle α decides the instant at which each thyristor turns ON.
3. At any instant, only one thyristor conducts and connects the highest instantaneous phase voltage to the load.
4. The load voltage (V_o) is therefore a sequence of controlled segments of phase voltages V_a , V_b , V_c .



Operation Cycle

- From $(\alpha$ to $120^\circ + \alpha)$: **T1** conducts → load connected to phase V_a .
- From $(120^\circ + \alpha$ to $240^\circ + \alpha)$: **T2** conducts → load connected to phase V_b .
- From $(240^\circ + \alpha$ to $360^\circ + \alpha)$: **T3** conducts → load connected to phase V_c .
- This process repeats every cycle.

Average DC Output Voltage

$$V_{dc} = \frac{3\sqrt{2} V_{ph}}{2\pi} \cos \alpha$$

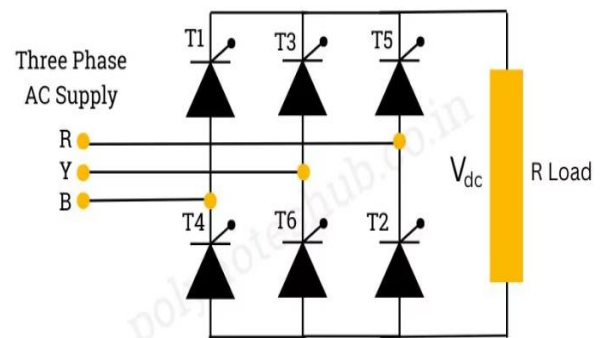
Where:

- V_{ph} = RMS value of phase voltage
- α = firing angle

2.6 Working of Three-Phase Fully Controlled Converter with Resistive Load

Circuit Description

- The circuit consists of **six thyristors (T1–T6)** connected in a three-phase bridge configuration.
- Input: a **three-phase AC supply**.
- Output: connected to a **resistive load (R)**.
- Control: By applying gate pulses at suitable firing angle α to each SCR.



Working Principle

1. Conduction Pattern

- At any time, **two thyristors conduct**:
 - One from the **upper group or Positive group (T1, T3, T5)**.
 - One from the **lower group or Negative group (T4, T6, T2)**.
- Each thyristor conducts for **120 degrees**.

2. Operation Cycle

- T1** conducts with **T6** from $(\alpha$ to $60^\circ + \alpha)$.
- T1** conducts with **T2** from $(60^\circ + \alpha$ to $120^\circ + \alpha)$.
- T3** conducts with **T2** from $(120^\circ + \alpha$ to $180^\circ + \alpha)$.
- T3** conducts with **T4** from $(180^\circ + \alpha$ to $240^\circ + \alpha)$.
- T5** conducts with **T4** from $(240^\circ + \alpha$ to $300^\circ + \alpha)$.
- T5** conducts with **T6** from $(300^\circ + \alpha$ to $360^\circ + \alpha)$.
- The sequence then repeats.

3. Conduction Sequences

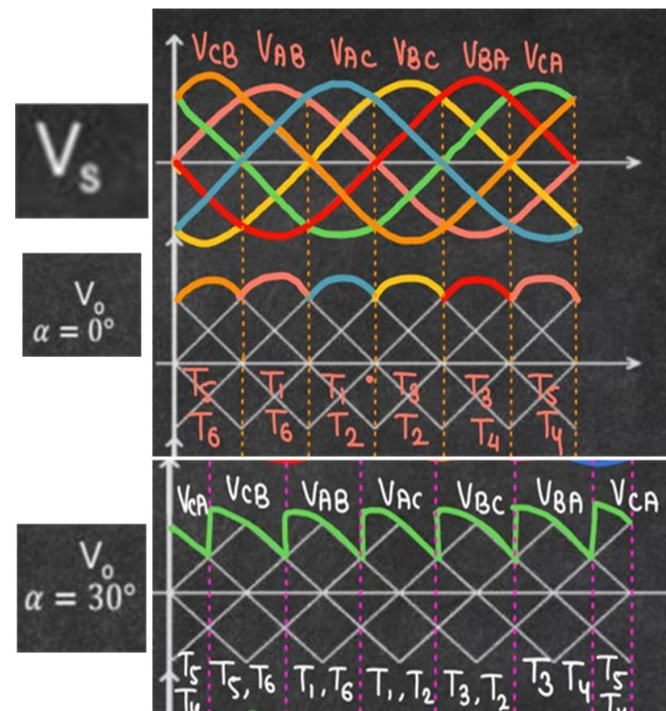
- Thyristors T1 and T6** conduct → Output voltage across the load is line voltage **Vab**.
- Thyristors T3 and T2** conduct → Output voltage across the load is line voltage **Vbc**.
- Thyristors T5 and T4** conduct → Output voltage across the load is line voltage **Vca**.

4. Average DC Output Voltage

- Formula for average output voltage is:

$$V_{dc} = (3 \times \sqrt{2} \times V_m / \pi) \times \cos(\alpha)$$

where:

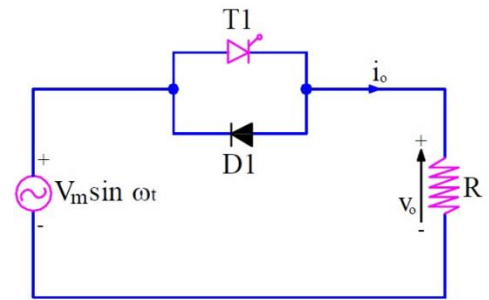


- V_m = maximum value of phase voltage
- α = firing angle

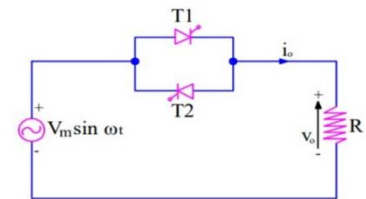
2.7 Working of Single-Phase AC Regulator

Circuit Description

- A **single-phase AC regulator** is used to control the RMS value of AC voltage supplied to the load.
- It uses **SCRs** (or TRIAC) as switches.
- Two main configurations:
 1. **Half-wave AC regulator** – One SCR + diode.
 2. **Full-wave AC regulator** – Two SCRs connected in anti-parallel (or one TRIAC).



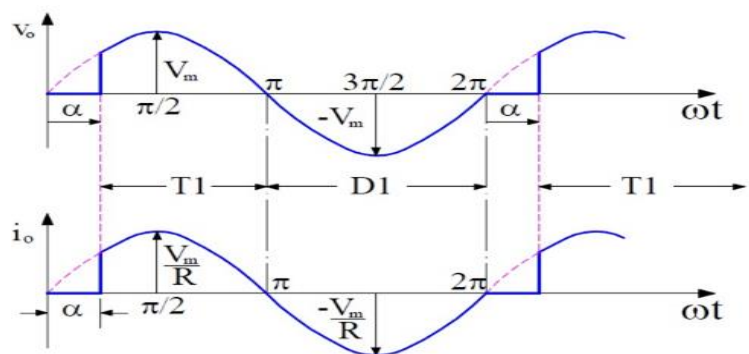
1- Phase half wave AC Regulator



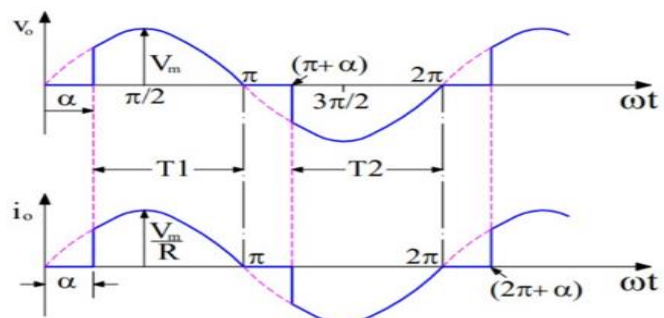
1- Phase Full wave AC Regulator

Working Principle

- AC regulator works on the principle of **Phase Angle Control**.
- The SCR is triggered at a delay angle α in each half cycle of the AC supply.
- This controls the **portion of input voltage** applied to the load.



Output voltage and current waveform of 1-phase half wave regulator



Output voltage and current waveform of 1-phase Full wave regulator

(a) Positive Half Cycle

- SCR is forward biased.
- It remains OFF from $0 \rightarrow \alpha$.
- At $\omega t = \alpha$, gate pulse is applied $\rightarrow$ SCR turns ON.
- It conducts until $\omega t = \pi$.

(b) Negative Half Cycle

- In half-wave regulator: only diode conducts, output uncontrolled.
- In full-wave regulator: second SCR (or TRIAC) conducts after firing angle α .
- Hence, conduction happens in both halves with controlled delay.

(C) Waveforms

- **Input Voltage:** Pure sinusoidal AC.
- **Output Voltage:** Sinusoidal segments starting at firing angle α , rest of the cycle blocked.
- By varying α , RMS value of output voltage can be controlled.

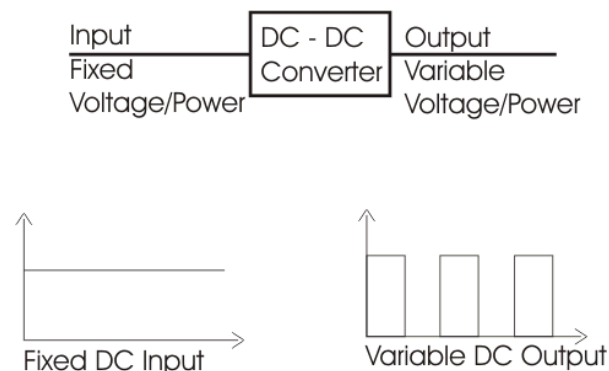
Applications

- Light dimmers.
- Fan speed regulators.
- AC heating control.
- Induction motor speed control (low/medium power).

2.8 Working Principle of Step-Up & Step-Down Chopper

Introduction to Chopper

- A **chopper** is a **DC-DC converter** that converts fixed DC input into variable DC output.
- It works as a **high-speed ON/OFF switch** (using SCR, MOSFET, IGBT).
- By controlling the **switching time (T_{on}/T_{off})**, the average output voltage is varied.



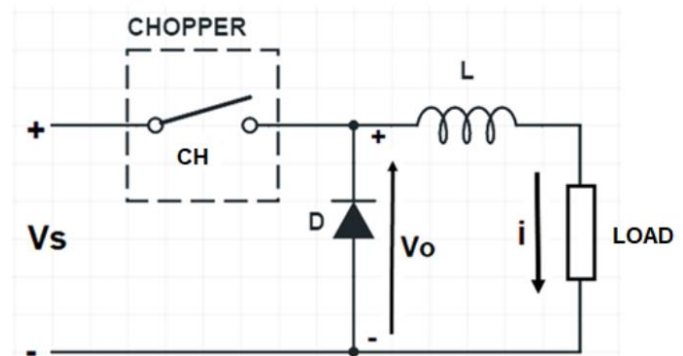
Step-Down Chopper (Buck Converter)

Definition

- A **step-down chopper** is a DC-DC converter used to reduce the input DC voltage to a lower output DC voltage.
- The average output voltage is always **less than the input voltage**.

Circuit Description

- Consists of:



- **Chopper switch (CH)** (transistor, MOSFET, or IGBT)
- **Freewheeling diode (FD)**
- **Inductor (L)** and **Load (R or RL)**

Key Terms

- **Toff** → Time interval when chopper is OFF.
- **Vs** → Source (input) voltage.
- **Vo** → Output (load) voltage.
- **T** → Total chopping period = Ton + Toff.

Operation

1. When Chopper (CH) is ON:

- $V_o = V_s$
- Current rises as inductor stores energy.
-

During ON Time of Chopper

Equation:

$$V_s = V_L + V_o$$

$$\Rightarrow V_s - V_o = L \times (di/dt)$$

⇒ Change in current,

$$\Delta I = (V_s - V_o) \times T_{on} / L \dots\dots\dots (i)$$

During OFF Time of Chopper

Inductor discharges through diode.

Equation:

$$V_o = L \times (di/dt)$$

$$\Rightarrow \Delta I = (V_o \times T_{off}) / L \dots\dots\dots (ii)$$

Equating (i) and (ii)

$$(V_s - V_o) \times T_{on} / L = (V_o \times T_{off}) / L$$

Simplifying:

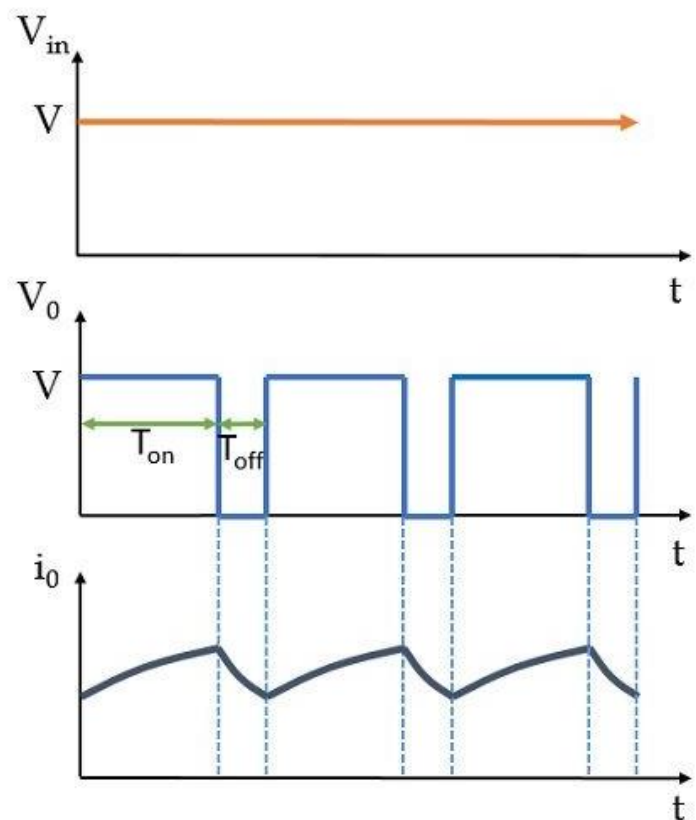
$$(V_s - V_o) \times T_{on} = V_o \times T_{off}$$

$$V_s / V_o = (T_{on} + T_{off}) / T_{on}$$

Final Expression

$$V_o = (T_{on} / T) \times V_s$$

Where,



Voltage and Current Waveforms

- **Duty cycle (D)** = T_{on} / T
- Therefore, $V_o = D \times V_s$

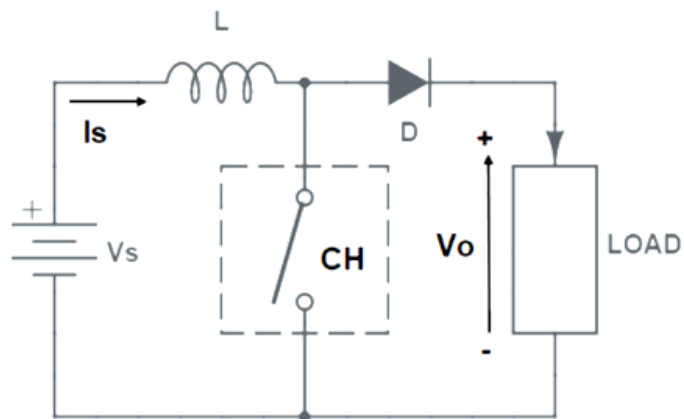
Conclusion

- The output voltage is always **less than input voltage**.
- Hence, it is called a **Step-Down Chopper (Buck Converter)**.

STEP UP CHOPPER

Circuit Components

- **Switching Device (CH):** Transistor, MOSFET, or IGBT (used as a controlled switch).
- **Diode (D):** Provides current path when switch is OFF.
- **Inductor (L):** Stores energy when switch is ON and releases it when switch is OFF.
- **Capacitor (C):** Maintains smooth DC output.
- **Load (R):** Connected at output.



Working of Step-Up Chopper (Boost Converter)

The operation of a step-up chopper can be divided into **two modes**:

1. Switch ON Period (T_{on})

- When the chopper switch (CH) is turned **ON**:
 - The input supply voltage V_s drives current through the inductor L and switch **CH**.
 - The inductor **stores energy** in the form of a magnetic field.
 - During this time, the load is isolated because the diode **D** is reverse biased.
 - Hence, **load current (I_o) = 0** in the ON period.
- **Important Note:**
 - The inductor plays a crucial role in boosting the voltage.
 - A **large inductance value** is required to store sufficient energy for boosting the load voltage above the source voltage.

2. Switch OFF Period (T_{off})

- When the chopper switch (CH) is turned **OFF**:
 - The current through the inductor cannot fall to zero instantly.
 - The inductor **reverses its polarity** and releases stored energy.

- This forces the current to flow through the **diode (D)** and the **load**.
- The load therefore receives energy both from the **inductor** and the **source**, resulting in a **boosted output voltage ($V_o > V_s$)**.
- The inductor current decays **exponentially** during T_{off} .

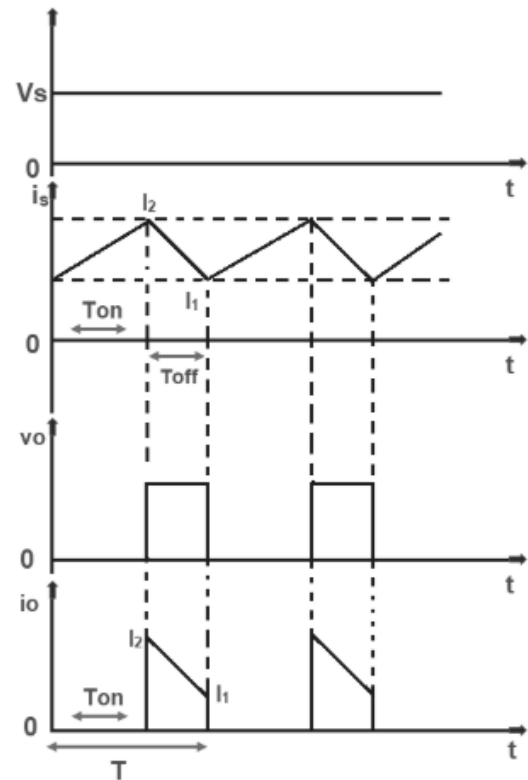
Waveform Explanation of Step-Up Chopper

1. Source Voltage (V_s)

- The input source is a **DC supply** of constant magnitude V_s .
- Hence, the waveform of source voltage is a **straight horizontal line**, parallel to the time axis.

2. Source Current (I_s)

- When **chopper (CH)** is ON:
 - The source current increases from its minimum value **I1** to its maximum value **I2**.
 - This current flows only through the **inductor L** during ON time.
 - Thus, **inductor current rises from I1 to I2**.
- When **chopper (CH)** is OFF:
 - The source current decreases from its peak value **I2** back to its minimum value **I1**.
 - Hence, **inductor current falls from I2 to I1**.



3. Load Current (I_o)

- During **ON period of the chopper**:
 - The diode is reverse biased.
 - No current flows through the load.
 - Hence, **load current = 0** in ON time.
- During **OFF period of the chopper**:
 - Inductor releases stored energy.
 - Current flows through the **diode D** and the **load**.
 - Load current decreases gradually from **I2 to I1** during T_{off} .

Derivation of Output Voltage for Step-Up Chopper

1. Energy Stored in Inductor (During ON Time)

When the chopper is switched ON:

- Energy stored in the inductor (L) is given by:

$$\begin{aligned}\text{Energy} &= (\text{Voltage across } L) \times (\text{Average current through } L) \times T_{\text{on}} \\ &= [V_s \times (I_1 + I_2) / 2] \times T_{\text{on}} \dots\dots\dots (\text{Equation 1})\end{aligned}$$

2. Energy Released by Inductor (During OFF Time)

When the chopper is switched OFF:

- Inductor releases its stored energy to the load.

$$\begin{aligned}\text{Energy} &= (\text{Voltage across } L) \times (\text{Average current through } L) \times T_{\text{off}} \\ &= [(V_o - V_s) \times (I_1 + I_2) / 2] \times T_{\text{off}} \dots\dots\dots (\text{Equation 2})\end{aligned}$$

3. Energy Balance

Assuming the system is **lossless**, energy stored = energy released.

$$[V_s \times (I_1 + I_2) / 2] \times T_{\text{on}} = [(V_o - V_s) \times (I_1 + I_2) / 2] \times T_{\text{off}} \dots\dots\dots (\text{Equation 3})$$

4. Simplification

Canceling common terms:

$$V_s \times T_{\text{on}} = (V_o - V_s) \times T_{\text{off}}$$

Rearranging:

$$V_s \times T_{\text{on}} = V_o \times T_{\text{off}} - V_s \times T_{\text{off}}$$

$$V_o \times T_{\text{off}} = V_s \times (T_{\text{on}} + T_{\text{off}})$$

But $(T_{\text{on}} + T_{\text{off}}) = T$ (total chopping period).

$$\text{So, } V_o \times T_{\text{off}} = V_s \times T$$

5. Final Expression

$$V_o = V_s \times (T / T_{\text{off}})$$

Also, Duty cycle $\alpha = T_{\text{on}} / T$

$$\text{So, } T_{\text{off}} = T - T_{\text{on}} = T \times (1 - D)$$

Therefore:

$$V_o = V_s \times [1 / (1 - D)] \dots\dots\dots (\text{Equation 4})$$

2.9 Control Modes of Chopper

Introduction

- A **chopper** is a type of **DC–DC converter** that converts a fixed DC input voltage into a variable DC output voltage.
- It works as a **high-speed ON–OFF switch** using SCR, MOSFET, IGBT, or GTO.
- By controlling the **ratio of ON time (Ton) to OFF time (Toff)** of the chopper switch, we can control the **average output voltage (Vdc)**.
- This process is called **chopper control**, and it can be carried out in different **control modes**.

Duty cycle can be varied usually in 2 ways:

1. Time Ratio Control
2. Current Limit Control

1. Time Ratio Control (TRC)

- In this method, the **average output voltage** is controlled by varying the ratio of the ON time to the total period of chopper operation.
- The ratio is called **Duty Cycle (D)**.

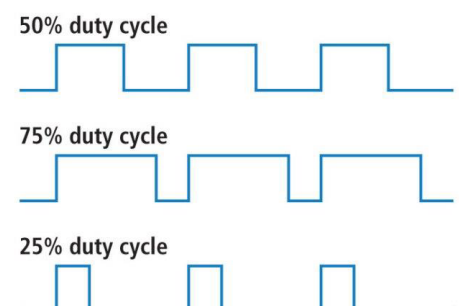
$$D = \frac{T_{on}}{T_{on} + T_{off}} \quad ; \quad V_{dc} = D \cdot V_s$$

Where:

- D = duty cycle ($0 < D < 1$)
- Vs = input DC supply voltage

(a) Constant Frequency Control or Pulse Width Modulation (PWM)

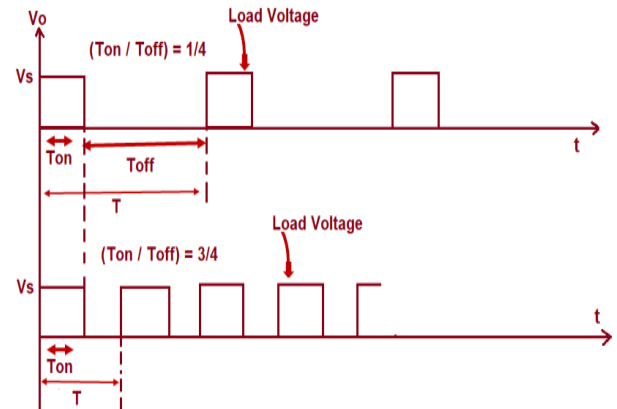
- In this mode, the **total time period (T = Ton + Toff)** is kept **constant**, so the switching frequency ($f = 1/T$) is fixed.
- Output voltage is controlled by varying **Ton** and **Toff** proportionally.
- Hence, duty cycle D is varied while frequency remains constant.
- This is the **most widely used control method** because:
 - It provides a stable switching frequency.
 - It is easy to design filters.
 - It reduces harmonics in the output.



✓ **Example:** Used in **DC power supplies, converters for communication systems, etc.**

(b) Variable Frequency Control

- In this mode, either **Ton** or **Toff** (or both) are varied while the other remains constant.
- This means the **frequency of chopping is not fixed** but changes according to load requirements.
- Two types:
 1. **On-Time Control** – Ton is varied, Toff fixed.
 2. **Off-Time Control** – Toff is varied, Ton fixed.
- This method gives a **wide range of control**, but:
 - The switching frequency is irregular.
 - It introduces more ripple in output.
 - Filtering becomes more difficult.



✓ **Example:** Used in **traction control (electric trains), induction heating, and welding applications.**

2. Current Limit Control (CLC)

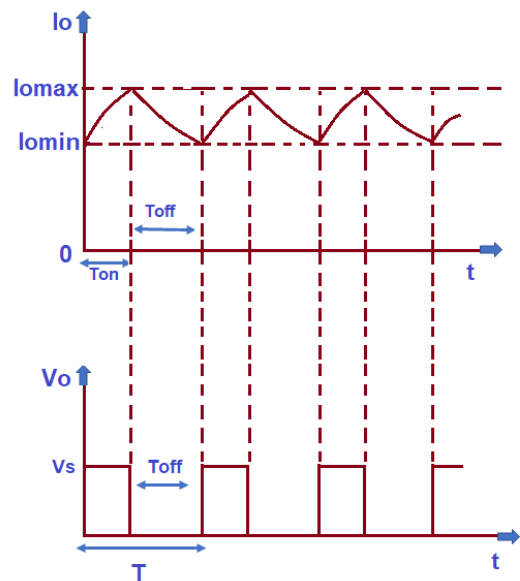
Definition

In this method, the chopper is controlled such that the load current always remains within a preset minimum and maximum limit. The chopper is automatically turned ON and OFF to maintain current between:

- **Maximum current:** $I_{o(max)}$
- **Minimum current:** $I_{o(min)}$

Working Principle

1. **Chopper ON:**
When the load current drops to $I_{o(min)}$, the chopper is turned ON. Current increases in the load.
2. **Current Rise:**
During ON period, load current rises from $I_{o(min)}$ to $I_{o(max)}$.
3. **Chopper OFF:**
When current reaches $I_{o(max)}$, the chopper is turned OFF. Current begins to fall.



4. Current Fall:

During OFF period, load current falls back to $I_{o(min)}$.

Load Current Nature

- Load current never becomes zero.
- It fluctuates between $I_{o(min)}$ and $I_{o(max)}$.
- Hence, current is always continuous.

Advantages

- Protects the load (e.g., DC motor) from overcurrent.
- Provides **automatic current control**.
- Ensures smooth motor operation in drives.

✓ **Example:** Commonly used in **DC motor drives and electric traction**.

Summary Table

<u>Control Method</u>	<u>Parameter Controlled</u>	<u>Frequency</u>	<u>Application</u>
PWM (TRC)	Pulse Width (TON)	Constant	Output Voltage
FMC (TRC)	Frequency (T)	Variable	Output Voltage
CLC	Current (I_{max} & I_{min})	Automatic	Current Protection

Conclusion

- Chopper control can be achieved either by **Time Ratio Control (TRC)** or by **Current Limit Control**.
- **TRC with constant frequency** is the most commonly used method because of its simplicity and good output quality.
- **Variable frequency control** is used where wide control is required.
- **Current limit control** is essential in motor drive applications to protect against overcurrent.

2.10 Operation of Chopper in All Four Quadrants

Introduction

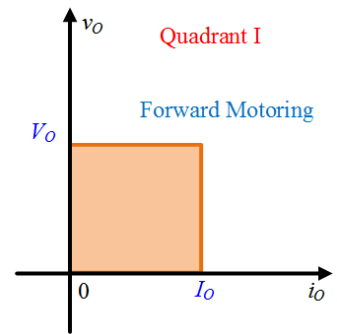
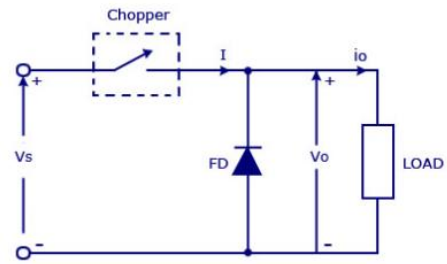
- A **chopper** is a DC–DC converter used to control output voltage and current.
- Depending on whether the **voltage and current are positive or negative**, a chopper can operate in **four quadrants of the V–I plane**.
- Each quadrant corresponds to a different **mode of operation** of the load (motoring/braking).

1. First Quadrant Chopper (Class-A: Step-Down Chopper)

- Output voltage (V_o) > 0 and Load current (I_o) > 0.
- Both voltage and current are positive.
- Power flows from source → load.
- This is **normal motoring mode**.
- Average output voltage:

$$V_{dc} = D \cdot V_s ; \quad 0 < D < 1$$

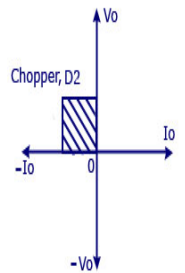
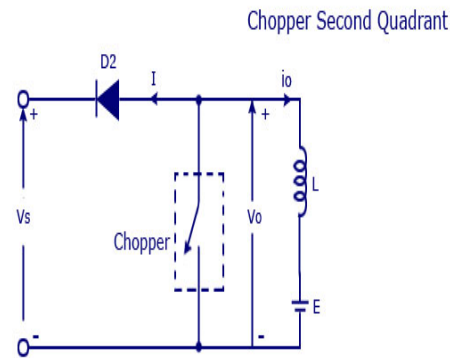
✓ Used for **DC motor speed control (forward motoring)**.



2. Second Quadrant Chopper (Class-B: Step-Up Chopper)

- Output voltage (V_o) > 0 but Load current (I_o) < 0.
- Voltage is positive, current is negative.
- Power flows from **load** → **source** (regenerative braking).
- Inductor stores energy during ON time, delivers back to source during OFF time.

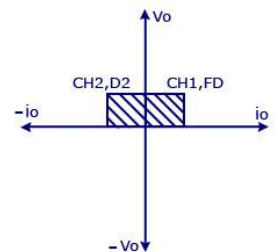
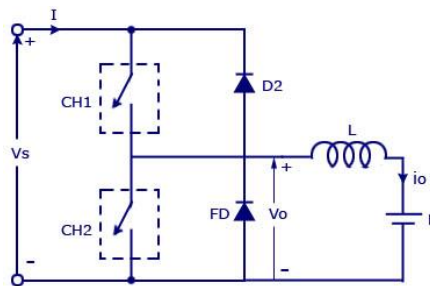
✓ Used in **regenerative braking of DC motors**.



Type-C Chopper (Two-Quadrant Type-A Chopper)

Circuit Description

- Formed by connecting **Type-A (Step-Down)** and **Type-B (Step-Up)** choppers in parallel across the same load.
- A **freewheeling diode (FD)** is connected across the load.
- Two SCRs/choppers + two diodes are used.



Working Principle

1. **First Quadrant (Motoring Mode):**

- Chopper + Freewheeling diode (FD) operate together (like **Type-A**).
- Output voltage $V_o = V_s$ (positive).

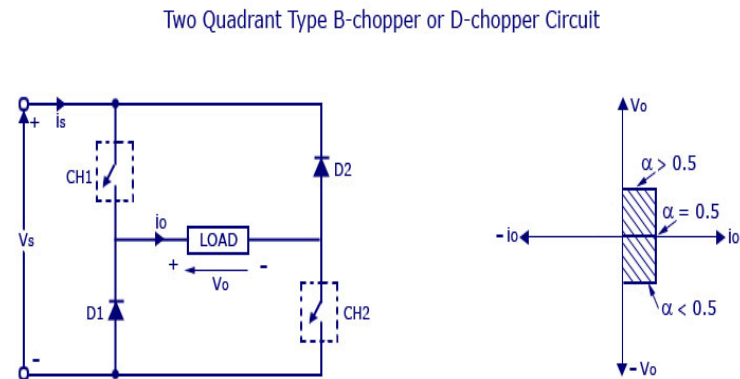
- Current flows from **source** → **load**, hence positive.
- 2. **Second Quadrant (Regenerative Braking Mode):**
 - Chopper + Diode (D2) operate together (like **Type-B**).
 - Output voltage remains positive, but current reverses.
 - Current flows from **load** → **source**, i.e., regenerative braking

✓ **Type-C Chopper** → Quadrant I (motoring) & Quadrant II (regenerative braking).

Type-D Chopper (Two-Quadrant Type-B Chopper)

In the circuit of a Type-D Chopper, there are two choppers (switches) and two diodes.

- When both choppers (CH₁ and CH₂) are ON, the output voltage (V_o) is equal to the supply voltage (V_s).
- When the choppers are OFF, the diodes D₁ and D₂ start conducting, and the output voltage becomes $-V_s$.



The important point is:

- **Both diodes and choppers conduct current in only one direction, so the load current (I_o) is always positive.**

Operation Based on T_{on} and T_{off}

Condition	Average V_o	Quadrant of Operation
$T_{on} > T_{off}$	Positive	First Quadrant (Power flows from source to load)
$T_{on} < T_{off}$	Negative	Fourth Quadrant (Power is fed back from load to source)

Key Features

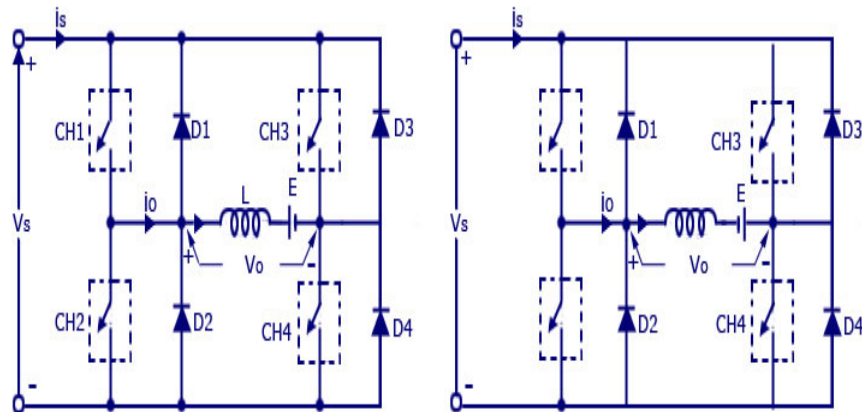
- **When the average V_o is positive, the chopper works in the First Quadrant.**
- **When the average V_o becomes negative, it works in the Fourth Quadrant.**
- **Therefore, the Type-D Chopper can operate in both first and fourth quadrants.**

Type-E Chopper (Four-Quadrant Chopper)

Circuit Description

- Consists of 4 semiconductor switches (CH1, CH2, CH3, CH4) and 4 diodes (D1–D4) connected in antiparallel.
- Each chopper is responsible for one quadrant of operation.
- Load usually includes inductance (L) and DC source (E) like a motor.
- By controlling the switching sequence, the chopper can work in **all four quadrants of the V–I plane**.

E-type Chopper Circuit Diagram With Load emf E and E Reversed



Operation in Each Quadrant

1. First Quadrant (Forward Motoring, Step-Down Mode)

- CH1 and CH4 ON $\rightarrow$ load is directly connected to source.
- Load voltage $V_0 = V_s$, load current $I_0 > 0$.
- When CH1 is OFF, current freewheels through CH4 and D2.
- Acts as a **Step-Down Chopper**.



Power flows **source** $\rightarrow$ **load**.

2. Second Quadrant (Forward Regenerative Braking, Step-Up Mode)

- CH2 ON $\rightarrow$ current flows through CH2, E, and D4 (inductor stores energy).
- When CH2 OFF, stored energy in inductor feeds back to the source through D1 and D4.
- Here, $V_0 > 0$, but $I_0 < 0$.
- Acts as a **Step-Up Chopper**.



Power flows **load** $\rightarrow$ **source** (regeneration).

3. Third Quadrant (Reverse Motoring, Step-Down Mode)

- CH2 ON and CH3 operated, CH1 OFF.

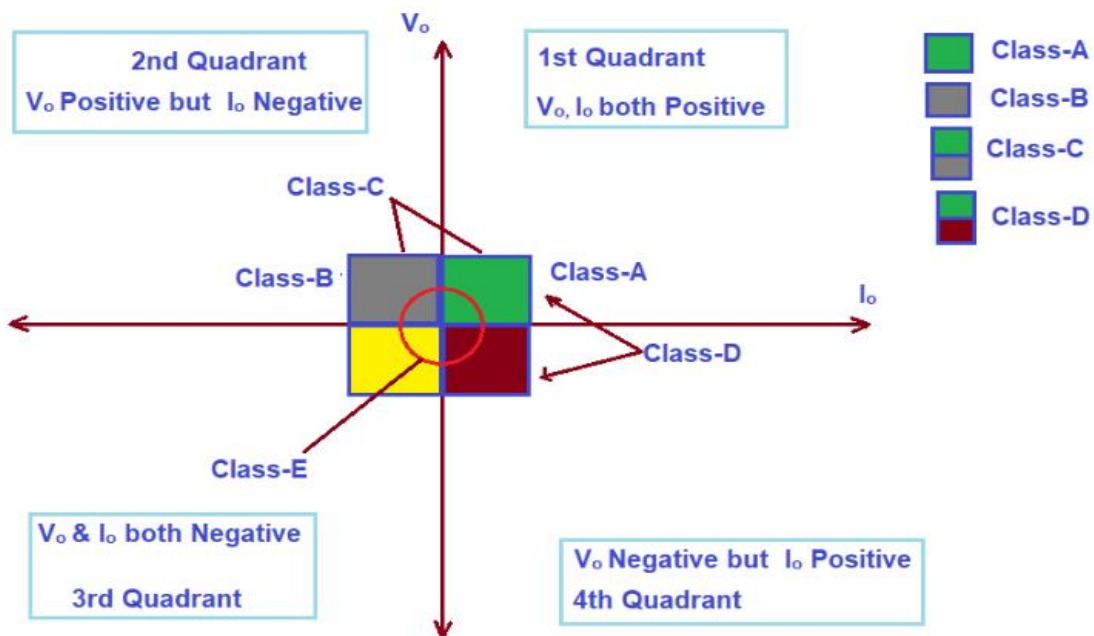
- Load polarity reversed $\rightarrow V_0 < 0, I_0 < 0$.
- Acts as a **Step-Down Chopper**.

✓ Power flows **source** $\rightarrow$ **load** (reverse motoring).

4. Fourth Quadrant (Reverse Regenerative Braking, Step-Up Mode)

- **CH4 operated**, while CH1, CH2, CH3 OFF.
- Current flows through **CH4, D2, E, L** (inductor stores energy).
- When **CH4 OFF**, energy feedback occurs through **D2 and D3**.
- Here, $V_0 < 0, I_0 > 0$.
- Acts as a **Step-Up Chopper**.

✓ Power flows **load** $\rightarrow$ **source** (reverse regeneration).



POSSIBLE QUESTION WITH PREVIOUS YEAR QUESTION

SHORT QUESTION

1. What do you mean by phase angle control of thyristor?
2. What is the difference between uncontrolled rectifier and controlled rectifier?
3. What is the conduction angle?
4. What is the advantage of freewheeling diode?
5. Define firing angle and conduction angle of an ~~scr~~?
6. What is Chopper?
7. What is duty cycle?
8. What do you mean by uncontrolled rectifier?
9. Name one current controlled semiconductor device?

LONG QUESTION

1. Explain single phase half controlled bridge converter for r load?
2. Explain about mid point type converter with r load?
3. Explain Step up chopper with neat diagram. (Year 2020) (Year 2022)
4. Explain single phase half controlled bridge converter with RL load? (Year 2022)
5. Explain the working of Step down chopper? (Year 2021)
6. A single phase half wave SCR circuit feeds power to a resistive load ,draw waveforms for source voltage load voltage load current and voltage across the SCR for a given firing angle α ?
7. Explain different chopper configuration with neat diagram? (Year 2020)
8. Explain the working of a half wave converter with RL load with and without freewheeling diode show the output waveforms?
9. Explain the working of single phase half wave converter with resistive load with a neat circuit diagram and a draw its waveforms?
10. Explain the working of a half wave converter with RL load with and without freewheeling diode show the output waveforms?
11. Explain the working of single phase full wave controlled rectifier with ~~rl~~ load and free wheeling diode draw its waveforms? (Year 2020)

MODULE -3

UNDERSTAND THE INVERTERS AND CYCLO-CONVERTERS

3.1 Classify inverters.

3.2 Explain the working of series inverter.

3.3 Explain the working of parallel inverter

3.4 Explain the working of single-phase bridge inverter.

3.5 Explain the basic principle of Cyclo-converter.

3.6 Explain the working of single-phase step up & step down Cyclo-converter.

3.7 Applications of Cyclo-converter.

3.1 Classify inverters

An **inverter** is a power electronic device that converts **DC power into AC power** of desired voltage and frequency.

It is widely used in **UPS, motor drives, HVDC transmission, renewable energy systems** etc.

Classification of Inverters

(I) According to the Output Characteristic

1. **Square Wave Inverter** – simple, cheap, high harmonics.
2. **Sine Wave Inverter** – pure sine output, suitable for sensitive loads.
3. **Modified Sine Wave Inverter** – improved over square, used in general UPS.

(II) According to the Source of Inverter

1. **Voltage Source Inverter (VSI)** – input is constant DC voltage, most common.
2. **Current Source Inverter (CSI)** – input is constant DC current (with large inductor)

(III) According to the Type of Load

1. **Single-Phase Inverter**
 - (a) Half-Bridge Inverter
 - (b) Full-Bridge Inverter
2. **Three-Phase Inverter**
 - (a) 180° conduction mode
 - (b) 120° conduction mode

(IV) According to PWM Technique

1. **Simple Pulse Width Modulation (SPWM)**

2. **Multiple Pulse Width Modulation (MPWM)**
3. **Sinusoidal Pulse Width Modulation (SPWM)**
4. **Modified Sinusoidal PWM (MSPWM)**

(V) According to Number of Output Levels

1. **Two-Level Inverter** – basic inverter.
2. **Multilevel Inverter** – produces stepped waveform, reduced harmonics.

(VI) According to Connection of Commutating Element

1. **Series Inverter** – commutating components connected in series with load.
2. **Parallel Inverter** – commutating components in parallel.
3. **Bridge Inverter** – widely used for higher power applications.

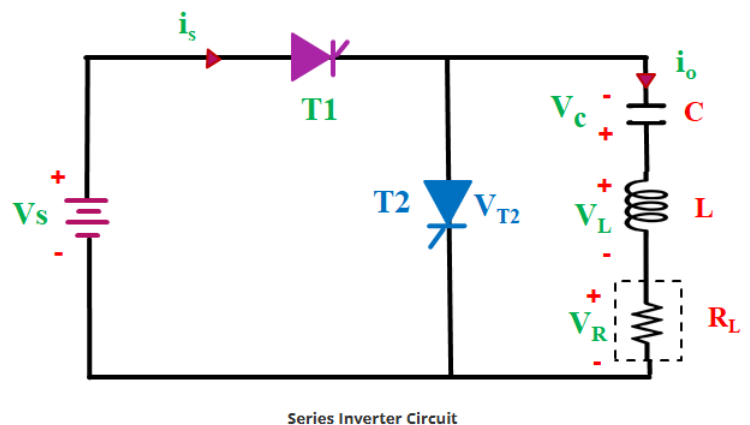
3.2 Explain the working of series inverter.

Introduction

- A **series inverter** is a type of inverter where the **commutating elements (L & C)** are connected **in series with the load**.
- It is also called a **self-commutated inverter**.
- It uses **thyristors (SCRs)** for switching.
- Widely used for **low- and medium-power applications** like induction heating, UPS, and communication systems.

Circuit Description

- Consists of:
 - **DC supply (V_s)**
 - **Load (R–L type)** connected in series with commutating capacitor (C) and inductor (L)
 - Two SCRs (T1 and T2) used as switches
- **L and C provide forced commutation** for SCRs.



Working of Series Inverter – Modes of Operation

Mode I (T1 ON, T2 OFF)

- Firing pulse is applied to **T1**, so **T1 turns ON** and **T2 remains OFF**.
- Current flows:

$V_s \rightarrow T1 \rightarrow \text{Load}(R-L) \rightarrow C \rightarrow \text{back to } V_s$

- Load current is **sinusoidal** (due to underdamped RLC circuit).

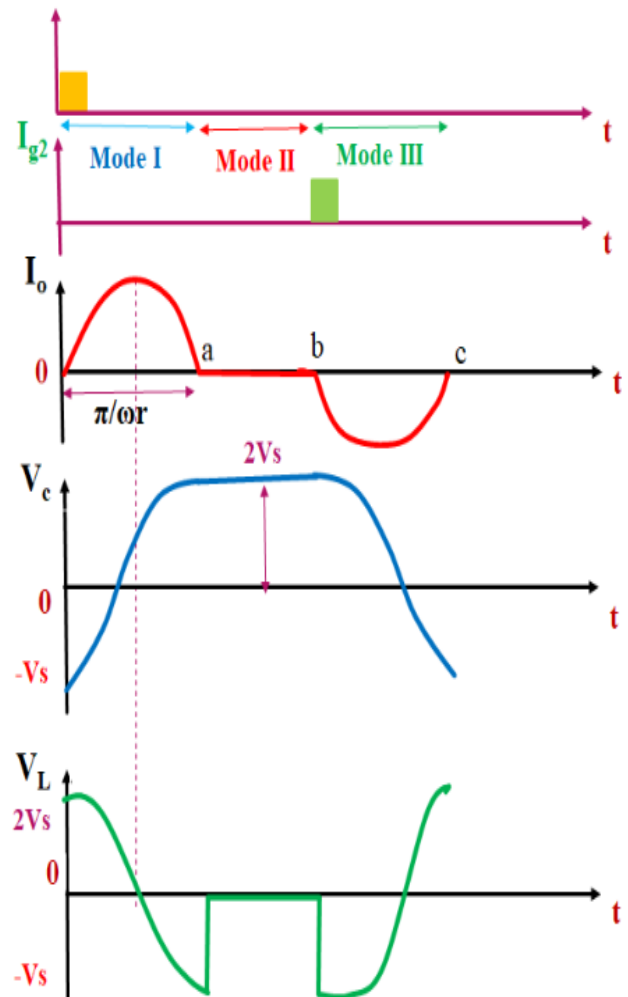
- Capacitor **charges gradually** from $-V_s \rightarrow +V_s$.
- When load current reaches maximum $\rightarrow$ capacitor voltage = $+V_s$.
- When load current falls to zero (point 'a') $\rightarrow$ capacitor voltage = $+2V_s$.
- At this instant, current is zero $\rightarrow$ **T1 turns OFF automatically.**

Mode II (T1 OFF, T2 OFF)

- From **a** $\rightarrow$ **b**, both thyristors **T1 and T2 are OFF.**
- No current flows through load.
- Capacitor voltage remains constant at $+2V_s$.
- This is the **off-period (dead time)** of the inverter.

Mode III (T1 OFF, T2 ON)

- Firing pulse is now applied to **T2**, so **T2 turns ON.**
- Capacitor **discharges** from $+2V_s \rightarrow -V_s$ through **T2, R, L, and Load.**
- This produces **reverse current** in the load.
- When load current again falls to zero (point 'c'), **T2 turns OFF automatically.**
- From **c** $\rightarrow$ **d**, both thyristors are OFF until **T1 is triggered again.**



Cycle Repetition

- By alternately firing **T1 and T2**, the cycle repeats.
- Thus, a **sinusoidal AC output** is obtained from a **DC input**.

Waveforms

- **Load Current** $\rightarrow$ Sinusoidal alternating wave.
- **Capacitor Voltage** $\rightarrow$ Oscillates between $-V_s$ and $+2V_s$.
- **Thyristor Currents** $\rightarrow$ Alternately conducting during each half-cycle.

Applications:

1. **Induction Heating** – used in furnaces, cooking, and metallurgical processes.
2. **Sonar Transmitters** – for underwater detection and navigation.
3. **Fluorescent Lighting** – high-frequency supply improves efficiency of lamps.
4. **Ultrasonic Generators** – used in cleaning, medical ultrasound, and welding.

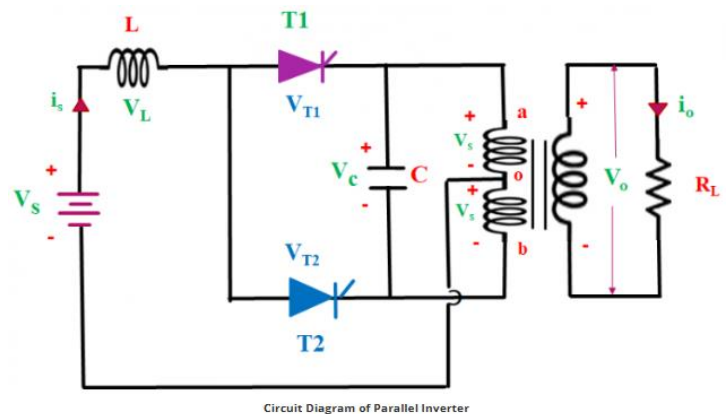
3.3 Explain the working of parallel inverter

Introduction

- A **Parallel Inverter** is a type of commutated inverter where the **commutating capacitor (C)** is connected **in parallel with the load** (through a center-tapped transformer).
- It uses **two thyristors (T1 & T2)**, a **capacitor (C)**, a **commutating inductor (L)**, and a **center-tapped transformer**.
- Called "parallel" because **C is parallel with the load**.
- Working is **similar to Class-B commutation**.

Circuit Description

- **DC source (V_s)** connected through inductor **L** to transformer's center tap.
- **Primary winding** of transformer is center-tapped $\rightarrow$ divided into two halves (a_o and O_b).
- **Two thyristors (T1 and T2)** are connected at the ends of the primary winding.
- **Capacitor C** connected across the whole primary winding (in parallel with load).
- Transformer secondary supplies the **AC load**.



Operation of Parallel Inverter

The working of a **parallel inverter** is divided into different modes, depending on which thyristor is conducting and how the capacitor behaves.

Mode I ($0 < t < t_1$) $\rightarrow$ T_1 ON, T_2 OFF

- Firing pulse applied to T_1 , so T_1 turns **ON** and T_2 remains **OFF**.
- Current flows:

$V_s \rightarrow T_1 \rightarrow AO$ (upper half of transformer primary) $\rightarrow$ back to V_s

- As a result:
 - Voltage V_s induced in both upper and lower halves of transformer primary.
 - Load (secondary) receives $+V_s$.
- Total voltage across primary winding = $2V_s$.
- Capacitor **C** charges to $+2V_s$ (upper plate positive, lower plate negative).



Load voltage = $+V_s$.

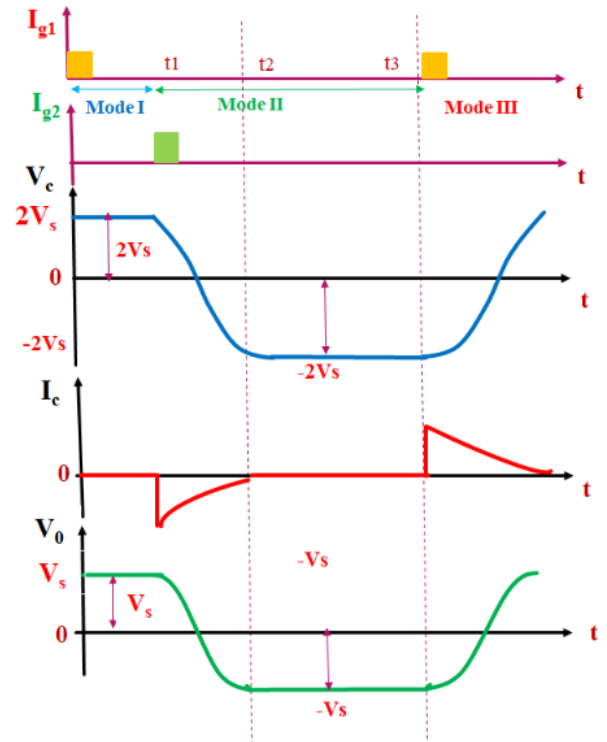
Mode II ($t_1 < t < t_3$) → T_2 ON, T_1 OFF

- Firing pulse applied to T_2 , so T_2 turns ON.
- Capacitor starts discharging through T_1 , which turns T_1 OFF (Class-B commutation).
- Current flows:

$V_s \rightarrow T_2 \rightarrow BO$
(lower half of transformer primary) $\rightarrow$ back to V_s

- During discharge:
 - Capacitor voltage decreases from $+2V_s \rightarrow -2V_s$.
 - Load voltage changes from $+V_s \rightarrow -V_s$.
- Between t_2 and t_3 , capacitor holds $-2V_s$ (upper plate negative).

✓ Load voltage = $-V_s$ (constant).



Mode III ($t_3 < t < t_4$) → T_1 ON, T_2 OFF

- Again, firing pulse given to T_1 , so T_1 turns ON and T_2 turns OFF.
- Current flows same as Mode I, through AO winding.
- Capacitor discharges through $T_2 \rightarrow$ turns T_2 OFF.
- Capacitor recharges from $-2V_s \rightarrow +2V_s$.
- Load voltage swings from $-V_s \rightarrow +V_s$.

✓ Load voltage = $+V_s$.

Cycle Repeats

- By alternately firing T_1 and T_2 , capacitor voltage oscillates between $+2V_s$ and $-2V_s$, and load voltage alternates between $+V_s$ and $-V_s$.
- Thus, an AC output is obtained.

Waveforms

1. **Load Voltage (V_o):** Alternates between $+V_s$ and $-V_s$.
2. **Capacitor Voltage (V_c):** Alternates between $+2V_s$ and $-2V_s$.
3. **SCR Current:** Alternates depending on T_1/T_2 conduction.

Applications

1. **Uninterrupted Power Supplies (UPS)** – most important application.

2. **Emergency backup systems** – for computers, hospitals, and communication equipment.
3. **Industrial AC drives** – low and medium power motor drives.
4. **Stand-alone inverters** – for small AC loads from DC batteries.
5. **Power conditioning systems** – where DC needs to be converted into AC for utility.

3.4 Explain the working of single-phase bridge inverter.

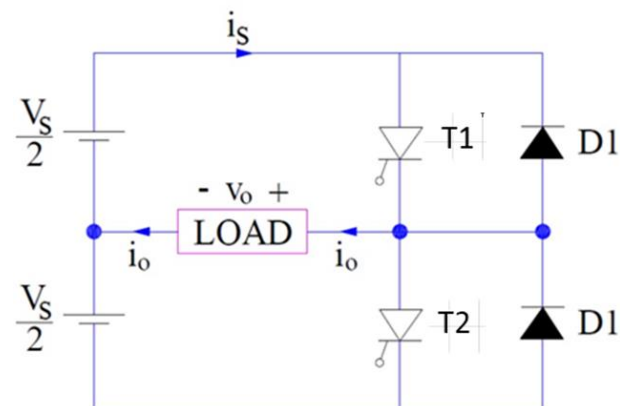
Introduction

- A **Bridge Inverter** is a **Voltage Source Inverter (VSI)**, meaning the input is a **DC voltage source**.
- It converts DC into single-phase AC for supplying residential or industrial loads.
- There are **two main types**:
 1. **Single-Phase Half-Bridge Inverter**
 2. **Single-Phase Full-Bridge Inverter**

1. Single-Phase Half-Bridge Inverter

Circuit Description

- The circuit consists of:
 - **Two thyristors (T1 & T2)**
 - **Two diodes (D1 & D2)** → provide feedback/freewheeling for inductive loads
 - **Three-wire DC supply** (i.e., $+V_s/2$, 0, $-V_s/2$)



Working Principle (Operation Modes)

Mode I (T1 ON, T2 OFF)

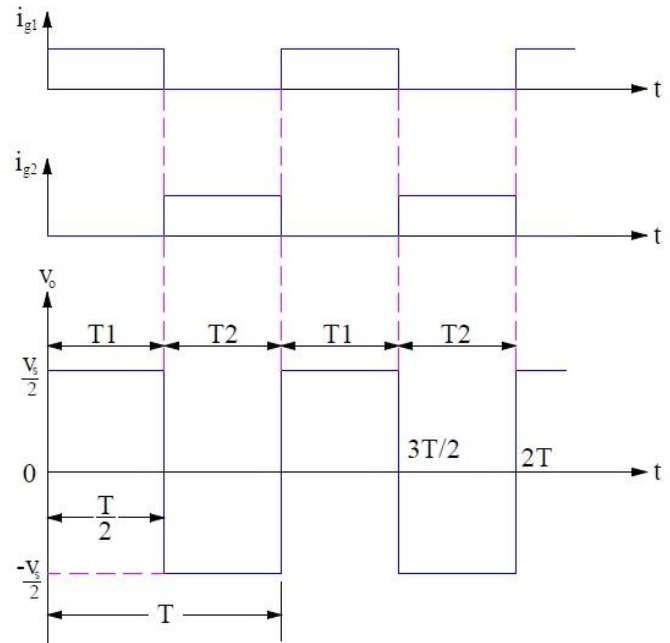
- When firing pulse is given to **T1**, it conducts.
- Current flows from $+V_s/2 \rightarrow T1 \rightarrow \text{Load} \rightarrow -V_s/2$.
- Load voltage $V_0 = +V_s/2$.
- Load current direction depends on type of load (resistive or inductive).

Mode II (T1 OFF, T2 ON)

- When firing pulse is removed from **T1**, it turns OFF.
- Next, firing pulse applied to **T2**, it conducts.
- Current flows from $-V_s/2 \rightarrow T2 \rightarrow \text{Load} \rightarrow +V_s/2$.
- Load voltage $V_0 = -V_s/2$.

Continuous Operation

- By alternately switching **T1** and **T2**, load voltage alternates between $+V_s/2$ and $-V_s/2$.
- Thus, a **square-wave AC output** is produced.



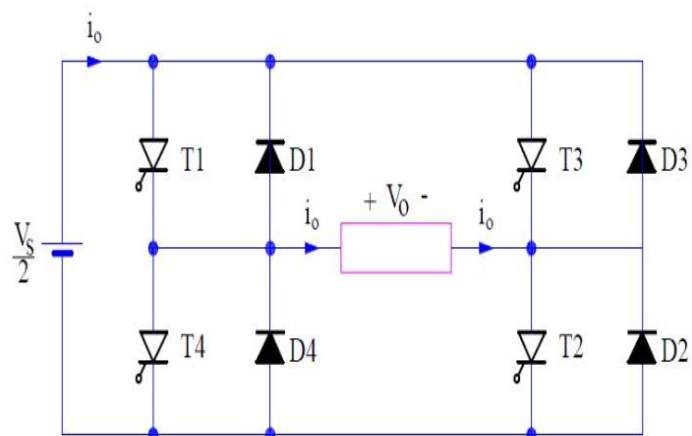
Output Waveforms

1. **For R Load:** Load current is in phase with load voltage.
 - Pure square wave of $\pm V_s/2$.
2. **For R-L Load:** Current lags behind voltage.
 - Freewheeling diodes (D1, D2) conduct during off-periods to maintain current continuity.

2. Single-Phase Full-Bridge Inverter

Circuit Description

- The circuit consists of:
 - **Four thyristors (T1, T2, T3, T4)** arranged in an **H-bridge configuration**.
 - **Four diodes (D1, D2, D3, D4)** connected in **anti-parallel** with each thyristor (for freewheeling with inductive loads).
 - **Two-wire DC supply (V_s)**.
 - **Load** connected across the bridge diagonal.
- **Anti-parallel diodes** ensure continuous current flow when load is inductive (R-L).



Operation

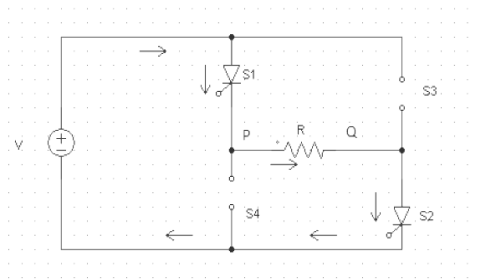
Mode I ($0 < t < T/2$) → Positive Half Cycle

- Gate pulses **ig1** and **ig2** are applied.
- **T1 and T2 conduct simultaneously**, while **T3 and T4 remain OFF**.
- Current path:

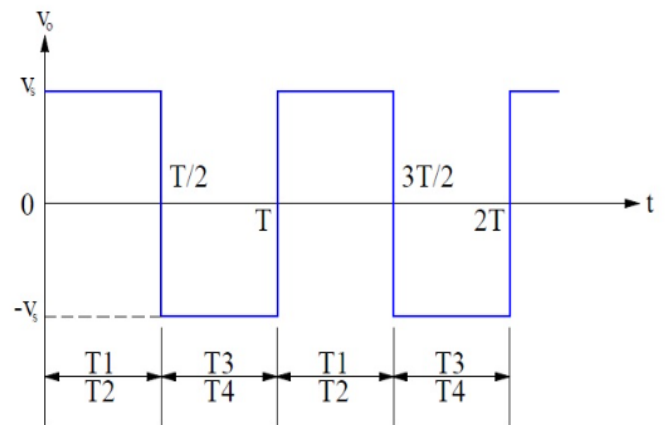
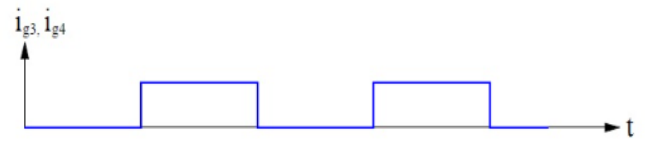
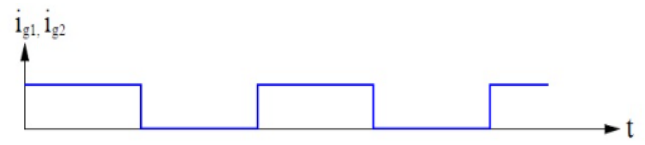
$V_s \rightarrow T1 \rightarrow \text{Load} \rightarrow T2 \rightarrow \text{back to } V_s$

- Load voltage:

$V_0 = +V_s$



fig; conducting mode 1



Mode II ($T/2 < t \leq T$) → Negative Half Cycle

- Gate pulses **ig3** and **ig4** are applied.
- **T3 and T4 conduct simultaneously**, while **T1 and T2 remain OFF**.
- Current path:

$V_s \rightarrow T3 \rightarrow \text{Load} \rightarrow T4 \rightarrow \text{back to } V_s$

- Load voltage:

$V_0 = -V_s$

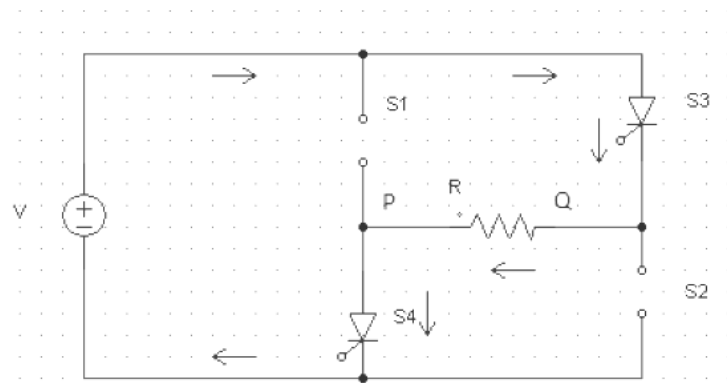


fig : conducting mode 2

Gating Sequence

- **ig1, ig2** → applied for **0 to T/2**
- **ig3, ig4** → applied for **T/2 to T**
- This sequence repeats every cycle, producing an **alternating square wave output**.

Output Waveforms

1. **Load Voltage (V_o):** Alternates between $+V_s$ and $-V_s$.
2. **Load Current (I_o):**
 - For **R load** → in phase with V_o (square wave).
 - For **R-L load** → lags behind V_o , with diodes providing freewheeling.

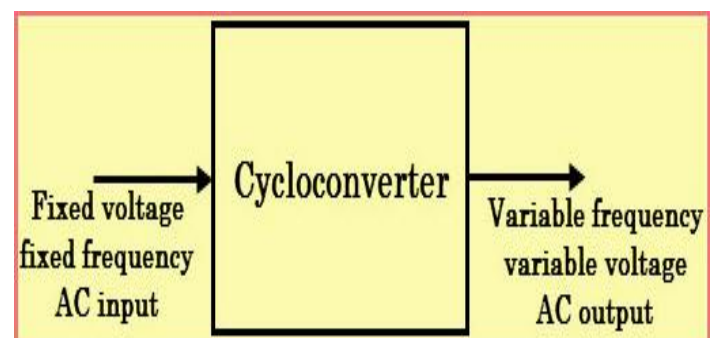
Comparison between Half & Full Bridge Inverters:

Half Bridge Inverter	Full Bridge Inverter
It comprises of two thyristors and two free-wheeling diodes.	It consists of four thyristors and four flyback diodes.
The magnitude of load / output voltage is half of the magnitude of input DC source.	The magnitude of load voltage is equal to the magnitude of DC input source. This means, the magnitude of output voltage is twice the magnitude of load voltage for hf bridge inverter
The main drawback of this inverter is the requirement of three wire DC input supply.	The output power of full bridge inverter is four times that of hf bridge inverter

3.5 Explain the basic principle of Cyclo-converter.

Cyclo-converter – Basic Principle

- A **cyclo-converter** is a power electronic device that **directly converts AC power at one frequency into AC power at another (usually lower) frequency** without using an intermediate DC stage.
- It is built using **thyristors (SCRs)** arranged in such a way that they can control the direction and magnitude of the output voltage.



⚙️ How it Works:

1. **Input Supply:** The cyclo-converter takes **fixed-frequency AC input** (usually 50 Hz or 60 Hz).
2. **Phase Control:** By controlling the **firing angle** of thyristors, segments of the input waveform are selected and combined.
3. **Output Formation:** These controlled segments are stitched together to form an **AC output waveform of desired frequency**.
 - The output frequency is usually a **sub-multiple** of the input frequency (e.g., 50 Hz input $\rightarrow$ 25 Hz or $16\frac{2}{3}$ Hz output).
4. **Polarity Control:** Two groups of thyristors are used:
 - One group conducts during the **positive half cycles**.
 - The other conducts during the **negative half cycles**.

3.6 Explain the working of single-phase step up & step-down Cyclo-converter.

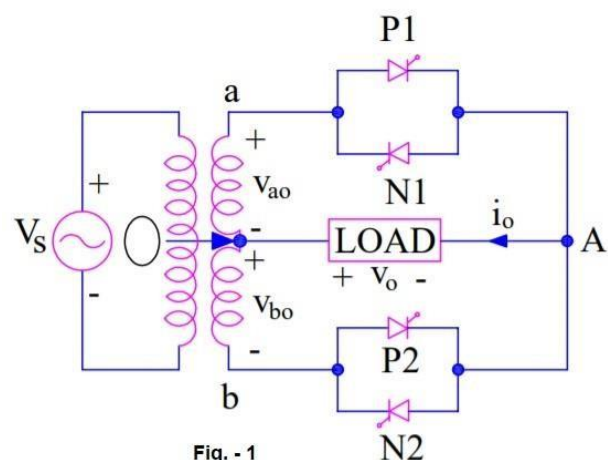
Step- up Cyclo converter

Introduction

- A **Step-up Cycloconverter** is a power electronic device that converts **AC at a lower frequency into AC at a higher frequency** directly.
- It is mainly used where a **higher frequency supply** is needed from a **low-frequency source**, for example:
 - **Induction heating**
 - **Aircraft power systems**
 - **High-frequency applications**

Circuit Description

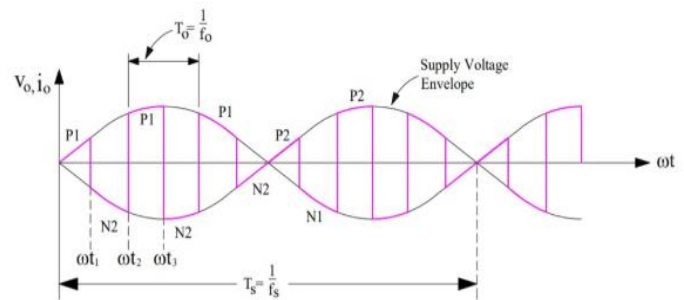
- A single-phase transformer has **secondary winding with a mid-tap** (center point O).
- Four **thyristors (SCRs)** are connected:
 - **Positive group** $\rightarrow$ P1 and P2 (load voltage is positive when these conduct).
 - **Negative group** $\rightarrow$ N1 and N2 (load voltage is negative when these conduct).
- Load is connected between **mid-point O** and terminal **A**.
- Load is assumed **resistive** (voltage and current in phase).



Working of Step-up Cycloconverter

Positive Half Cycle ($\omega t = 0 \rightarrow \pi$)

- During this interval, **P1** (positive group) and **N2** (negative group) are **forward biased**.
- At $\omega t = 0$, SCR **P1** is **fired** $\rightarrow$ Load voltage is **positive** (A positive, O negative).
- Load voltage follows the **positive envelope** of the input supply.
- At $\omega t = \omega t_1$, SCR **P1** is **force commutated**, and SCR **N2** is **fired**.
- When **N2** **conducts**, load voltage becomes **negative** (O positive, A negative) $\rightarrow$ Output follows the **negative envelope** of the supply.
- At $\omega t = \omega t_2$, SCR **N2** is **force commutated**, and **P1** is **fired again** $\rightarrow$ Output is **positive**.



Negative Half Cycle ($\omega t = \pi \rightarrow 2\pi$)

- At $\omega t = \pi$, terminal **b** is positive w.r.t terminal **a**, so **P2** and **N1** are forward biased.
- SCR **N2** is **commutated** and **P2** is **fired** $\rightarrow$ Load voltage is **positive**.
- At time $\omega t = (1/2f_s) + (1/2f_o)$, SCR **P2** is **force commutated**, and SCR **N1** is **fired**.
- When **N1** **conducts**, load voltage is **negative**, following the **negative envelope** of the supply.

Sequence of Conduction

- In the **first half cycle**: $P1 \leftrightarrow N2$ operate alternately.
- In the **second half cycle**: $P2 \leftrightarrow N1$ operate alternately.
- This alternate switching between **positive and negative envelopes** produces a **higher output frequency**.

Output Frequency Relation

- If the **supply frequency** = f_s , and in one input cycle there are **6 output cycles**, then:
 $f_o = 6 \times f_s$
- Example: If supply frequency is 50 Hz $\rightarrow$ Output frequency will be 300 Hz.

Step- down Cyclo converter

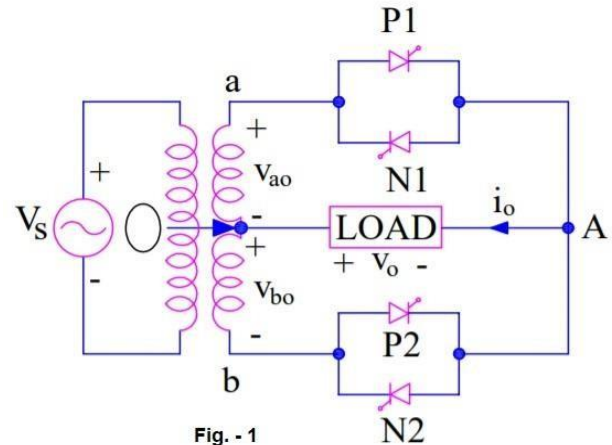
Introduction

- A **Step-down Cycloconverter** is a power electronic device that converts a **fixed-frequency AC input into a lower-frequency AC output**.
- It is also called a **frequency changer**.
- If f_s = input supply frequency and f_o = output frequency, then:
 $f_o < f_s$

- Example: From a 50 Hz supply, the output may be 25 Hz or 10 Hz.
- Unlike step-up cycloconverter, **forced commutation is not required**.
- **Natural (line) commutation** is used, provided by the input AC supply itself.
- This makes the control **simpler and more reliable**.

Circuit Description

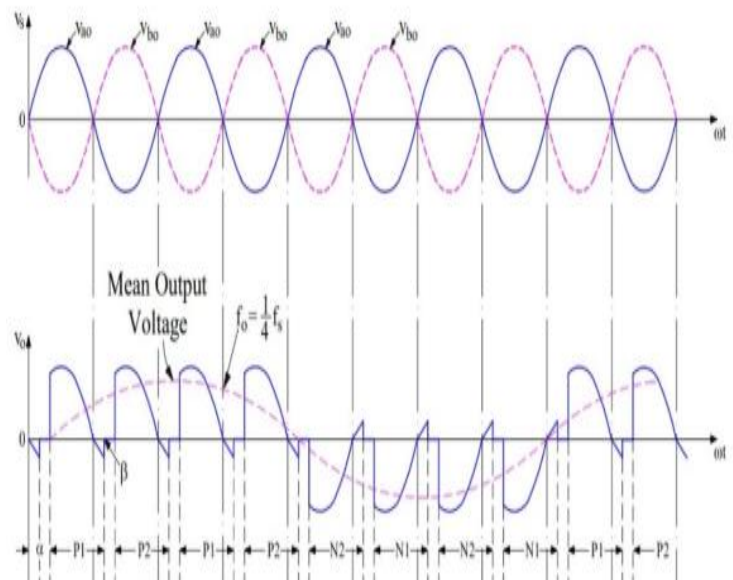
- A single-phase transformer has **secondary winding with a mid-tap** (center point O).
- Four **thyristors (SCRs)** are connected:
 - **Positive group** → P1 and P2 (load voltage is positive when these conduct).
 - **Negative group** → N1 and N2 (load voltage is negative when these conduct).
- Load is connected between **mid-point O** and terminal **A**.
- Load is assumed **resistive** (voltage and current in phase).



2. Operation Modes

Step-down Cycloconverter – Conducting Sequence (Discontinuous Load Current)

- **Positive half cycle ($\omega t = 0 \rightarrow \pi$):**
 - A positive w.r.t O → **P1 forward biased**.
 - P1 fired at $\omega t = 0 \rightarrow$ current flows A → O.
 - Current decays to zero at $\omega t = \beta \rightarrow$ **P1 naturally commutated**.
- **Next half cycle ($\omega t = \pi \rightarrow 2\pi$):**
 - B positive w.r.t O → **P2 forward biased**.
 - P2 fired at $(\pi + \alpha) \rightarrow$ current flows A → O.
 - Current decays to zero at $(\pi + \beta) \rightarrow$ **P2 commutated**.
 - Sequence repeats → 4 positive half cycles.
- **Negative half cycles:**
 - At $(4\pi + \alpha)$, **N2 fired** → current flows O → A, then decays to zero.
 - At $(5\pi + \alpha)$, **N1 fired** → current flows O → A, then decays to zero.
 - Generates 4 negative half cycles.
- **Cycle repeats:** 4 positive → 4 negative half cycles.



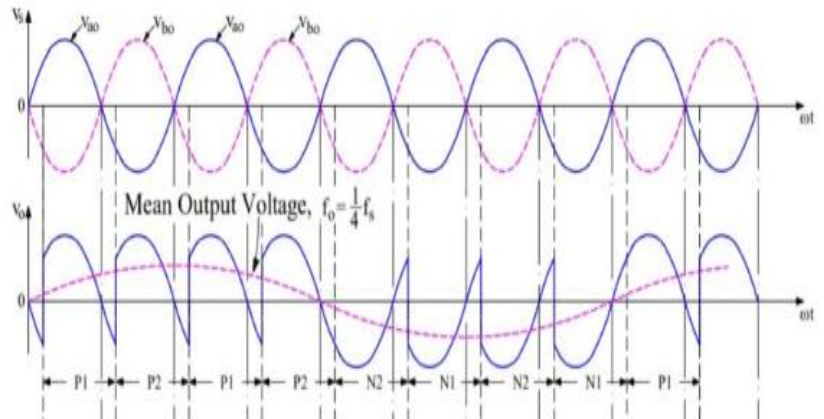
✓ Key Points:

- **Current is discontinuous** (goes to zero before next SCR fires).
- **Natural commutation** occurs automatically.
- Output frequency: $f_o = f_s / 4$.

Step-down Cycloconverter – Continuous Load Current

Positive Half Cycles

- When **a is positive w.r.t O**, SCR **P1 is triggered at ($\omega t = \alpha$)** → load voltage positive, current builds up.
- At $\omega t = \pi$, supply/load voltage = 0, but current continues (since load current is continuous).
- P1 remains conducting until **P2 is triggered at ($\pi + \alpha$)**.
- P2 ON → reverse voltage appears across P1 → **P1 is naturally commutated**.
- Load current builds further with P2 ON.
- At $(2\pi + \alpha)$, P1 is triggered again, P2 commutates.
- Thus, **P1 and P2 conduct alternately** for four positive half cycles, with current continuously rising.



Negative Half Cycles

- After four positive half cycles, **N2 is triggered** → load voltage negative, current decreases from positive value (RU) towards negative.
- At $(5\pi + \alpha)$, **N1 is triggered**, current becomes more negative.
- N1 and N2 conduct alternately, producing **four negative half cycles**.
- Load current waveform becomes negative but remains continuous.

Observations

- **Load current is continuous** → it never falls to zero, unlike in discontinuous mode.
- **Natural commutation** occurs when the next SCR is fired and reverse biases the previous one.
- The current waveform is **symmetric w.r.t ωt -axis**.
- **Mean load voltage waveform** is sinusoidal at **lower frequency**.

Key Result

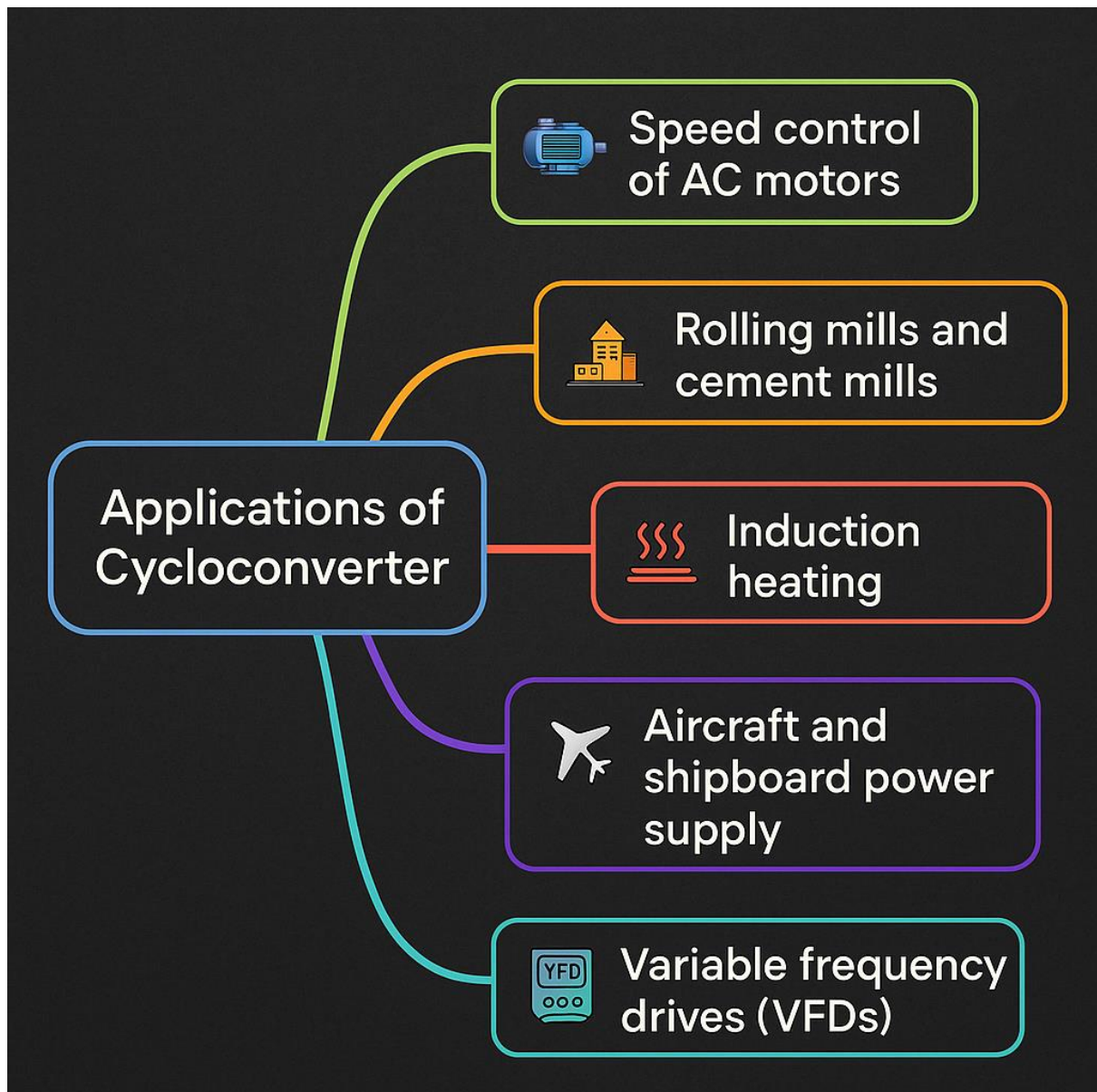
$$f_o = \frac{1}{4} f_s$$

Output frequency is one-fourth of supply frequency.

✓ Summary for Students:

- In continuous mode, **P1** ↔ **P2** conduct alternately for positive half cycles, and **N2** ↔ **N1** for negative half cycles.
- Current never falls to zero → smoother output.
- Output frequency: $f_o = f_s / 4$.

3.7 Applications of Cyclo-converter.



POSSIBLE QUESTION WITH PREVIOUS YEAR QUESTION

SHORT QUESTION

1. What is an inverter? (Year 2021)
2. Classify different types of inverters? (Year 2021)
3. What are the difference between converter and inverter
4. What is inverter and name various types of inverter?
5. What are the applications of Inverters ?
6. What is Cycloconverter ?
7. State two application of Cycloconverter?
8. What is the use of cycloconverter?
9. Name different type of Cycloconverter?

LONG QUESTION

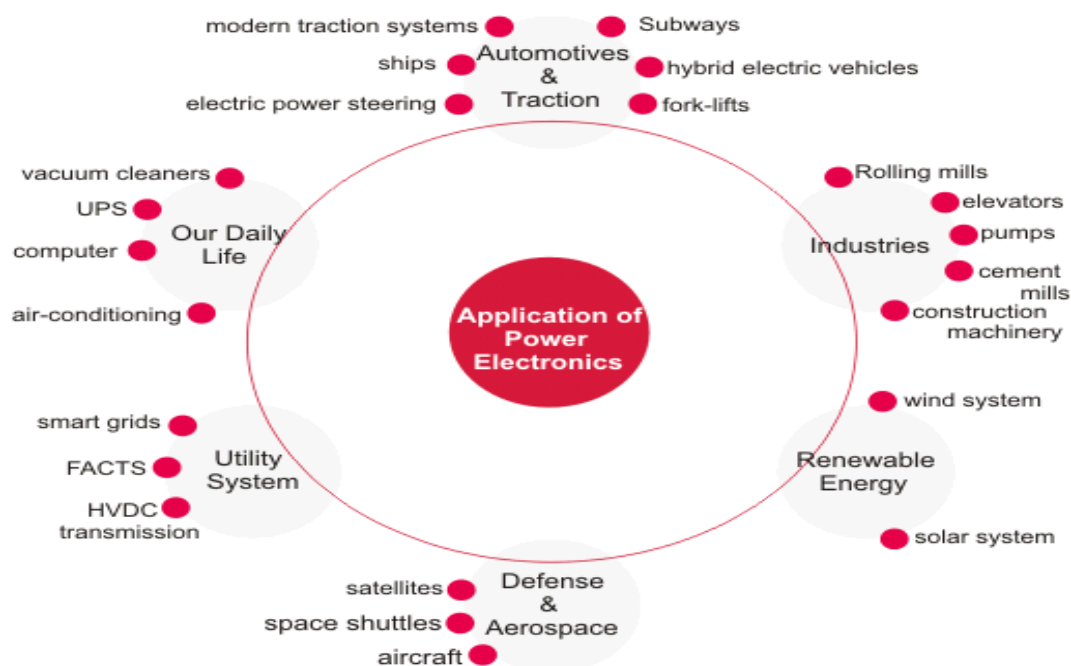
1. Explain single phase voltage source bridge inverter with resistive load ?
2. Describe about parallel inverter?
3. Explain about full bridge inverter with r load?
4. Explain about half bridge inverter with r load? (Year 2021)
5. Describe the working of basic parallel inverter and show the triggering and output waveforms?
6. Explain with circuit diagram and necessary waveform the principle of operation of single phase half bridge inverter?
7. Explain the working of a voltage source series inverter with a neat diagram? (Year 2022)
8. Explain with waveform about working of step down cycloconverter ? (Year 2022)
9. Explain with circuit diagram the principle of operation of cycloconverter ?
10. Explain with circuit diagram the principle of operation of a single phase to single phase mid point type step down cycloconverter ? (Year 2020)
11. Explain bridge type step up cycloconverter ?

SYALLBUS

4. UNDERSTAND APPLICATIONS OF POWER ELECTRONIC CIRCUITS

- 4.1 List applications of power electronic circuits.**
- 4.2 List the factors affecting the speed of DC Motors.**
- 4.3 Speed control for DC Shunt motor using converter.**
- 4.4 Speed control for DC Shunt motor using chopper.**
- 4.5 List the factors affecting speed of the AC Motors.**
- 4.6 Speed control of Induction Motor by using AC voltage regulator.**
- 4.7 Speed control of induction motor by using converters and inverters (V/F control).**
- 4.8 Working of UPS with block diagram.**
- 4.9 Battery charger circuit using SCR with the help of a diagram.**
- 4.10 Basic Switched-mode power supply (SMPS) - explain its working & applications**

4.1 List applications of power electronic circuits.



4.2 List the factors affecting the speed of DC Motors

The speed of a DC motor is given by:

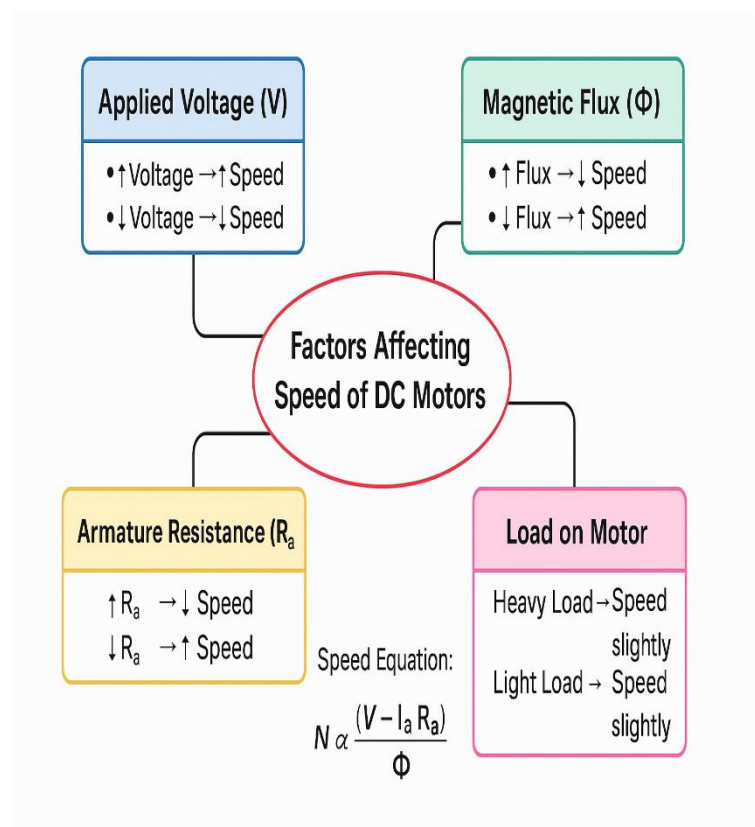
$$N \propto \frac{V - I_a R_a}{\Phi}$$

Where:

- **N** = Speed of motor (in RPM)
- **V** = Applied voltage (in Volts)
- **I_a** = Armature current (in Amperes)
- **R_a** = Armature resistance (in Ohms)
- **Φ** = Flux per pole (in Weber)

Factors Affecting Speed:

1. **Applied Voltage (V):**
 - Higher voltage → speed increases
 - Lower voltage → speed decreases
2. **Magnetic Flux (Φ):**
 - Higher flux → speed decreases
 - Lower flux → speed increases
3. **Armature Resistance (R_a):**
 - More R_a → more voltage drop → less speed
 - Less R_a → higher speed
4. **Load on Motor:**
 - Heavy load → speed decreases slightly
 - Light load → speed increases slightly



☞ Now your SCETVT Odisha students can directly reproduce:

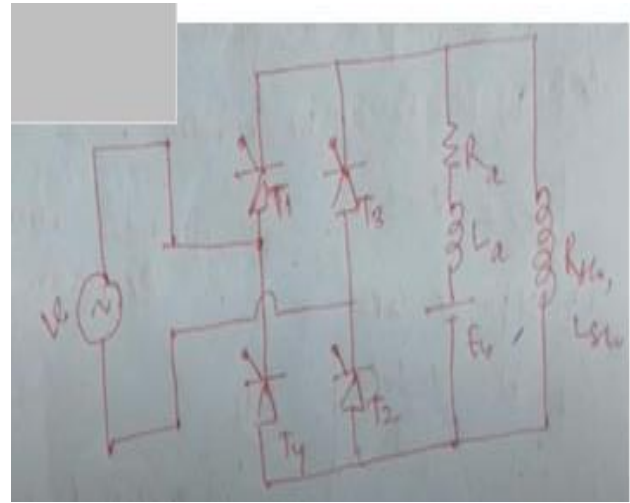
- **2 marks** → just list + equation

- 5 marks → definition + 4 points + equation

4.3 Speed control for DC Shunt motor using converter.

Circuit Explanation

- A **single-phase full-wave converter** is used.
- It consists of **4 thyristors (T₁, T₂, T₃, T₄)** arranged in a bridge.
- Output of the converter is connected to the **armature winding (R_a, L_a, E_b)** and **field winding (R_{sh})** of the DC shunt motor.
- By varying the **firing angle (α)** of thyristors, the **average DC voltage** applied to the armature is controlled.
- This changes the **speed of the motor**.



Modes of Operation

1. **Mode-1 (Positive Half Cycle):**
 - Thyristors **T₁ and T₂** conduct (with gate pulses).
 - Current flows through **armature and field winding**.
 - Path: $V_s \rightarrow T_1 \rightarrow \text{Armature} + \text{Field} \rightarrow T_2 \rightarrow V_s$
2. **Mode-2 (Negative Half Cycle):**
 - Thyristors **T₃ and T₄** conduct.
 - Current again flows through armature and field winding.
 - Path: $V_s \rightarrow T_3 \rightarrow \text{Armature} + \text{Field} \rightarrow T_4 \rightarrow V_s$

For any DC Motor:

$$E_b = V_a - I_a R_a \text{ and } E_b = \frac{P\Phi ZN}{60A} = k\Phi N.$$

Hence

$$N = \frac{V_a}{k\Phi} - \frac{I_a R_a}{k\Phi}.$$

For Continuous Conduction Mode:

The average output voltage of a single-phase full-wave converter is:

$$V_a = \frac{1}{\pi} \int_{\alpha}^{\pi+\alpha} V_m \sin(\omega t) d(\omega t) = \frac{2V_m}{\pi} \cos \alpha$$

So,

$$N = \frac{V_a}{k\Phi} - \frac{R_a T_a}{k^2}$$

Substituting V_a :

$$N = \frac{2V_m}{k\pi} \cos \alpha - \frac{R_a T_a}{k^2}$$

(using $I_a = T_a/\Phi$ and grouping constants into k).

Key Results:

1. For $0 < \alpha < \frac{\pi}{2}$:

$$N = \frac{V_{max}}{k}$$

(Maximum speed, nearly constant)

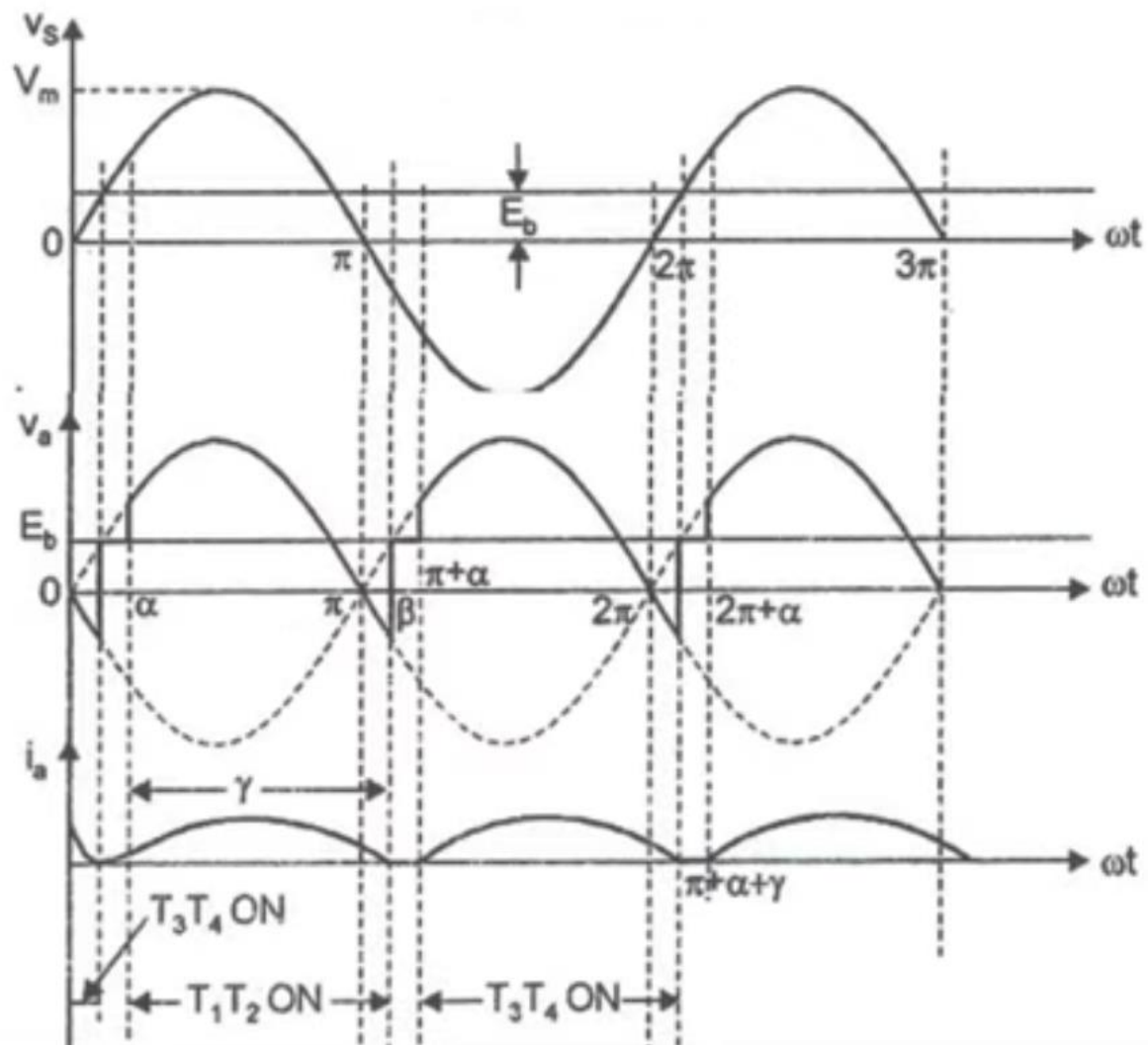
2. For $\frac{\pi}{2} < \alpha < \pi$:

$$N = \frac{V_{max}}{k} \cos \alpha$$

(Speed decreases as α increases)

Conclusion:

- The speed of a DC shunt motor can be controlled by **varying the firing angle α** of the converter.
- Smaller $\alpha \rightarrow$ higher average voltage $\rightarrow$ higher speed.
- Larger $\alpha \rightarrow$ lower voltage $\rightarrow$ lower speed.



4.4 Speed control for DC Shunt motor using chopper.

Working Principle

- A **chopper** controls the average DC voltage applied to the armature of a DC shunt motor.
- Average output voltage:

$$V_o = \alpha V_s$$

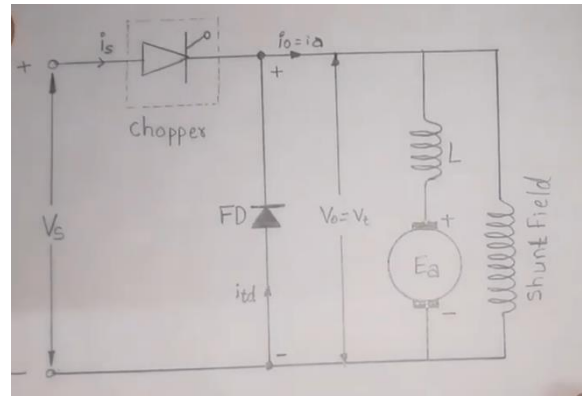
where

$$\alpha = \frac{T_{ON}}{T_{ON} + T_{OFF}}$$

- If α increases ($T_{on} \uparrow$) $\rightarrow$ Voltage $\uparrow \rightarrow$ Speed $\uparrow$
- If α decreases ($T_{on} \downarrow$) $\rightarrow$ Voltage $\downarrow \rightarrow$ Speed $\downarrow$

Important Notes

1. DC shunt motor has **low armature inductance**, so performance is poor.
2. To improve performance, **extra inductance** is added in series with armature.
3. **When chopper is ON:** supply is applied, energy stored in inductance.
4. **When chopper is OFF:** stored energy flows through **freewheeling diode**, maintaining motor current.



Equation

$$V_o = \alpha V_s = \frac{T_{ON}}{T} V_s$$

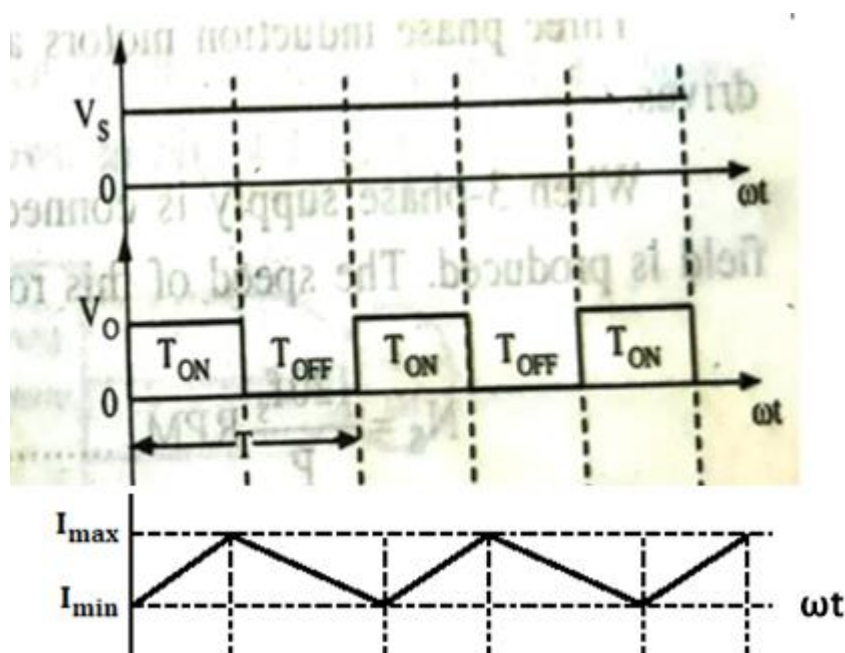
Also, since $f = \frac{1}{T}$:

$$V_o = f \cdot T_{ON} \cdot V_s$$

Conclusion:

By varying the **duty ratio (α)** of the chopper, the speed of a DC shunt motor can be increased or decreased smoothly.

WAVEFORMS



4.5 List the factors affecting speed of the AC Motors

The speed of AC motors depends on supply frequency, number of poles, slip, and load.

1. Supply Frequency (f):

- Speed $\propto$ supply frequency.
- If frequency increases $\rightarrow$ speed increases.
- If frequency decreases $\rightarrow$ speed decreases.

2. Number of Poles (P)

- Speed $\propto 1/\text{Poles}$.
- More poles $\rightarrow$ lower speed.
- Fewer poles $\rightarrow$ higher speed.

3. Slip (s): *(for induction motors)*

- Actual rotor speed N = Synchronous speed – Slip speed.
- Higher slip $\rightarrow$ lower motor speed.
- Smaller slip $\rightarrow$ motor runs closer to synchronous speed.

4. Load on Motor:

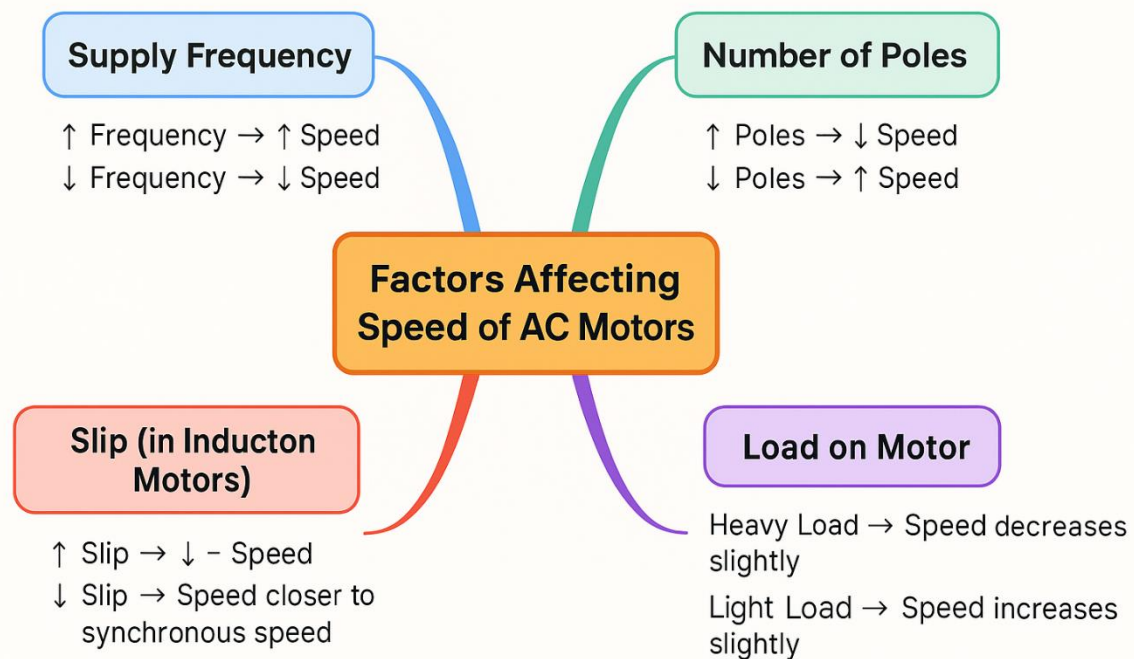
- Heavy load $\rightarrow$ motor draws more current $\rightarrow$ speed decreases slightly.
- Light load $\rightarrow$ speed increases slightly (for induction motors).

Speed Equation of Induction Motor

$$N = N_s(1 - s)$$

Where,

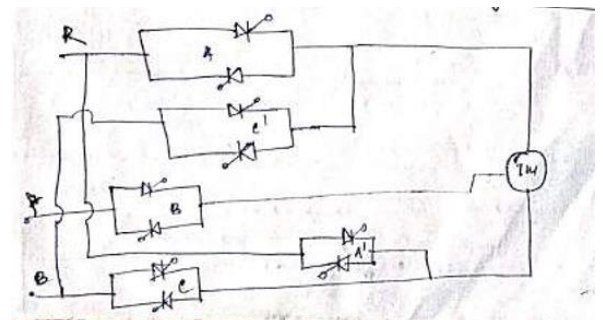
- $N_s = \frac{120f}{P}$ = Synchronous speed
- s = Slip



4.6 Speed control of Induction Motor by using AC voltage regulator.

Circuit

- The 3-phase supply lines **R, Y, B** are connected to the induction motor stator through an **AC voltage regulator**.
- Each line has **two thyristors (SCRs) in anti-parallel connection** (A, A'; B, B'; C, C').
- These SCRs control the **RMS voltage** applied to the motor.



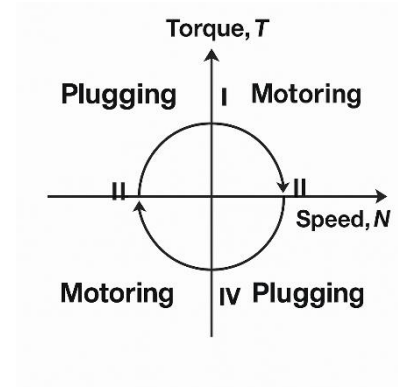
Working with Thyristor Pairs

- Thyristor pairs **A, B, C** provide operation in **Quadrants I & IV**.
- Thyristor pairs **A', B', C'** provide operation in **Quadrants II & III**.
- While shifting from one thyristor pair to another (e.g., from A, B, C to A', B', C'), care must be taken that the outgoing pair is fully turned off before the incoming pair is activated.

Explanation

- Using thyristor pairs, an induction motor can be operated in all four quadrants (I, II, III, IV) of the Torque (T) vs Speed (N) characteristics.

- Quadrants represent:
 - **I Quadrant:** Forward motoring
 - **II Quadrant:** Forward braking (plugging)
 - **III Quadrant:** Reverse motoring
 - **IV Quadrant:** Reverse braking (plugging)



Advantages

- Allows quick reversal of motor.
- Provides braking action during reversal.
- Useful for applications requiring rapid changes in direction.

Disadvantages (Cons)

1. Output voltage depends on both delay angle and current flow period, which are affected by load power factor. Hence, if load changes, output voltage also changes continuously.
2. Due to fluctuations in voltage and current, **harmonics** are produced.
 - Causes **eddy current losses** in the core.
 - Leads to **overheating** of the induction motor.

4.7 Speed control of induction motor by using converters and inverters (V/F control).

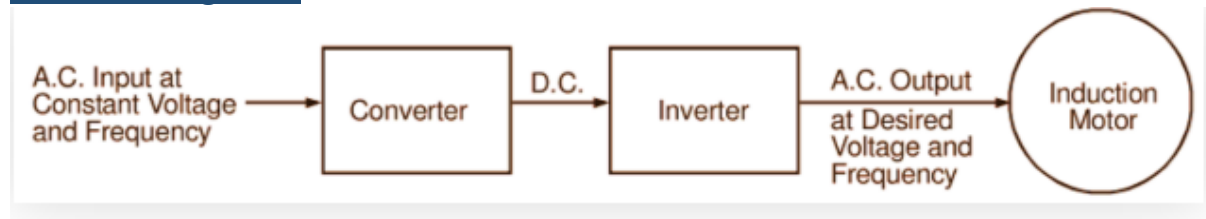
Principle of V/F Control

- The synchronous speed of an induction motor depends on **supply frequency**

$$N_s = \frac{120f}{P}$$

- Flux in motor is proportional to the ratio **V/f**.
- To keep flux constant (and avoid saturation), the **supply voltage is varied in proportion to frequency**.
- This method is known as **V/F Control** or **Constant Flux Control**.

Circuit Arrangement



1. **Converter (Rectifier):**
 - Converts 3-phase AC supply into DC.
2. **Inverter:**
 - Converts the DC back into 3-phase AC of variable frequency and variable voltage.
3. **Induction Motor:**
 - Fed from the inverter with adjustable V and f.

Working

- At low frequency: both voltage and frequency are reduced proportionally to maintain constant V/F ratio → constant flux.
- At high frequency: voltage is limited to rated value, but frequency increases → flux decreases → constant power region.
- By controlling inverter frequency, the **speed of induction motor is controlled** smoothly over wide range.

✓ Advantages of V/F Control

1. Provides **smooth and stepless speed control** over a wide range.
2. Can control speed **from zero to above rated speed**.
3. Maintains **constant flux**, avoiding saturation.
4. **High efficiency** compared to other methods.
5. **Wide applications** – fans, pumps, conveyors, lifts, and traction.
6. Allows **constant torque operation** below rated speed and **constant power operation** above rated speed.

✗ Disadvantages (Cons)

1. **Expensive and complex** due to converter–inverter set.
2. **Harmonics present** in inverter output → causes heating and torque pulsations.
3. **Switching losses** reduce efficiency.
4. Voltage spikes may cause **insulation stress** in motor windings.
5. Requires **extra cooling arrangement** due to additional heating.

6. **Poor performance at very low frequencies** (difficult to maintain V/F ratio).

4.8 Working of UPS with block diagram.

Definition

UPS (Uninterrupted Power Supply) is a device that provides continuous power to the load without interruption during mains supply failure or fluctuation.

Types of UPS

Generally, the UPS system is classified into:

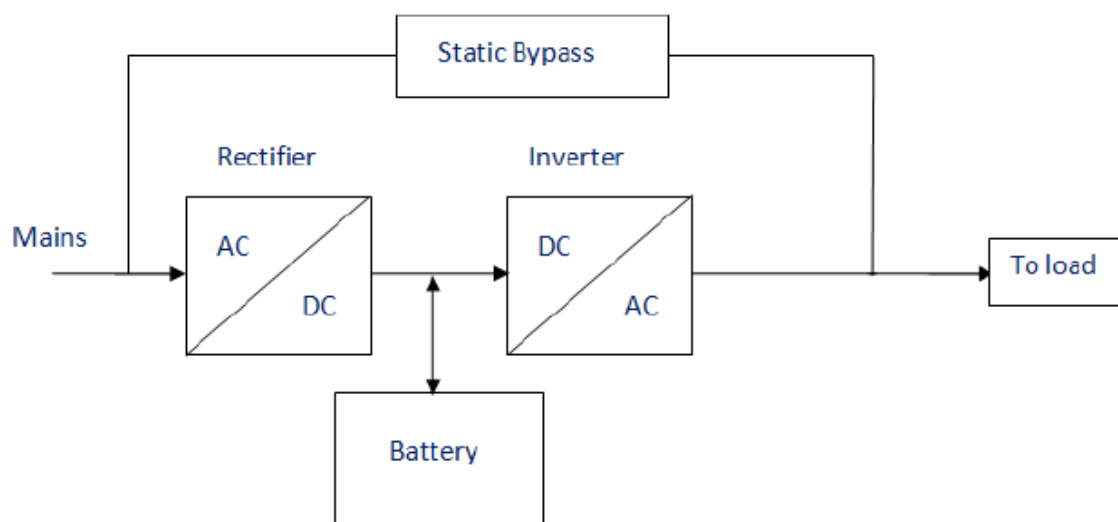
1. **On-line UPS**
2. **Off-line UPS**
3. **Line-interactive UPS**

On- Line UPS

Working Principle

- In this type of UPS, the **double conversion method** is used.
- **Step 1 (Rectification):** AC input is first converted to DC by the rectifier. This DC is used to:
 - Charge the rechargeable battery.
 - Supply the inverter directly.
- **Step 2 (Inversion):** The inverter converts DC back to AC, which is supplied to the load.
- Thus, the load is **always supplied through inverter**.

Block Diagram



Operation During Power Failure

- When mains supply fails, the rectifier has no role.
- The **battery supplies DC to the inverter**, which continues to feed AC to the load.
- Hence, the transfer time is **zero** (since load is always on inverter).

Important Notes

- Known as **Double Conversion UPS** because power passes through **rectifier + inverter** stages continuously.
- Provides **complete electrical isolation** between input and output.
- To prevent overheating, **battery charging current is limited**.
- However, due to **inrush current or large step load current**, a transfer delay of **4–6 ms** may occur in practice.

Advantages

- Zero transfer time during mains failure.
- Best power quality and protection.
- Provides electrical isolation.

Disadvantages

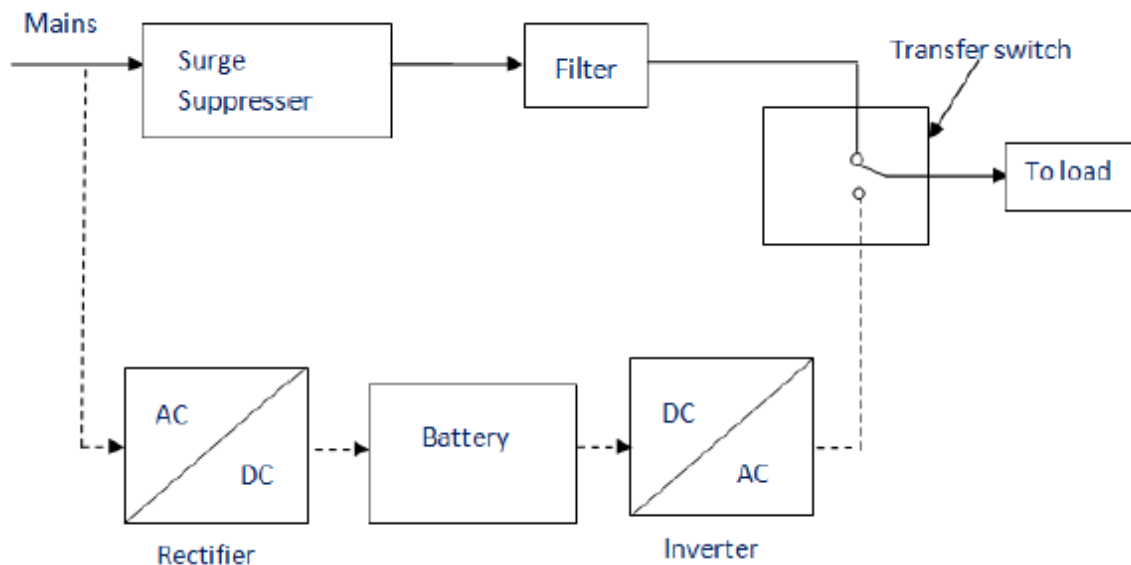
- Costly due to continuously running converters and cooling systems.
- Lower efficiency compared to off-line UPS.

Off-line UPS (Standby UPS)

Working Principle

- In this UPS, the **primary source** is the filtered AC mains.
- Under normal condition (mains ON):
 - Load is directly supplied from **AC mains** (solid path).
 - Rectifier charges the **storage battery**.
- During **power failure (mains OFF)**:
 - The transfer switch shifts the load to the inverter (dashed path).
 - The **DC power from the battery** is converted to AC by the inverter and supplied to the load.

Block Diagram



Features

- Works only when mains fails → also called **Standby UPS**.
- Provides **basic backup + surge protection**.
- Transfer time $\approx$ **25 milliseconds**, due to detection and switching delay.

Advantages

- **Least expensive** UPS system.
- Small size and simple design.
- Provides surge protection along with backup.

Disadvantages

- Transfer delay (20–25 ms) may cause issues for sensitive equipment.
- Limited protection compared to on-line UPS.

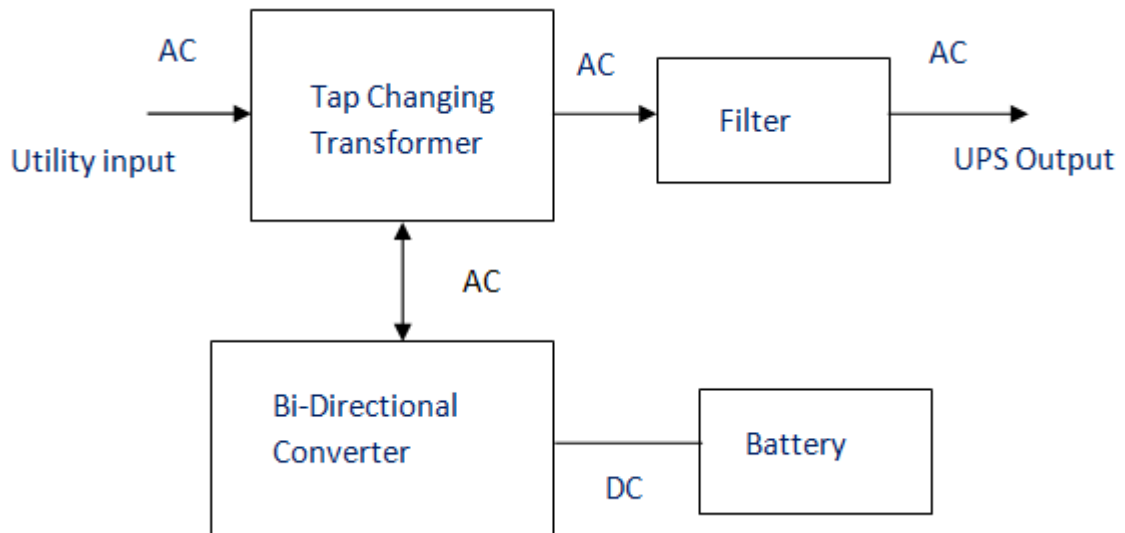
Line-interactive UPS

Working Principle

- A Line-Interactive UPS works similar to an **Off-line UPS**, but with an additional **tap-changing transformer**.
- Under normal condition (mains ON):
 - Load is supplied from mains through **tap-changing transformer**.
 - Transformer regulates voltage by changing taps depending on input voltage.

- Rectifier keeps the **battery charged**.
- During power failure (mains OFF):
 - Battery supplies DC to inverter.
 - Inverter converts DC into AC and supplies it to the load.

Block Diagram



Features

- Provides better voltage regulation than Off-line UPS.
- Includes extra filtering, which reduces transient losses.
- Transfer time is less compared to Off-line UPS.

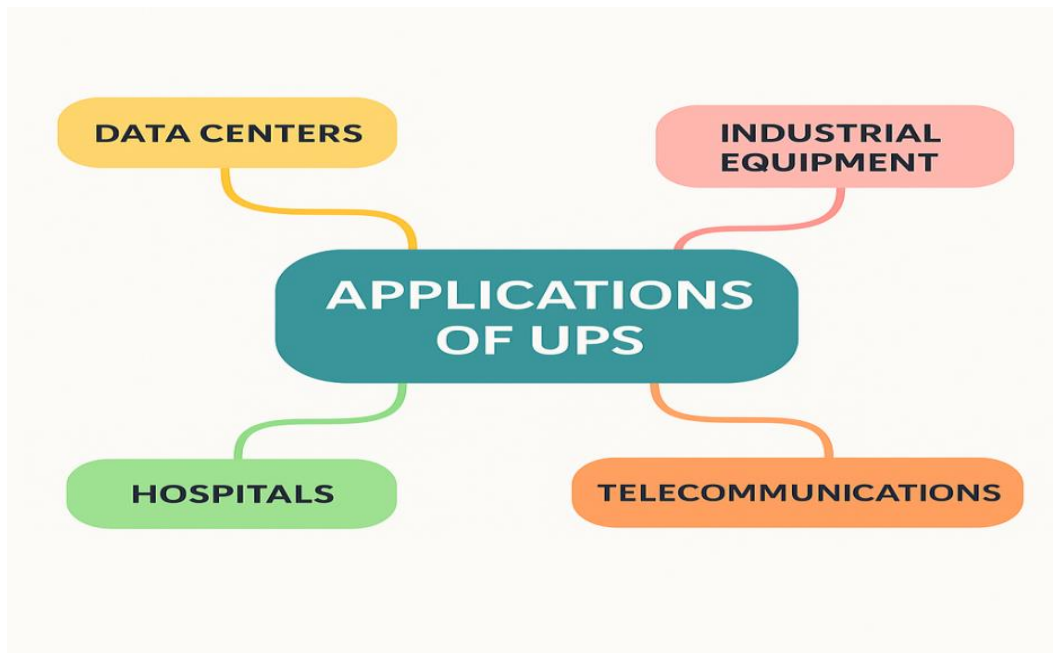
Advantages

- Provides **voltage regulation without switching to battery** (increases battery life).
- Better protection compared to Off-line UPS.
- Cost is less than On-line UPS.

Disadvantages

- More expensive than Off-line UPS.
- Not as reliable as On-line UPS for highly critical applications.

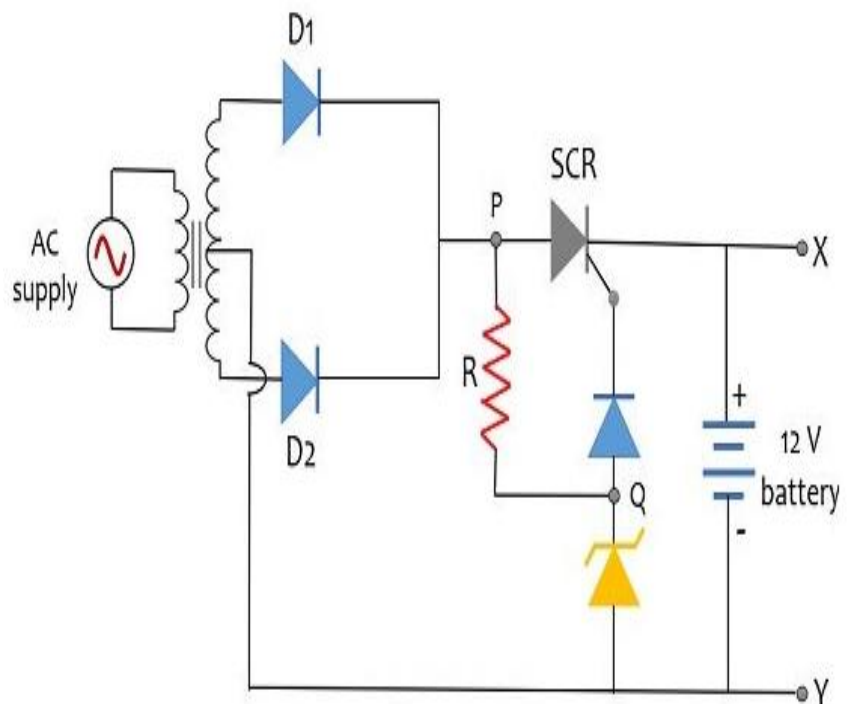
APPLICATIONS



4.9 Battery charger circuit using SCR with the help of a diagram

Circuit Elements

1. **AC Supply** → 230 V, 50 Hz input.
2. **Step-Down Transformer** → Reduces AC voltage from 230 V to a lower level suitable for charging.
3. **Rectifier Circuit** → Converts AC to DC.
4. **SCR (Silicon Controlled Rectifier)** → Works as a controlled switch to regulate charging current.
5. **Zener Diode** → Acts as a **voltage regulator**, ensures battery does not overcharge.
6. **Battery (12 V)** → Load to be charged.



Working of SCR-based Battery Charger

Step 1: Step-down Transformer

- **Input:** 230 V AC, 50 Hz.
- The transformer reduces the high input voltage to a lower level (around 15 V AC at secondary side).
- This low voltage is suitable for charging a **12 V battery**.

Step 2: Rectifier Circuit

- The secondary of transformer is connected to a **full-wave rectifier**.
- Rectifier converts AC to **DC pulsating output**.

Operation of rectifier diodes:

- During positive half cycle → Diode D1 conducts (forward biased), D2 remains OFF.
- During negative half cycle → Diode D2 conducts, D1 remains OFF.
- Thus, both halves of AC are rectified → full-wave DC output is obtained.

Step 3: SCR as Controlled Switch

- SCR is connected in series with the charging circuit.
- When SCR is triggered, current flows to the battery → charging takes place.
- SCR automatically **turns OFF** when the battery reaches full charge.

Step 4: Automatic Cut-Off using Comparator + Zener

- Suppose the rectified DC = 15 V.
- When battery reaches ~14.5 V:
 - The rectified voltage becomes less than battery voltage.
 - SCR cannot conduct further → charging stops automatically.
- Comparator circuit (with **Zener diode**) monitors this voltage difference.
 - If battery voltage < reference → comparator triggers SCR → charging ON.
 - If battery voltage $\geq$ reference → SCR is blocked → charging OFF.

Step 5: Zener Diode Role

- Zener diode provides a **reference voltage** for comparison.
- Its breakdown voltage is selected according to battery charging voltage (for a 12 V battery → around 14.5 V).

- Transformer secondary and Zener rating depend on the required charging potential.

Advantages

- Provides automatic control of charging.
- Protects the battery from **overcharging**.
- Simple and reliable circuit.

Disadvantages

1. The charging process is slow.
2. AC ripples present (no filter).
3. Half-wave rectifier → slow charging/discharging.
4. Suitable only for low to medium-Ah batteries

4.10 Basic Switched-mode power supply (SMPS) - explain its working & applications

Switched Mode Power Supply (SMPS)

Definition

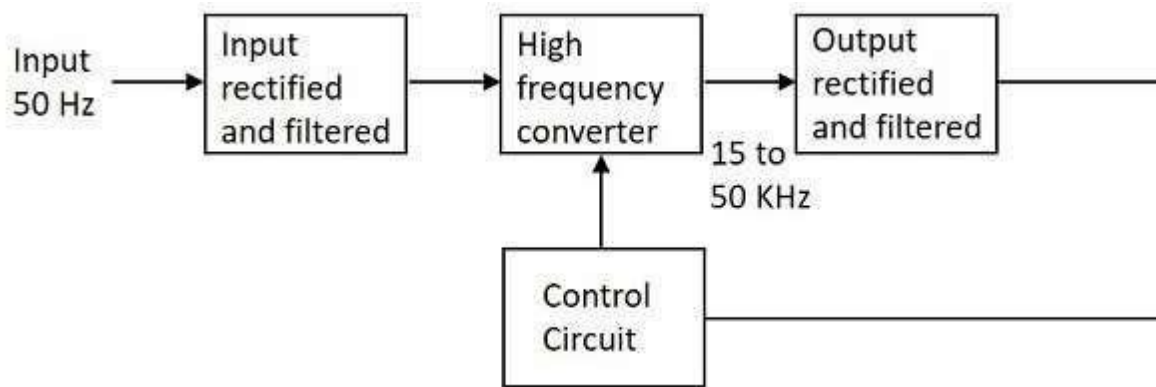
A **Switched Mode Power Supply (SMPS)** is a regulated power supply that uses a **high-frequency switching transistor** as a controlled switch to regulate the output voltage efficiently.

Why SMPS?

- Higher **efficiency** than Linear Power Supply (LPS).
- Requires **smaller filter capacitors** (since switching is at high frequency).
- Uses **small and light-weight transformers** (high-frequency operation).
- Lower cost and compact in size.

Working of SMPS (Stage by Stage)

BLOCK DIAGRAM OF SMPS



1. Input Stage

- 230 V AC, 50 Hz mains is directly given to **rectifier + filter circuit** (no bulky transformer).
- Rectifier converts AC to unregulated DC.
- A filter capacitor smooths fluctuations, but large capacitance is required to handle variations.
- This **unregulated DC** is supplied to the switching section.

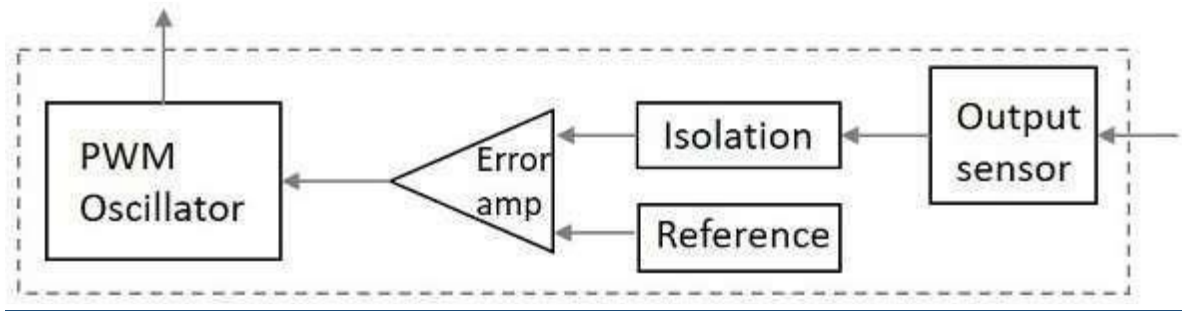
2. Switching Section

- A high-speed **power transistor or MOSFET** acts as a switch.
- It switches **ON and OFF at high frequency** (tens of kHz).
- This chopped DC is applied to the **primary of a high-frequency transformer**.
- These transformers are **small, light, and efficient** compared to 50/60 Hz transformers.
- Result → higher power conversion efficiency.

3. Output Stage

- The transformer output is again **rectified and filtered**.
- Provides a stable **regulated DC output**.
- Output is monitored by the **control circuit** for feedback regulation.

4. Control Unit (Feedback Circuit)



- **Output sensor** monitors the DC output.
- Signal is passed through an **isolation circuit** (to protect main circuit from spikes).
- Compared with a **reference voltage** using an **error amplifier (comparator)**.
- The error signal adjusts the **chopping frequency / duty cycle** of the switching transistor.
- **PWM Oscillator** generates the required pulse-width modulated signal for control.
- This feedback loop maintains the output voltage at the desired level.

Advantages and Disadvantages of SMPS



Advantages

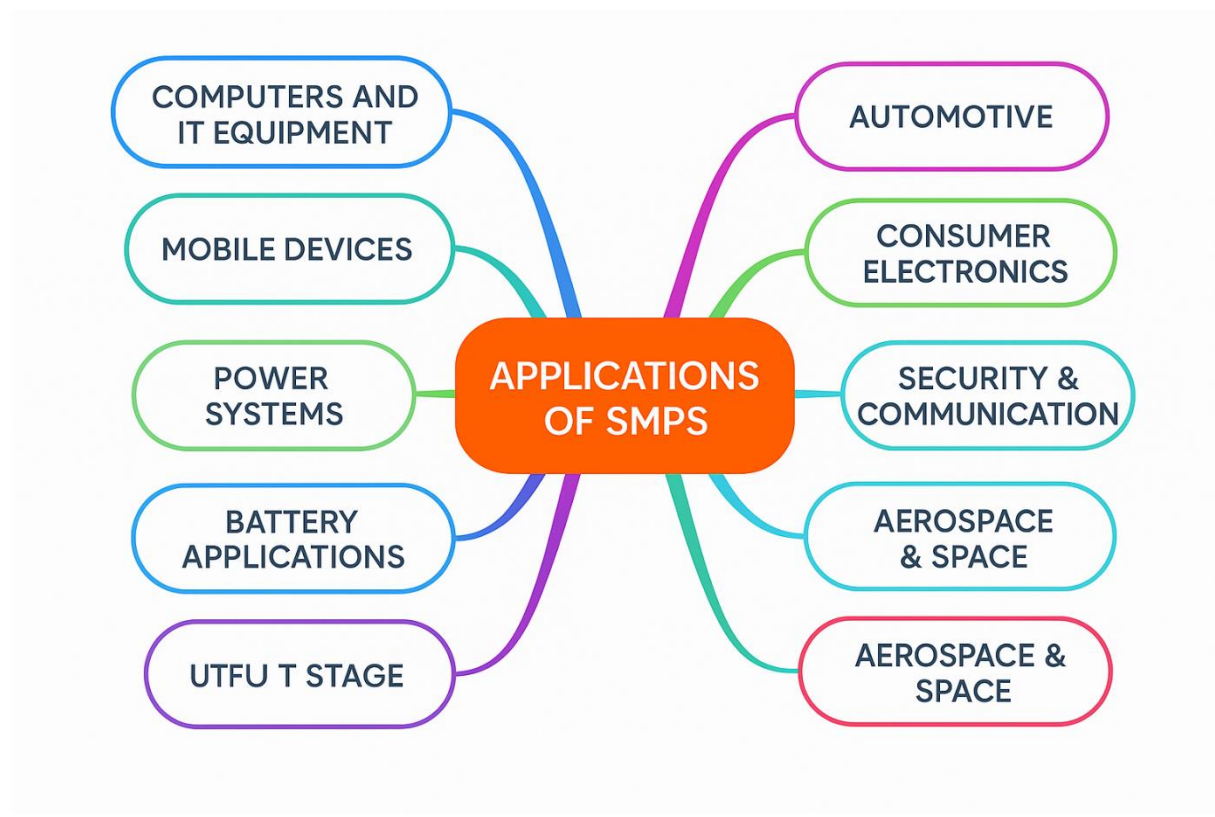
1. High efficiency (80–90%).
2. Less heat generation → less power wasted.
3. Reduced harmonic feedback into supply mains.
4. Compact and small in size.
5. Low manufacturing cost.
6. Can provide multiple output voltages.



Disadvantages

1. Generates noise due to high-frequency switching.
2. Circuit is complex compared to Linear Power Supply.
3. Produces electromagnetic interference (EMI).

APPLICATIONS



UNIT-5

PLC AND ITS APPLICATIONS

Syllabus

- 5.1 Introduction of Programmable Logic Controller(PLC)
- 5.2 Advantages of PLC
- 5.3 Different parts of PLC by drawing the Block diagram and purpose of each part of PLC.
- 5.4 Applications of PLC
- 5.5 Ladder diagram
- 5.6 Description of contacts and coils in the following states
i) Normally open ii) Normally closed iii) Energized output iv) latched Output v) branching
- 5.7 Ladder diagrams for i) AND gate ii) OR gate and iii) NOT gate.
- 5.8 Ladder diagrams for combination circuits using NAND, NOR, AND, OR and NOT
- 5.9 Timers-i) T ON ii) T OFF and iii) Retentive timer
- 5.10 Counters-CTU, CTD
- 5.11 Ladder diagrams using Timers and counters
- 5.12 PLC Instruction set
- 5.13 Ladder diagrams for following
(i) DOL starter and STAR-DELTA starter (ii) Stair case lighting (iii) Traffic light
Control (iv) Temperature Controller
- 5.14 Special control systems- Basics DCS & SCADA systems
- 5.15 Computer Control–Data Acquisition, Direct Digital Control System (Basics only)

Introduction to Programmable Logic Controllers (PLCs)

Definition

- **Programmable Logic Controllers (PLCs)**, also called **programmable controllers**, are special-purpose **industrial computers** used for automation of electromechanical processes.
- They belong to the **computer family**, but unlike general-purpose computers, they are rugged and designed for **industrial environments** (dust, heat, vibration, and electrical noise).

Basic Function

- A **PLC continuously monitors inputs** from field devices (like sensors, switches).
- Based on the **logic/program stored in its memory**, it makes decisions.
- It then **controls outputs** (like motors, solenoids, relays, lamps) to automate machines or processes.

Why PLCs?

- Earlier, industries used **relay-based control panels** → bulky, hard to modify, high maintenance.
- PLCs replaced relays because they are **flexible, compact, reliable, and reprogrammable**.

5.2 Advantages of PLC

1. Reduced Space

- PLCs are **solid-state electronic devices**, very compact compared to bulky **hard-wired controllers** with relays and timers.

2. Higher Life and Reliability

- Rugged design → withstands vibration, temperature, noise, and dust.
- Very few moving parts → less wear and tear → long life.

3. Economical

- Once installed, PLCs rarely fail.
- Considered a **one-time investment** → cost recovery is fast due to reduced downtime and maintenance.

4. Energy Saving

- Power consumption is only about **1/10th of equivalent relay-based systems**.

5. Ease of Maintenance

- Modular replacement of faulty parts.
- **Easy troubleshooting** using software tools.
- **Error diagnostics** through programming unit (self-diagnostic features).

6. Tremendous Flexibility

- No rewiring required for program changes.
- Can perform **arithmetic, counting, timing, comparison, time delays**, etc.
- High processing speed.
- Supports both **analog and digital processes**.
- Allows **Online/Offline programming**.

7. Shorter Project Time

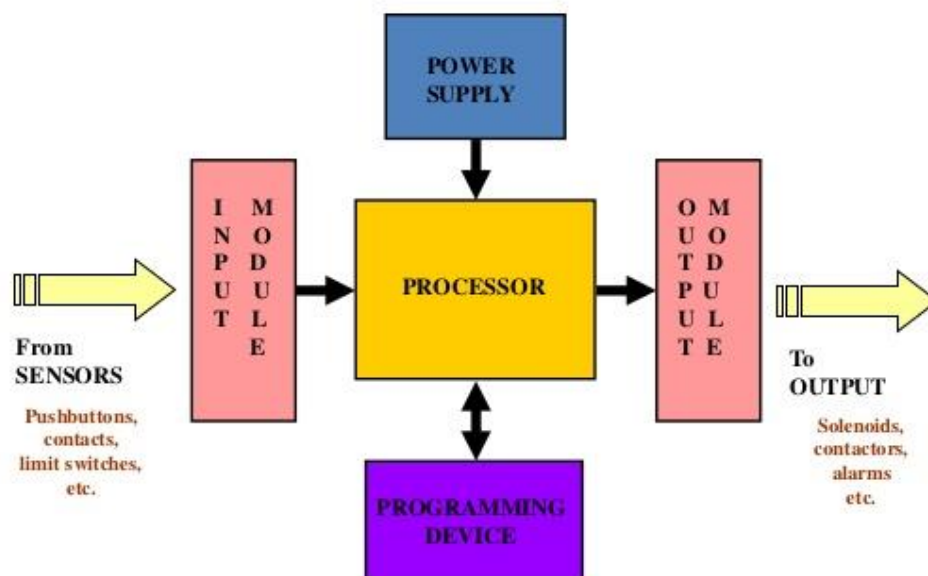
- In hard-wired systems, wiring is done only after the task is fully defined.
- With PLCs, wiring and controller construction are **independent of program design** → saves time.

8. Easier Storage, Archiving, and Documentation

- Compatible with **PC, printer, and storage devices**.
- Control programs can be **easily stored, copied, and documented** for future use.

5.3 Different parts of PLC by drawing the Block diagram and purpose of each part of PLC.

PLC BLOCK DIAGRAM



Basic Components of PLC

1. Processor Section (CPU)

- The **CPU** is the **brain/heart of PLC**.
- It consists of:
 - **ROM** → Stores system programs (firmware).
 - **RAM** → Stores user program and temporary data.
 - **Logic Solver** → Executes the logic instructions.
 - **User Memory** → Stores user-written control programs.
- Functions of CPU:

- Controls, monitors, and supervises all PLC operations.
- Makes decisions and executes instructions based on program stored in memory.

2. Input Module

- Acts as an **interface between input devices** (sensors, switches, transducers) and the CPU.
- Converts **analog signals** → **digital signals** so CPU can process them.
- Provides isolation and protection to CPU.

3. Output Module

- Acts as an **interface between CPU and output devices** (motors, relays, solenoids, lamps).
- Converts **digital signals** → **analog signals** for field devices.
- Provides proper voltage and current levels for actuators.

4. Power Supply

- Supplies power to CPU, input, and output modules.
- May be integral (built-in) or separate.
- Most PLCs work with **24V DC** or **230V AC (internally converted to DC)**.

5. Memory Section

- Part of CPU where data and program are stored/retrieved.
- Types:
 - **Data Memory** → Stores numerical data (for calculations, bar code, counters, timers).
 - **User Memory** → Stores user's application program.
 - **ROM/EPROM** → Permanent storage for system software.

6. Programming Device

- Dedicated device used to **write, load, and edit programs** into the PLC memory.
- Also used for **monitoring execution** and **troubleshooting** ladder logic.
- Common programming devices:
 - **Hand-Held Terminal (HHT)**
 - **Dedicated Programming Console**
 - **Personal Computer (PC) with PLC software**

Applications of PLC

1. Industrial Applications

- **Assembly Lines** – control of conveyor belts, robotic arms, sequencing.
- **Packaging Systems** – filling, capping, labeling, and sorting.

- **Process Industries** – control of temperature, pressure, flow, level (cement, steel, chemical plants).

2. Power Sector

- **Power Plants** – boiler control, turbine operation, coal/ash handling.
- **Substations** – automatic switching, load management, fault monitoring.
- **Renewable Energy** – wind turbine control, solar panel tracking.

3. Transportation

- **Traffic Signals** – automatic red/green light control.
- **Railways** – automatic gate control at level crossings, track switching.
- **Airports** – baggage handling, escalators, parking systems.

4. Building Automation

- **Elevators & Escalators** – safe movement control.
- **HVAC Systems** – heating, ventilation, air conditioning.
- **Security** – fire alarms, access control, CCTV systems.

5. Food & Beverage Industry

- **Bottling Plants** – filling, sealing, labeling bottles.
- **Dairy & Bakery** – temperature control in ovens, pasteurization, cooling.
- **Quality Control** – defect detection and rejection.

6. Automotive Industry

- **Car Manufacturing** – welding, painting, assembling with robots.
- **Testing Systems** – safety and performance testing.
- **Material Handling** – automated guided vehicles, lifts, conveyors.

7. Water & Wastewater Management

- **Water Supply** – pumps and reservoir level control.
- **Wastewater Treatment** – monitoring pH, chemical dosing.
- **Agriculture** – automatic irrigation systems.

5.5 Ladder diagram

Definition

A **Ladder Diagram (LD)** is a schematic diagram used in **industrial automation** to represent logic control circuits.

It looks like a **ladder** with:

- **Two vertical rails** (power supply lines).
- **Horizontal rungs** (logic operations).
- Each rung contains **control logic** for the PLC.

Difference between Electrical Schematic & Ladder Diagram

1. **Representation**
 - **Electrical schematic:** uses actual components (switches, relays).
 - **Ladder diagram:** uses symbols to represent inputs/outputs.
2. **Execution**
 - **Electrical schematic:** works as per electrical circuit operation.
 - **Ladder diagram:** execution depends on PLC's **scan cycle**.

Why Ladder Diagram is Used in PLC Programming?

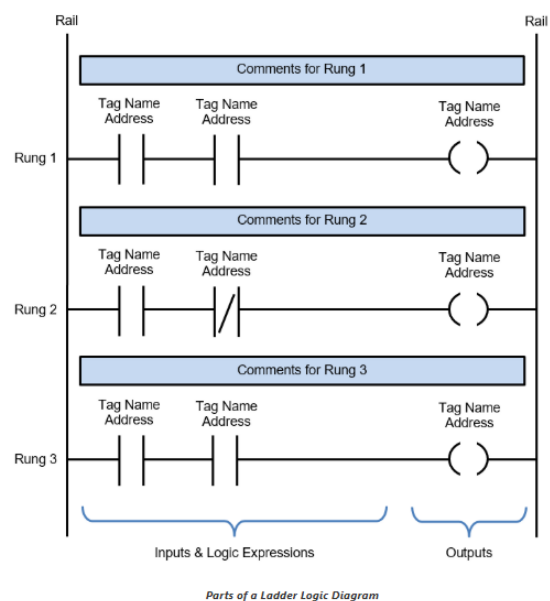
- Early designers were familiar with **relay logic**, so ladder diagrams mimic it.
- Factory maintenance staff could **easily read and troubleshoot** ladder diagrams.
- Easier to understand compared to text-based languages (C, BASIC, Pascal, FORTRAN).
- Provides **graphical form** of logic expressions (like relay control circuits).

How to Draw Ladder Logic Diagrams

- Rails = vertical power lines (**left = positive, right = zero/neutral**).
- Rungs = horizontal connections representing logic circuits.
- Logic flow is always **left → right**.
- Symbols (contacts, coils, timers, counters) are placed in rungs to form **logic expressions**.

Seven Basic Parts of Ladder Diagram

1. **Rails**
 - Two vertical lines at left & right.
 - Represent supply connections (active & neutral).
2. **Rungs**
 - Horizontal lines between rails.
 - Represent connections carrying logic operations.
3. **Inputs**
 - External control actions (push button, limit switch).
 - Shown by **NO (Normally Open)** or **NC (Normally Closed)** contact symbol.
4. **Outputs**
 - External devices controlled by PLC (motor, lamp, solenoid).
 - Shown by **relay coil symbol**.
5. **Logic Expressions**



- Combination of inputs & outputs to perform operations (AND, OR, NOT).
6. **Address Notation / Tag Names**
- Each input, output, or function in PLC has a memory address.
 - Tag names are descriptive labels (e.g., Start_Button, Motor1).
7. **Comments**
- Notes written beside each rung.
 - Describe logic and make troubleshooting easier.

✓ Summary for SCTEVT Students

- Ladder diagram = **graphical PLC language**.
- Based on **relay logic** → **easy to understand**.
- Consists of **rails, rungs, inputs, outputs, logic, addresses, and comments**.
- Most common PLC programming method used in industries.

5.6 Description of Contacts and Coils in PLC

i) Normally Open (NO) Contact



- **Symbol:**
- By default = **open** (no current flow).
- When condition/input is **TRUE (ON)** → contact closes → current flows to the right side.
- Used for push buttons, start switches, etc.

ii) Normally Closed (NC) Contact



- **Symbol:** (same as NO but with a diagonal line).
- By default = **closed** (current flows).
- When condition/input is **TRUE (ON)** → contact opens → current stops.
- Used for stop buttons, limit switches, safety devices.

iii) Energized Output (Output Coil)

- **Symbol:** 
- Works like a relay coil.
- When the rung logic is **TRUE** → output coil is **energized (ON)** → device (motor, lamp, solenoid) turns ON.
- When rung logic is **FALSE** → output coil is **de-energized (OFF)**.

iv) Latched Output

- **Symbol:**  for SET,  for RESET

- **Latched (Set):** Once energized, it **remains ON** even if the input condition goes FALSE.
- **Unlatched (Reset):** Separate reset coil turns the output OFF.
- Example: Start/Stop motor circuit using pushbuttons (Start = SET, Stop = RESET).

v) Branching

In PLC Ladder Logic, **branching** is used to create **multiple paths for current/logic flow**. There are **three types of branches**:

1. Series Branch

- Inputs/outputs are connected in **series** (one after another).
- Represents **AND logic** (all conditions must be TRUE).

Example:

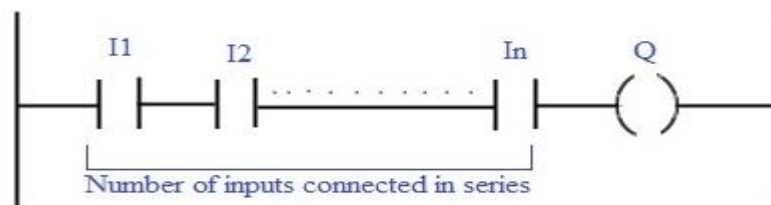
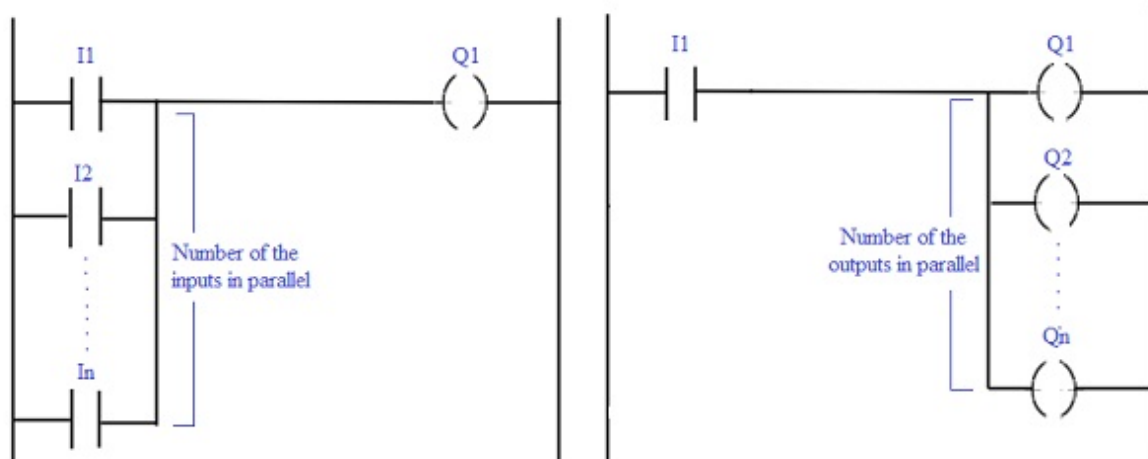


Figure: Representation of the Series Branch

2. Parallel Branch

- Inputs/outputs are connected in **parallel**.
- Represents **OR logic** (any condition TRUE will energize output).

Example:



3. Nest Branch

- Combination of **series and parallel branches** in the same rung.
- Used for complex control logic.

Example:

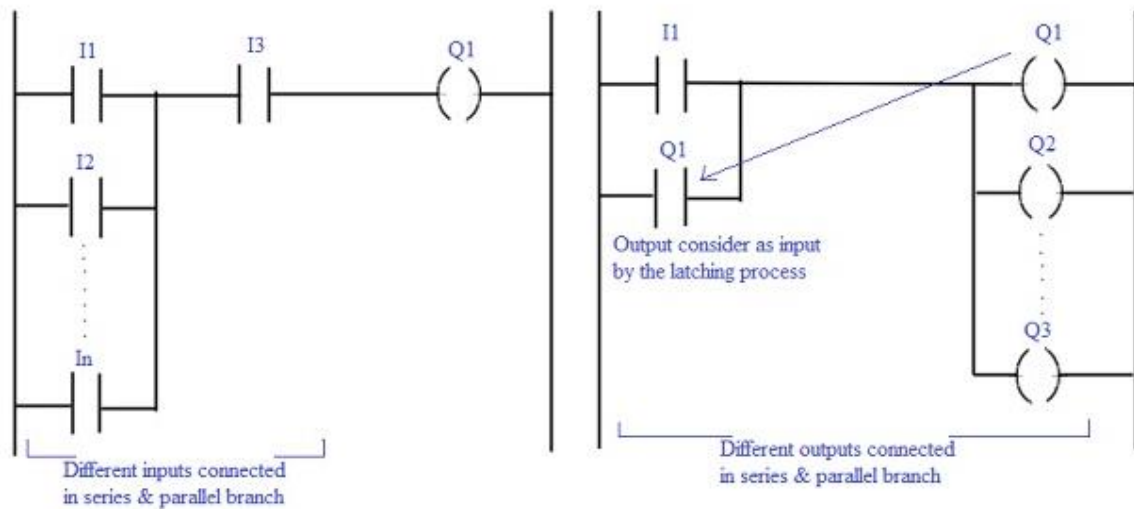


Figure: Representation of Nest Branch

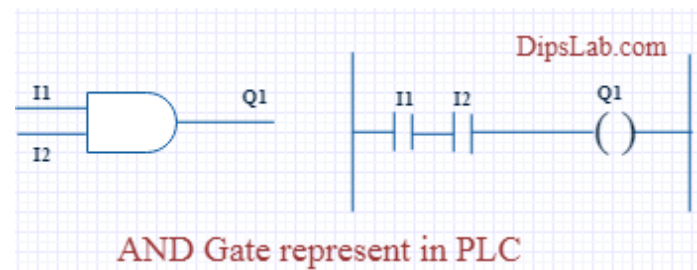
5.7 Ladder diagrams for i) AND gate ii) OR gate and iii) NOT gate.

i) AND gate

Ladder Diagram

Logic Gate Truth Table for AND Gate:

Input (I1)	Input (I2)	Output (Q1)
0	0	0
0	1	0
1	0	0
1	1	1



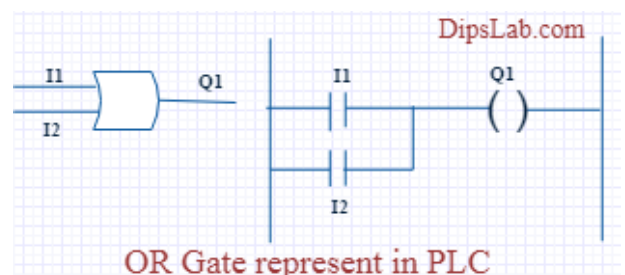
AND Gate represent in PLC

ii) OR gate

Ladder Diagram

Logic Gate Truth Table for OR Gate:

Input (I1)	Input (I2)	Output (Q1)
0	0	0
0	1	1
1	0	1
1	1	1



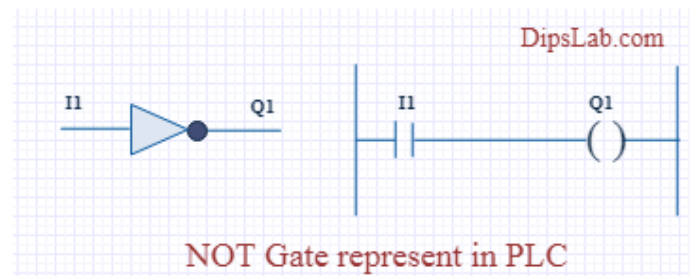
OR Gate represent in PLC

iii) NOT gate.

Logic Gate Truth Table for NOT Gate:

Input (I1)	Output (Q1)
0	1
1	0

Ladder Diagram

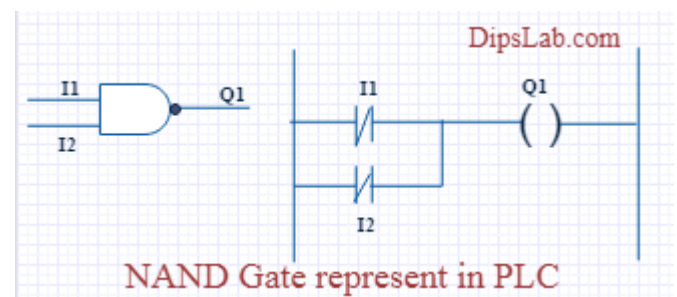


5.8 Ladder diagrams for combination circuits using NAND,NOR, AND, OR and NOT

NAND GATE

Logic Gate Truth Table for NAND Gate:

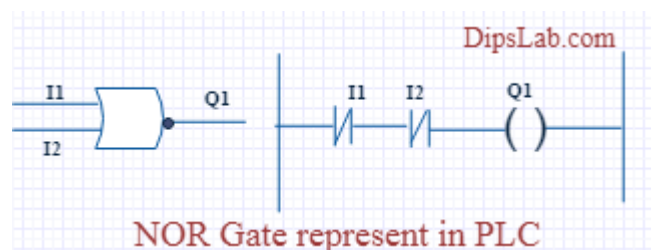
Input (I1)	Input (I2)	Output (Q1)
0	0	1
0	1	1
1	0	1
1	1	0



NOR GATE

Logic Gate Truth Table for NOR Gate:

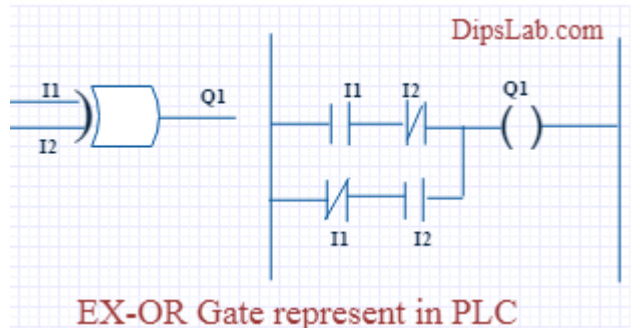
Input (I1)	Input (I2)	Output (Q1)
0	0	1
0	1	0
1	0	0
1	1	0



EX-OR GATE

Logic Gate Truth Table for EX-OR Gate:

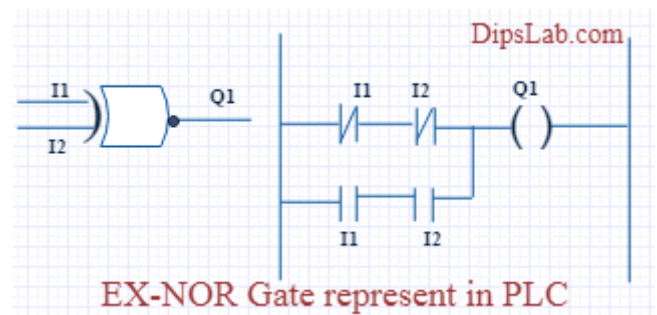
Input (I1)	Input (I2)	Output (Q1)
0	0	0
0	1	1
1	0	1
1	1	0



EX-NOR GATE

Logic Gate Truth Table for EX-NOR Gate:

Input (I1)	Input (I2)	Output (Q1)
0	0	1
0	1	0
1	0	0
1	1	1



5.9 Timers-i) T ON ii) T OFF and iii) Retentive timer

Timers are PLC instructions used to **delay turning ON or OFF outputs**.

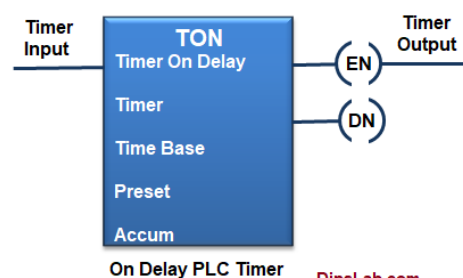
In Allen Bradley (AB) PLCs, each timer instruction consists of **three words**:

- **Word 0:** Status bits →
 - **EN (Enable Bit):** ON when timer is energized.
 - **TT (Timer Timing Bit):** ON while timer is counting.
 - **DN (Done Bit):** ON when preset time is reached.
- **Word 1:** Preset value (time set by programmer).
- **Word 2:** Accumulated value (time counted so far).

1. On Delay Timer (TON)

☞ Definition:

The **On Delay Timer (TON)** delays turning ON the output until the preset time elapses.



☞ Operation:

- When input = **TRUE (energized)** → timer starts counting.
- After **preset time**, output turns **ON**.
- If input goes FALSE before preset time → timer resets.

☞ Example:

- Start button pressed → Motor starts after 10 seconds delay.

☞ Status Bits:

- **EN** = 1 when input is TRUE.
- **TT** = 1 during delay counting.
- **DN** = 1 after preset time is completed.

2. Off Delay Timer (TOFF)

☞ Definition:

The **Off Delay Timer (TOFF)** delays turning OFF the output after the input goes FALSE.

☞ Operation:

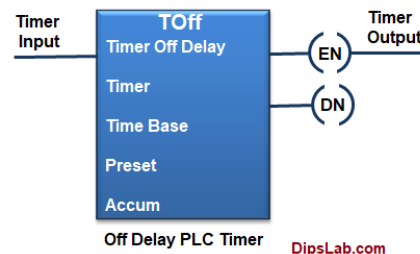
- When input = TRUE → output turns ON immediately.
- When input goes FALSE → timer starts counting.
- After **preset time**, output turns OFF.

☞ Example:

- Stop button pressed → Motor runs for 10 seconds, then stops.

☞ Status Bits:

- **EN** = 1 when input is TRUE.
- **TT** = 1 during OFF delay time.
- **DN** = 1 while output is ON.



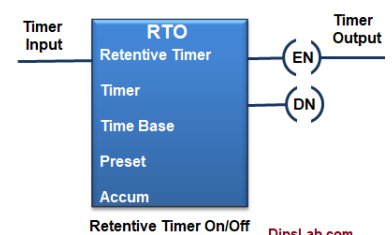
3. Retentive Timer On/Off (RTO)

☞ Definition:

The **Retentive Timer (RTO)** retains the accumulated time value even if the input goes FALSE or there is a power loss.

☞ Operation:

- Works like TON, but it **remembers elapsed time**.
- Timer continues counting from where it stopped when input is re-energized.



- Needs a **reset (RES instruction)** to clear accumulated time.

☞ Example:

- Heater must run for total 15 seconds. If it runs for 7s and stops, when restarted it will continue from 7s → completes remaining 8s.

☞ Status Bits:

- EN = 1** when input is TRUE.
- TT = 1** while timer is counting.
- DN = 1** when accumulated time $\geq$ preset time

✓ Summary for Students (SCETVT)

- TON (On Delay):** Output ON after preset delay.
- TOFF (Off Delay):** Output OFF after preset delay.
- RTO (Retentive):** Retains accumulated time until reset.
- Each timer uses **EN, TT, DN status bits** for logic control.

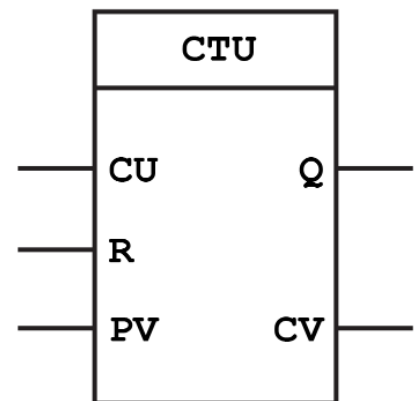
5.10 Counters-CTU, CTD

CTU – Count Up Counter

Symbol Explanation

The block has the following inputs and outputs:

- CU (Count Up Input):**
 - Each rising edge (pulse from 0 → 1) increments the counter.
- R (Reset):**
 - Resets the counter value (CV) back to zero.
- PV (Preset Value):**
 - Target number set by the programmer (e.g., 10 bottles).
- CV (Current Value / Accumulated Value):**
 - Displays how many pulses have been counted so far.
- Q (Output / Done Bit):**
 - Becomes **TRUE (1)** when $CV \geq PV$.
 - Can be used to stop/start a machine or trigger another operation.



Up Counter (CTU) Function Block

Working Principle

- Initially, **CV = 0**.
- Each input pulse at **CU** → CV increases by 1.
- When $CV \geq PV \rightarrow Q = 1$ (counter done).
- When **R = 1** → CV resets back to 0, Q becomes 0.

Example

- **Application:** Bottle Filling Line
- **PV = 10** (preset = 10 bottles).
- Each bottle passing sensor gives 1 pulse.
- After 10 bottles (CV = 10), **Q = 1** → conveyor stops.

✓ Summary for Students

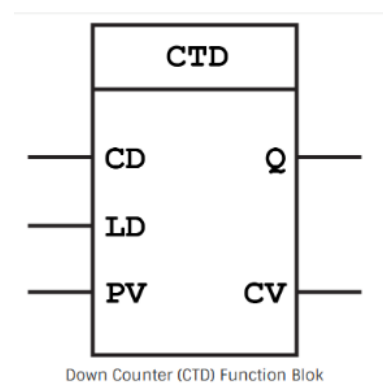
- **CTU counts upward** on input pulses.
- **Q = 1** when preset value reached.
- **R resets** the counter.
- Used for **counting items/events** in automation.

CTD – Count Down Counter

Symbol Explanation

The block has the following inputs and outputs:

- **CD (Count Down Input):**
 - Each rising edge (pulse) **decreases** the counter value (CV) by 1.
- **LD (Load):**
 - Loads the **preset value (PV)** into the counter when activated.
- **PV (Preset Value):**
 - Starting value for the counter (e.g., 10 items).
- **CV (Current Value):**
 - The present count (decreases with each input pulse).
- **Q (Output / Done Bit):**
 - Becomes **TRUE (1)** when **CV = 0**.
 - Can be used to stop a machine or trigger an alarm.



Working Principle

1. Initially, **CV = PV** (loaded using LD input).
2. Each pulse at **CD** → CV decreases by 1.
3. When **CV = 0** → **Q = 1** (counter done).
4. To restart, **LD** loads PV again into CV.

Example

- **Application:** Packaging Machine
- **PV = 20** (a box must hold 20 chocolates).
- Each chocolate added → CV decreases by 1.
- When CV = 0 (box full), **Q = 1** → conveyor shifts the box.

✓ Summary for Students

- **CTD counts downward** from preset to zero.
- **Q = 1** when CV reaches zero.
- **LD reloads** preset value into the counter.
- Used for **counting down items left to process**

PLC Instruction Set

A **PLC Instruction Set** is a collection of all the **commands/programming instructions** that can be used in ladder logic or other PLC languages.

These instructions tell the PLC what operations to perform.

1. Bit Logic Instructions

Used for **basic ON/OFF control** of inputs & outputs.

- **XIC (Examine If Closed)**: Checks if bit = 1 (same as Normally Open contact).
- **XIO (Examine If Open)**: Checks if bit = 0 (same as Normally Closed contact).
- **OTE (Output Energize)**: Turns ON the output coil when rung = TRUE.
- **OTL (Output Latch / Set)**: Sets an output bit to 1 (latched ON).
- **OTU (Output Unlatch / Reset)**: Resets an output bit to 0.
- **ONS (One Shot)**: Executes instruction for one PLC scan cycle (positive edge trigger).

2. Timer Instructions

Used for **time delay control**.

- **TON (Timer ON Delay)**: Output ON after a delay when input is TRUE.
- **TOF (Timer OFF Delay)**: Output OFF after a delay when input goes FALSE.
- **RTO (Retentive Timer ON)**: Accumulates time and retains value until reset.
- **RES (Reset Timer)**: Clears timer values.

3. Counter Instructions

Used for **event and object counting**.

- **CTU (Count Up)**: Increments counter value on each input pulse.
- **CTD (Count Down)**: Decrements counter value on each input pulse.
- **RES (Reset Counter)**: Clears counter value.

4. Data Handling Instructions

Used to **move, compare, and manipulate data** inside PLC memory.

- **MOV (Move)**: Copy data from one location to another.
- **COP (Copy)**: Copy multiple words of data.
- **CLR (Clear)**: Reset data word to zero.
- **CMP (Compare)**: Compare values.
- **EQU (Equal)**: True if values are equal.

- **LES (Less Than):** True if $A < B$.
- **GRT (Greater Than):** True if $A > B$.

5. Arithmetic Instructions

Used for **mathematical operations**.

- **ADD (Addition):** Adds two numbers.
- **SUB (Subtraction):** Subtracts numbers.
- **MUL (Multiplication):** Multiplies numbers.
- **DIV (Division):** Divides numbers.
- **NEG (Negate):** Changes sign of value.

6. Program Control Instructions

Used for **controlling program flow**.

- **JMP (Jump):** Skip to a specified label.
- **LBL (Label):** Destination for a jump.
- **MCR (Master Control Reset):** Enable/disable a block of rungs.
- **RET (Return):** Exit from subroutine.
- **TND (Temporary End):** Stops scan at that rung.

7. Advanced Instructions

Used for **complex automation & process control**.

- **PID (Proportional–Integral–Derivative):** Process control for temperature, pressure, etc.
- **SQO (Sequencer Output):** Controls outputs in sequence.
- **SQC (Sequencer Compare):** Compares input values in sequence.
- **SQR (Sequencer Reset):** Resets sequencer.
- **FAL (File Arithmetic Logic):** Performs arithmetic/logic on data files.

Ladder diagrams for following

(i) DOL starter and STAR-DELTA starter (ii) Stair case lighting (iii) Traffic light Control (iv) Temperature Controller

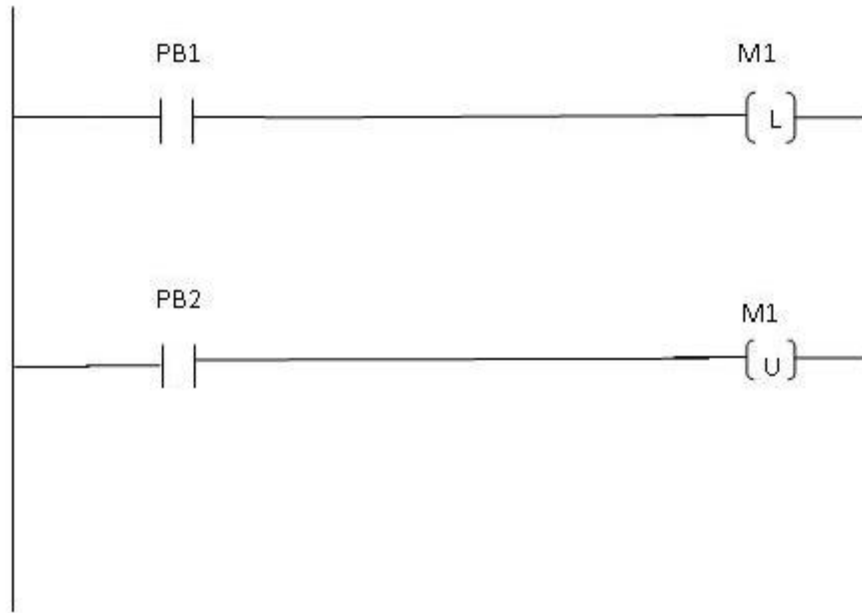
(i) DOL starter

Start a motor **M1** using a DOL starter with these controls:

- **PB1** = Start pushbutton (momentary) — normally **OPEN (NO)**
- **PB2** = Stop pushbutton (momentary) — normally **CLOSED (NC)** (recommended for safety)
- **Output: M1** (motor contactor coil)

Sequence (as given):

1. Press **PB1** → motor **M1** starts.
2. Release **PB1** and if **PB2** is not pressed → **M1** remains ON (latched).
3. Press **PB2** → **M1** stops.
4. Release **PB2** and PB1 not pressed → **M1** remains OFF.



◆ DOL Starter using Latch & Unlatch (OTL / OTU)

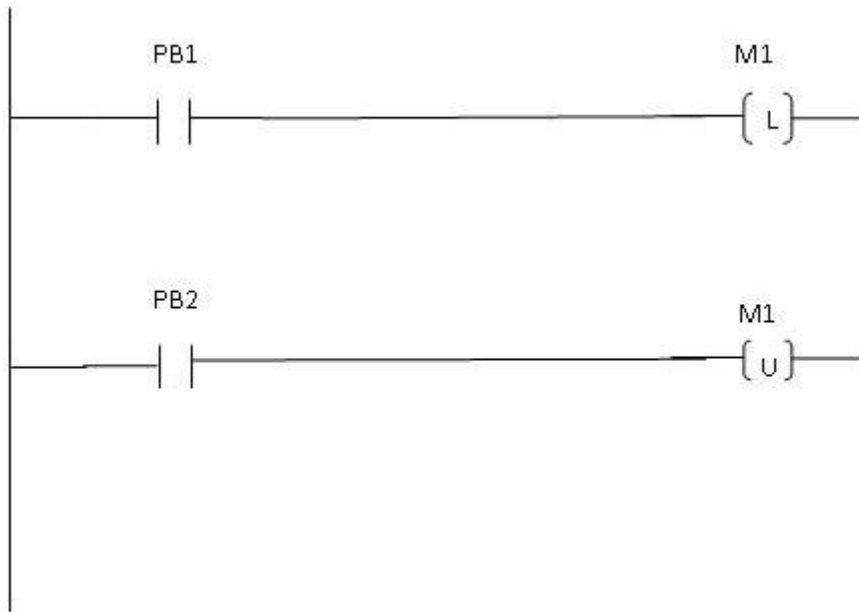
✂ Inputs & Outputs

- **PB1 (Start):** Normally Open push button → goes TRUE only while pressed.
- **PB2 (Stop):** Normally Closed push button → goes FALSE when pressed.
- **M1:** Output coil that drives the motor contactor.

🔄 Sequence of Operation

1. **Start Motor**
 - Press **PB1** → PLC rung goes TRUE → **OTL M1** instruction latches the M1 bit.
 - Motor contactor energizes and keeps running even after PB1 is released.
2. **Maintain Running**
 - M1 stays latched ON because OTL keeps the coil bit TRUE in memory.
3. **Stop Motor**
 - Press **PB2** → its contact changes state (NC → open), rung for OTU goes TRUE.
 - **OTU M1** instruction unlatches (resets) M1 bit → motor stops.
4. **Motor stays OFF** until PB1 is pressed again.

Ladder Diagram



STAR-DELTA STARTER

Star-Delta Starter (Simple Explanation)

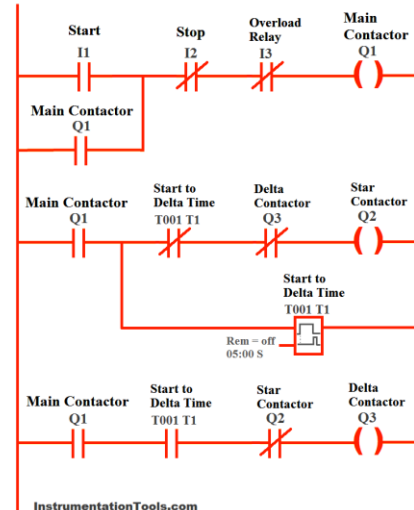
A **Star-Delta starter** is used to start an induction motor with **less starting current**.

The motor first runs in **STAR** (low voltage, less current) and after a set time it automatically switches to **DELTA** (full voltage, normal running).

◆ Devices Used

Name	Symbol	Type
Start push button I1	Normally Open (NO)	
Stop push button I2	Normally Closed (NC)	
Overload relay	OL	Normally Closed (NC)
Main contactor	Q1	Turns motor ON/OFF
Star contactor	Q2	Connects motor in STAR

STAR-DELTA MOTOR STARTER LADDER LOGIC



Name	Symbol	Type
Delta contactor	Q3	Connects motor in DELTA
Timer	T1	Decides time to change STAR → DELTA

🔧 Working Step by Step

Rung 1 – Main Contactor (Q1)

- **Connected to:** Start (I1), Stop (I2), Overload (OL).
- **How it works:**
 - Press **Start (I1)** → Q1 turns ON.
 - Q1 has a **self-hold contact** in parallel with Start.
→ This keeps Q1 ON even after the Start button is released.
 - If Stop (I2) is pressed or Overload trips, Q1 turns OFF.

Rung 2 – Star Contactor (Q2)

- Q2 turns ON **only when**:
 - Main contactor Q1 is ON,
 - Timer T1 has **not finished** (its contact is NC),
 - Delta contactor Q3 is OFF (its NC contact closed).
- So the motor runs in **STAR** connection for some time.

Timer (T1)

- Timer starts **as soon as Q1 is ON**.
- After preset time (e.g., 5–10 seconds), its contact changes from **NC to open**.
- This will turn OFF Star contactor (Q2).

Rung 3 – Delta Contactor (Q3)

- Q3 turns ON **only when**:
 - Main contactor Q1 is ON,
 - Timer T1 has finished (T1.DN = ON),
 - Star contactor Q2 is OFF (its NC contact closed).
- Now the motor runs in **DELTA** connection (full voltage).

(ii) Stair case lighting

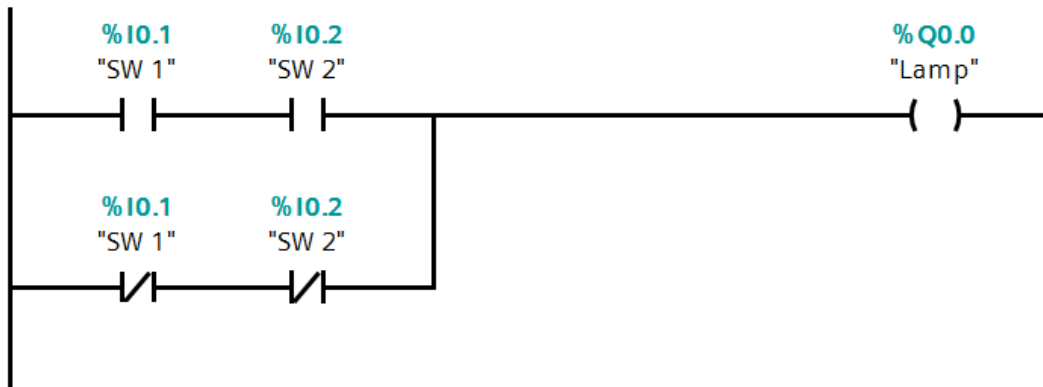
💡 Two-Way Lamp Control with Two Switches (SW1 & SW2)

In this program we use **two switches**:

- **SW1 = I0.1 (bottom switch)**
- **SW2 = I0.2 (top switch)**
- **Lamp = Q0.0**

□ Ladder Logic Arrangement

- We connect two NO (Normally Open) contacts of SW1 and SW2 in series.
- In parallel to this series path, we connect NC (Normally Closed) contacts of SW1 and SW2 in series.



(Ladder Diagram)

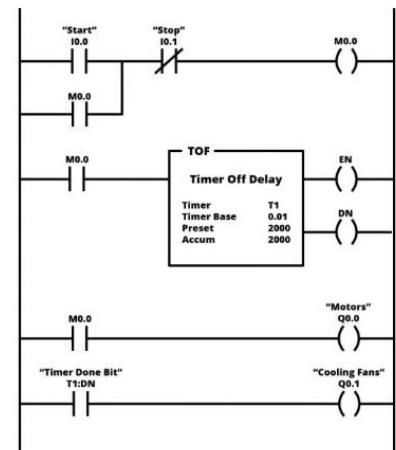
(iii) Traffic light Control

⚡ Program Purpose

- Start and stop **motors** using a **Start** and **Stop** push button.
- When motors stop, **cooling fans** keep running for some time (using an **OFF Delay Timer**).

Rung 1 – Motor Latching (M0.0)

- Press **Start (I0.0)** → M0.0 coil turns ON.
- **M0.0 contact** is in parallel with Start to keep the coil ON after Start is released (latch).
- **Stop (I0.1)** is NC → breaks circuit to stop the motor when pressed.



Rung 2 – Timer Off Delay (TOF T1)

- When **M0.0** is ON (motor running), the TOF timer is energized.
- Timer starts **counting when M0.0 turns OFF** (this is OFF delay behavior).
- **Preset = $2000 \times 0.01 = 20$ seconds** OFF delay.
- **Bits:**

- **EN** = 1 while rung is TRUE (M0.0 ON).
- **DN** = 1 until the OFF delay time finishes after M0.0 turns OFF.

Rung 3 – Motors Output (Q0.0)

When M0.0 is ON, the **motors output (Q0.0)** energizes.

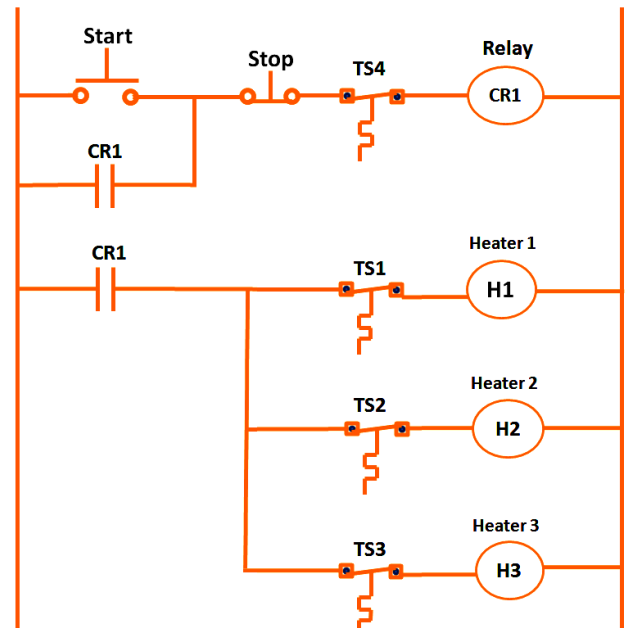
Rung 4 – Cooling Fans Output (Q0.1)

- **Cooling fans (Q0.1)** stay ON as long as the TOF timer **DN bit** is ON.
- **When motors stop (M0.0 OFF):**
 - TOF T1 keeps **DN = 1** for preset delay (20s) → fans run to cool the system.
 - After time finishes → DN goes 0 → fans OFF.

🔄 Sequence of Operation

1. **Press Start:**
 - Motors ON (Q0.0).
 - Timer T1 energized (but not counting yet because TOF counts after OFF).
2. **Press Stop:**
 - Motors OFF immediately (M0.0 OFF).
 - TOF timer starts **20 s OFF delay**.
 - Fans (Q0.1) stay ON during this delay.
3. **After 20 s:**
 - TOF DN goes 0 → fans turn OFF.

(iv) Temperature Controller



Name	Symbol	Type / Purpose
Start button	START	Normally Open (NO) — to start system
Stop button	STOP	Normally Closed (NC) — to stop system

Name	Symbol	Type / Purpose
Relay	CR1	Main control relay for heaters
Thermostat 1	TS1	Opens at 55°C — turns OFF Heater H1
Thermostat 2	TS2	Opens at 60°C — turns OFF Heater H2
Thermostat 3	TS3	Opens at 65°C — turns OFF Heater H3
Safety Thermostat	TS4	Opens at 70°C — turns OFF all heaters
Heaters	H1,H2,H3	Electrical heaters controlled by relays

Rung 1 — System Start & Safety Shutoff

- **START button (NO):** When pressed → energizes relay **CR1**.
- **STOP button (NC):** If pressed → breaks circuit → turns OFF CR1.
- **TS4 (NC):** Safety thermostat. If temperature $>70^{\circ}\text{C}$ → TS4 opens → CR1 turns OFF → all heaters OFF.
- **CR1 NO contact:** Connected parallel to START → **latches** the circuit so CR1 stays ON after START is released.

Rung 2 — Heater Control with Thermostats

- **Relay CR1:** Must be ON for heaters to work.
- **TS1:**
 - Below 55°C → TS1 closed → H1 ON.
 - At $\geq 55^{\circ}\text{C}$ → TS1 opens → H1 OFF.
- **TS2:**
 - Below 60°C → TS2 closed → H2 ON.
 - At $\geq 60^{\circ}\text{C}$ → TS2 opens → H2 OFF.
- **TS3:**
 - Below 65°C → TS3 closed → H3 ON.
 - At $\geq 65^{\circ}\text{C}$ → TS3 opens → H3 OFF.
- **Safety TS4:**
 - At $\geq 70^{\circ}\text{C}$ → TS4 opens → CR1 OFF → **all heaters OFF**.

Operation Summary

1. **Start system:**

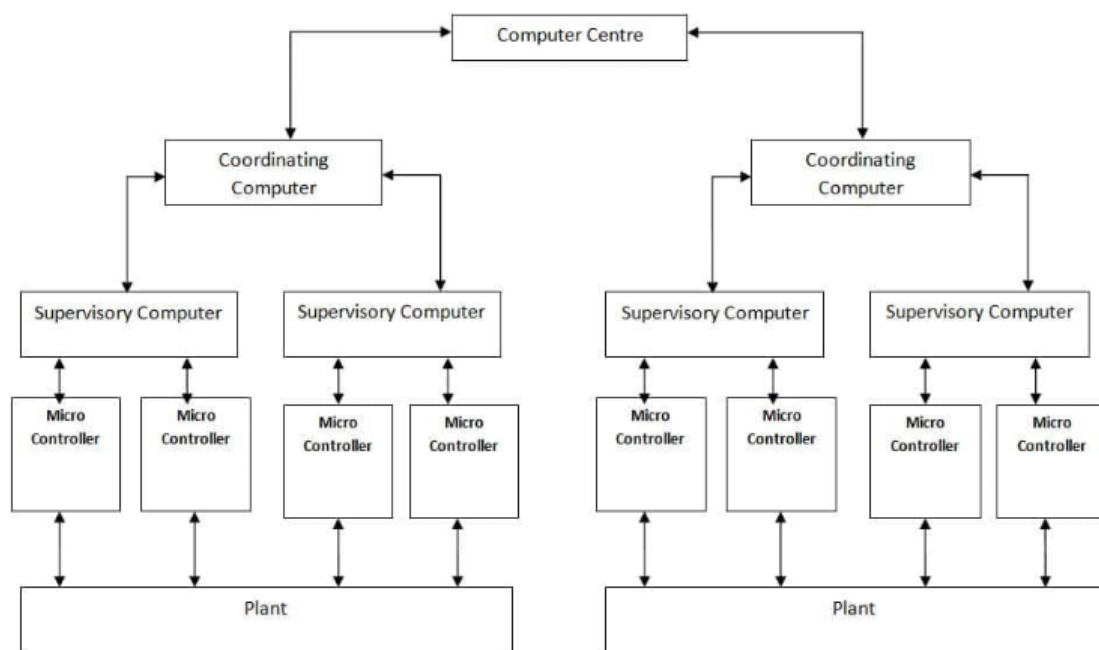
- Press START → CR1 energizes → latches itself → heaters ready.
- 2. **Heating sequence:**
 - Below 55°C → H1, H2, H3 ON.
 - 55–60°C → TS1 opens → H1 OFF (H2, H3 still ON).
 - 60–65°C → TS2 opens → H2 OFF (H3 still ON).
 - 65–70°C → TS3 opens → H3 OFF.
- 3. **Over-temperature protection:**
 - At >70°C, TS4 opens → CR1 OFF → all heaters OFF.
- 4. **Stop system:**
 - Press STOP → CR1 OFF → all heaters OFF.

5.14 Special control systems- Basics DCS & SCADA systems

Distributed Control System (DCS)

Definition

A **DCS** is a control system where **control functions are distributed** throughout the plant instead of being done by one big controller.



DCS STRUCTURE

DCS Structure Explained

This diagram shows how a **Distributed Control System (DCS)** is arranged in **levels** from the plant floor to the central computer.

◆ 1. Computer Centre (Top)

- The **highest level** of the system.
- Stores **plant-wide data**, runs **management software**, and can connect to enterprise networks.
- Handles long-term data storage, reporting, and overall plant supervision.

◆ 2. Coordinating Computers

- Connect the **Computer Centre** with the control network.
- **Coordinate data** between different areas of the plant.
- Combine information from multiple **supervisory computers** and send commands if needed.

◆ 3. Supervisory Computers

- These are the **main controllers** at the area/section level.
- Communicate with **microcontrollers** below them and with the **coordinating computer** above.
- Perform **process monitoring, control algorithms (PID, logic), alarm handling, and trending** for their section.

◆ 4. Microcontrollers (Local Controllers)

- Located **close to the plant equipment**.
- Directly connected to **sensors and actuators**.
- Execute **fast control actions** (e.g., temperature, pressure loops).
- Report data to the **supervisory computer**.

◆ 5. Plant Level

- The **actual process equipment**: pumps, motors, valves, sensors, heaters, turbines, etc.
- Microcontrollers read measurements (pressure, flow, temperature, level) and send commands to actuators.

🔗 How It Works Step-by-Step

1. **Field devices** (sensors/actuators) → send signals to **microcontrollers**.
2. **Microcontrollers** → control basic loops & send processed data to **supervisory computers**.
3. **Supervisory computers** → monitor section performance, run control logic, send data up.
4. **Coordinating computer** → gathers data from multiple sections and integrates it.
5. **Computer centre** → plant-wide monitoring, reporting, and management.

Advantages

- **High reliability** (distributed = no single point failure).

- Easier **expansion & maintenance**.
- Good for **large continuous processes**.
- Advanced **process control (PID, trending, alarms)**.

✓ Key Points for Students

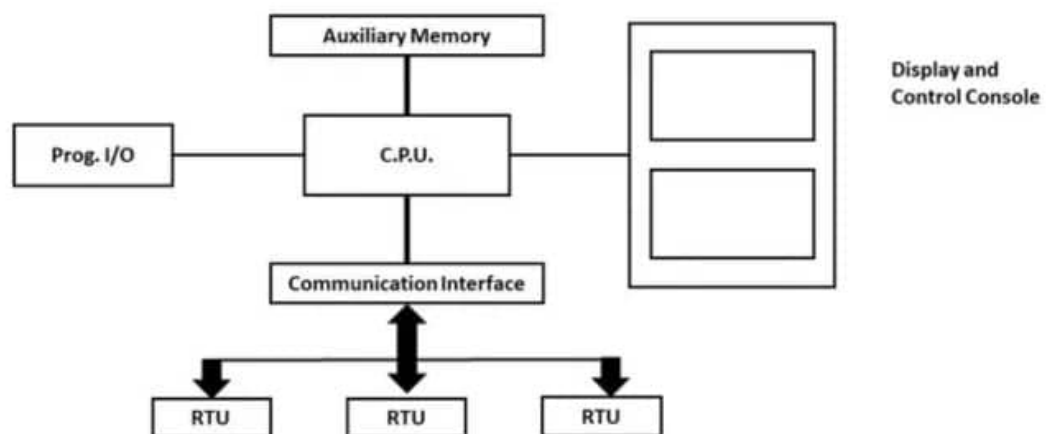
- **Hierarchy:** Plant → Microcontrollers → Supervisory Computers → Coordinating Computer → Computer Centre.
- **Distributed:** Each level handles part of the work (no single failure stops the whole plant).
- **Fast local control:** Microcontrollers handle real-time control.
- **Central monitoring:** Higher levels collect, analyze, and display plant-wide information.
- **Scalable & reliable:** Easy to expand and keep running if one section fails.

Supervisory Control and Data Acquisition (SCADA)

Definition

A **SCADA** system is used to **monitor and control equipment spread over wide areas** (pipelines, water supply, power grids).

Block Diagram of SCADA



◆ 1. C.P.U. (Central Processing Unit)

- The **brain** of the SCADA master station.
- Collects data from remote sites (RTUs/PLCs).

- Processes the data, runs software to show status, trigger alarms, and send control commands.

◆ 2. Auxiliary Memory

- Stores **historical process data**, configuration files, and programs.
- Keeps **alarm logs, trend data, and system events** for later analysis.

◆ 3. Programmed I/O

- Allows **input and output devices** to connect to the SCADA system.
- Interfaces with local sensors or controllers directly connected to the master station.

◆ 4. Display and Control Console

- The **operator's screen / HMI**.
- Shows **real-time process data, alarms, and trends**.
- Operators can issue **start/stop commands, setpoints**, and acknowledge alarms.

◆ 5. Communication Interface

- Connects the SCADA master station with remote field sites.
- Can use **wired lines, fiber optic, radio, cellular, or satellite links**.

◆ 6. RTUs (Remote Terminal Units)

- Located at **remote sites** (pump stations, substations, plants).
- Collect data from **field sensors** and send it to the SCADA master.
- Execute **basic local control** if needed.
- Receive control commands from the CPU and operate **valves, pumps, switches**.

🔄 How It Works

1. **Sensors/actuators** in the field send signals to **RTUs**.
2. **RTUs** send this data to the **SCADA CPU** via the communication interface.
3. **CPU** processes the data, stores it in **memory**, and displays it on the **control console**.
4. Operators can **monitor, log data, and send commands** (e.g., open/close valves, start pumps).
5. Commands travel back to the RTUs to control the remote equipment.

Advantages

- **Long-distance control** of remote sites.
- **Real-time monitoring** with alarms.
- Data logging & reporting.
- Can integrate with **industrial networks and internet**.

Difference Between SCADA And DCS

Feature	DCS (Distributed Control System)	SCADA (Supervisory Control and Data Acquisition)
Area	Local plant or factory	Wide area (pipelines, power grid, water supply)
Control	Continuous process control	Supervisory – monitor & remote control
Response	Fast real-time loop control	Slower, supervisory level
Architecture	Many distributed controllers connected to HMI	Central Master + Remote RTUs/PLCs
Use	Power plants, chemical, oil refineries	Water supply, electric grids, pipelines

✓ Key Points for Students

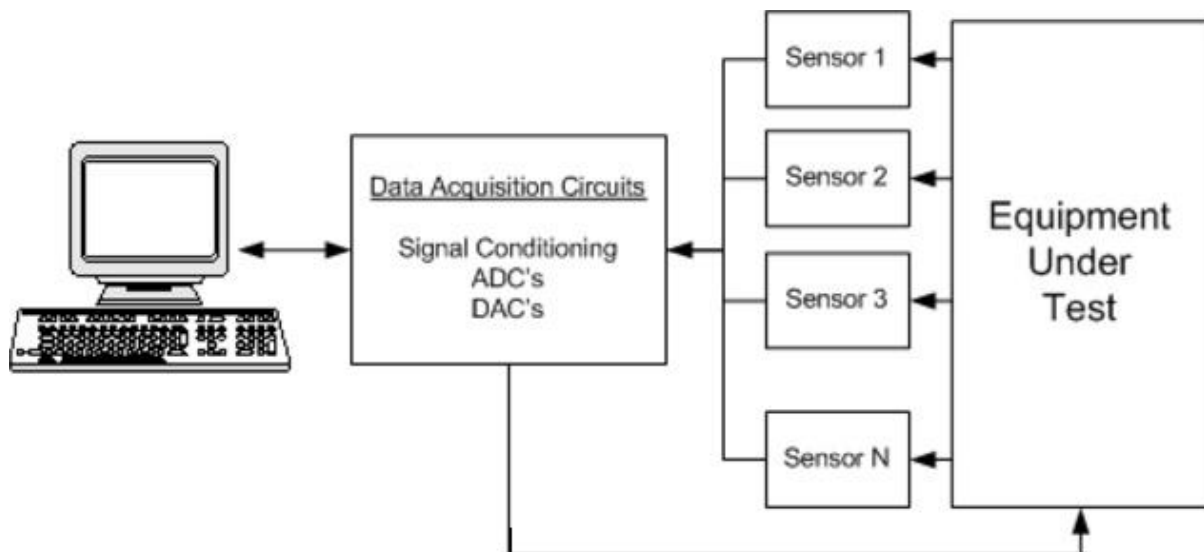
- **SCADA = Monitor & control distant sites** (pipelines, power, water).
- **CPU + Memory + Communication = Master Station.**
- **RTUs** collect field data and execute commands.
- **Communication Interface** links master station and remote RTUs.
- **Operator console** gives full control and monitoring from one place.

5.15 Computer Control–Data Acquisition, Direct Digital Control System (Basics only)

◆ Definition

A **Data Acquisition System (DAS)** is an electronic system that **measures, collects, and converts physical signals** (like temperature, pressure, flow, voltage, current) into **digital data for monitoring, analysis, and control**. It acts as the **bridge between real-world signals and a computer/processor**.

Diagram Of DCS



◆ 1. Equipment Under Test

- This is the **machine, process, or system** we want to measure (e.g., motor, turbine, circuit, engine, industrial process).
- Produces **physical parameters** such as **temperature, pressure, vibration, voltage, current, speed**.

◆ 2. Sensors (Sensor 1, Sensor 2 ... Sensor N)

- Each **sensor** measures a **specific parameter** from the equipment.
 - Example: Temperature sensor, pressure transducer, vibration sensor.
- Converts the **physical quantity** into an **electrical signal** (usually analog voltage or current).

◆ 3. Data Acquisition Circuits

This block performs **signal processing and conversion**:

- **Signal Conditioning**: Amplifies weak signals, filters noise, isolates from high voltage.
- **ADC (Analog-to-Digital Converter)**: Changes the analog signal to digital data that a computer can understand.
- **DAC (Digital-to-Analog Converter, if needed)**: Converts digital control signals back to analog outputs.

◆ 4. Computer / PC

- Collects the **digital data** from the data acquisition circuits.
- Displays data in **graphs, tables, or dashboards**.
- Stores data for **analysis, alarms, and control actions**.
- Can also send commands back to the system (for automated control).

🔗 Flow of Information

1. **Equipment** produces measurable signals.
2. **Sensors** pick up these signals and convert them to electrical form.
3. **Signal conditioning & ADC** prepare and digitize the signals.
4. **Computer** records, analyzes, and displays the data for operators or engineers.

⚡ Data Acquisition System (DAS) – Advantages, Disadvantages & Applications

✓ Advantages of DAS

- **Reduced data redundancy** – No need to store the same data multiple times.
- **Reduced updating errors & better consistency** – Data is uniform across the system.
- **Greater data integrity** – Data stays accurate and reliable.
- **Independence from application programs** – Data is not tied to one software only.
- **Improved data access** – Users can easily query and access data.
- **Better security** – Centralized control makes data safer.
- **Lower data entry & storage cost** – Less duplication and automated collection.
- **Faster development of new applications** – Central data makes it easier to build new software.

⚠ Disadvantages of DAS

- **Complex design** – Systems are difficult and time-consuming to plan.
- **High start-up cost** – Expensive hardware & software at the beginning.
- **Database damage risk** – If database fails, many applications stop working.
- **Conversion cost** – Moving from old file-based system to DAS is costly.
- **Training required** – Users and programmers need training to use the system.

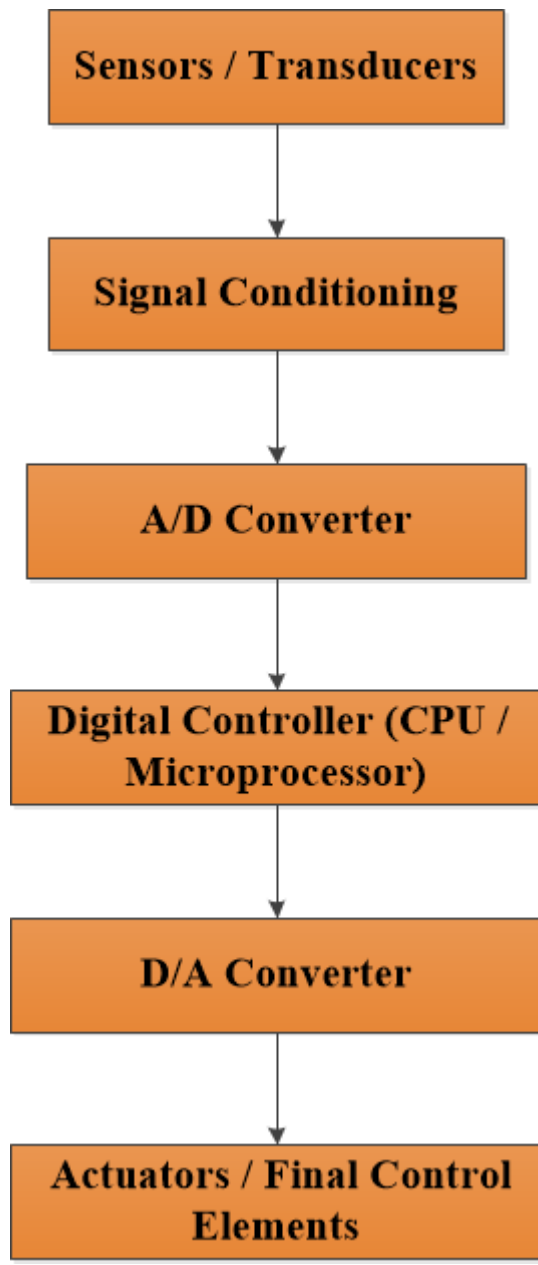
◆ Applications of DAS

- **Temperature measurement & logging**
- **Industrial process monitoring and control**
- **Power system monitoring (voltage, current, frequency)**
- **Medical testing (ECG, EEG)**
- **Environmental data logging (humidity, pressure, pollution)**
- **Research & laboratory experiments**

Direct Digital Control System

A **Direct Digital Control (DDC) system** is a control system where a **digital computer or microprocessor directly measures process variables (temperature, pressure, flow, etc.) and sends control signals** to actuators (valves, motors, heaters) in real time.

Block Diagram of DDC



Key Blocks:

- **Sensors / Transducers:** Measure process variables and give analog signals.
- **Signal Conditioning:** Amplifies, filters, isolates sensor signals.
- **A/D Converter:** Converts analog signals to digital for the CPU.
- **Digital Controller (CPU):** Runs control algorithms (PID, logic, timing).
- **D/A Converter:** Converts digital output to analog for actuators.
- **Actuators:** Valves, motors, dampers, heaters, etc., that control the process.

◆ Characteristics

- Control is **continuous** but handled by a **computer in discrete time steps**.
- **Highly flexible** — control logic can be changed by software.
- Supports **multi-loop control** (one CPU controlling many processes).

- Can integrate with **SCADA/DCS systems** for remote supervision.

✓ Advantages

- **Programmable & Flexible** – easy to change control logic.
- **Accurate & Stable** – digital processing reduces drift and error.
- **Data Logging** – stores trends, alarms, history.
- **Multi-loop Control** – one controller can handle many loops.
- **Remote Monitoring** – can connect to networks/SCADA easily.

⚠ Disadvantages

- **Needs reliable power** – CPU must stay powered.
- **Complex & costly** compared to simple analog controllers.
- **Requires skilled personnel** for programming and maintenance.
- **Sampling time limits** – very fast processes may be harder to control.

◆ Applications

- **Building Automation:** HVAC (air conditioning, heating, ventilation).
- **Industrial Processes:** Chemical, food, cement, paper, steel plants.
- **Power Plants:** Boiler & turbine control.
- **Water Treatment Plants:** Flow & level control.
- **Manufacturing Machines:** Temperature, pressure, motion control.

POSSIBLE QUESTION WITH PREVIOUS YEAR QUESTION **SHORT QUESTION**

1. What is PLC?
2. List any four logical arithmetic in PLC (Year 2022)
3. List down any two applications of PLC. (Year 2021)
4. What are the Advantages of PLC?
5. What are different modules in PLC? (Year 2020)
6. Draw the symbol of NO, NC and output coil. (Year 2021)
7. What is the purpose of latch coil? (Year 2020)

LONG QUESTION

1. Explain CTD & CTU instruction in PLC. (Year 2020)
2. Draw Ladder diagrams for AND, OR, NAND, NOR, XOR gates (Year 2021)
3. Draw ladder diagram for full adder circuit. (Year 2020)

4. Explain Ladder diagram for DOL and Star Delta starter
5. Explain different types of timers in PLC (Year 2020)