GANESH INSTITUTE OF ENGINEERING AND TECHNOLOGY

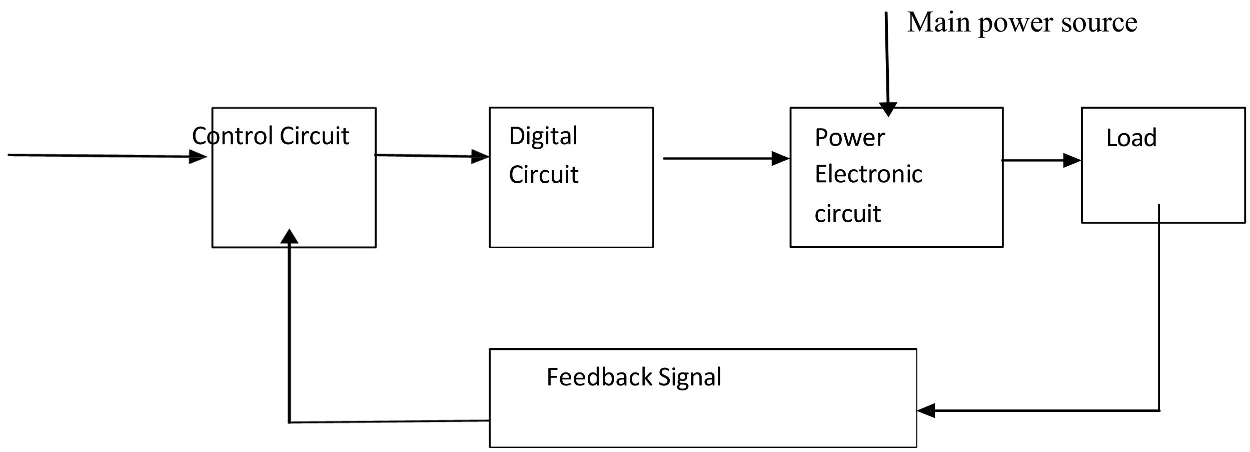
DISCIPLINE: **ELECTRICAL ENGINEERING**

SEMESTER : IV

Subject: Fundamentals of Power Electronics

Content Developed by: SWAGATIKA DAS

The operation of electric motor drives requires proper control of electrical power. Power electronics makes power control easy and efficient. Power electronics refers to the application of electronic devices for the control and conversion of electrical power. It deals with power handling equipment used for controlling electric power.



Power electronics based on the switching of power semiconductor devices. With the development of power semiconductor technology, the power handling capabilities and switching speed of power devices have been improved tremendously.

POWER ELECTRONIC DEVICES

1.1 Power Electronic Devices

Definition:
Power electronic devices are **semiconductor devices used to control, convert, and switch electrical power** efficiently.

Main functions:

- Power **control**
- Power **conversion** (AC–DC, DC–AC, DC–DC, AC–AC)
- Power **switching**

Characteristics:

- Handle **high voltage and current**
- Operate at **high speed**
- High **efficiency**
- Compact size

Examples:

- Power diode
- Power transistor
- SCR
- TRIAC
- MOSFET
- IGBT

Applications:

- Motor control
- SMPS
- Inverters
- UPS
- Electric vehicles
- Industrial drives

1.2 Power Transistor

A **power transistor** is a **current-controlled semiconductor device** used for **switching and amplification** in power circuits.

Classifications of Power Transistors:

1.Bipolar junction transistors(BJTS)

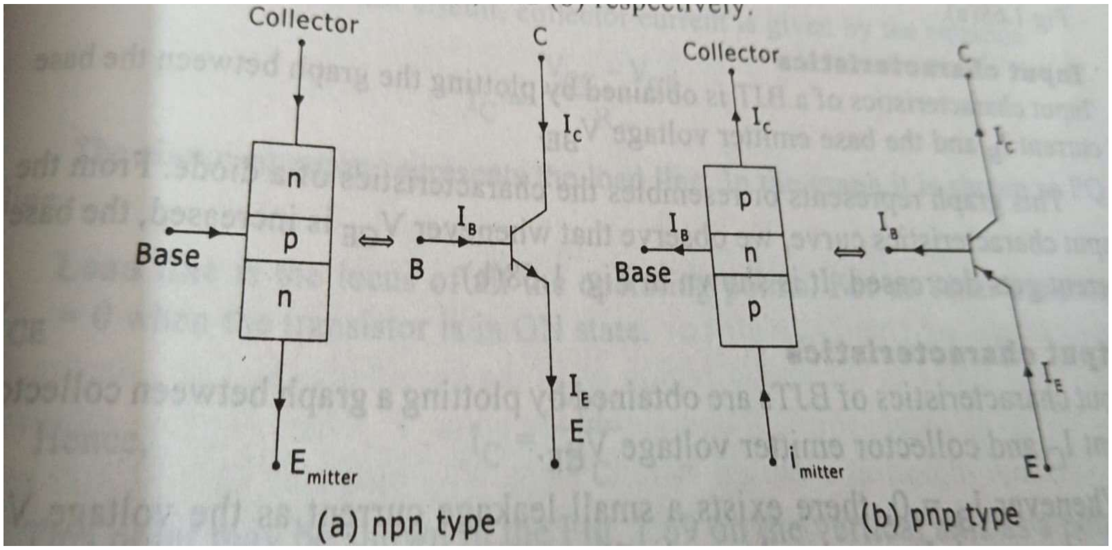
2.Metal oxide semiconductor field effect transistors(MOSFETS)

3.Insulated gate bipolar transistors(IGBTS)

Common type: **BJT (Bipolar Junction Transistor)**

1.2.1 Construction and Working Principle of Power Transistor Construction

- It is a two junction NPN or PNP semiconductor device.
- Power transistor is usually **NPN type**
- Has **three terminals**:
    - **Emitter (E)**
    - **Base (B)**
    - **Collector (C)**
- Collector is **large and thick** to handle high current
- Mounted on **heat sink** for cooling



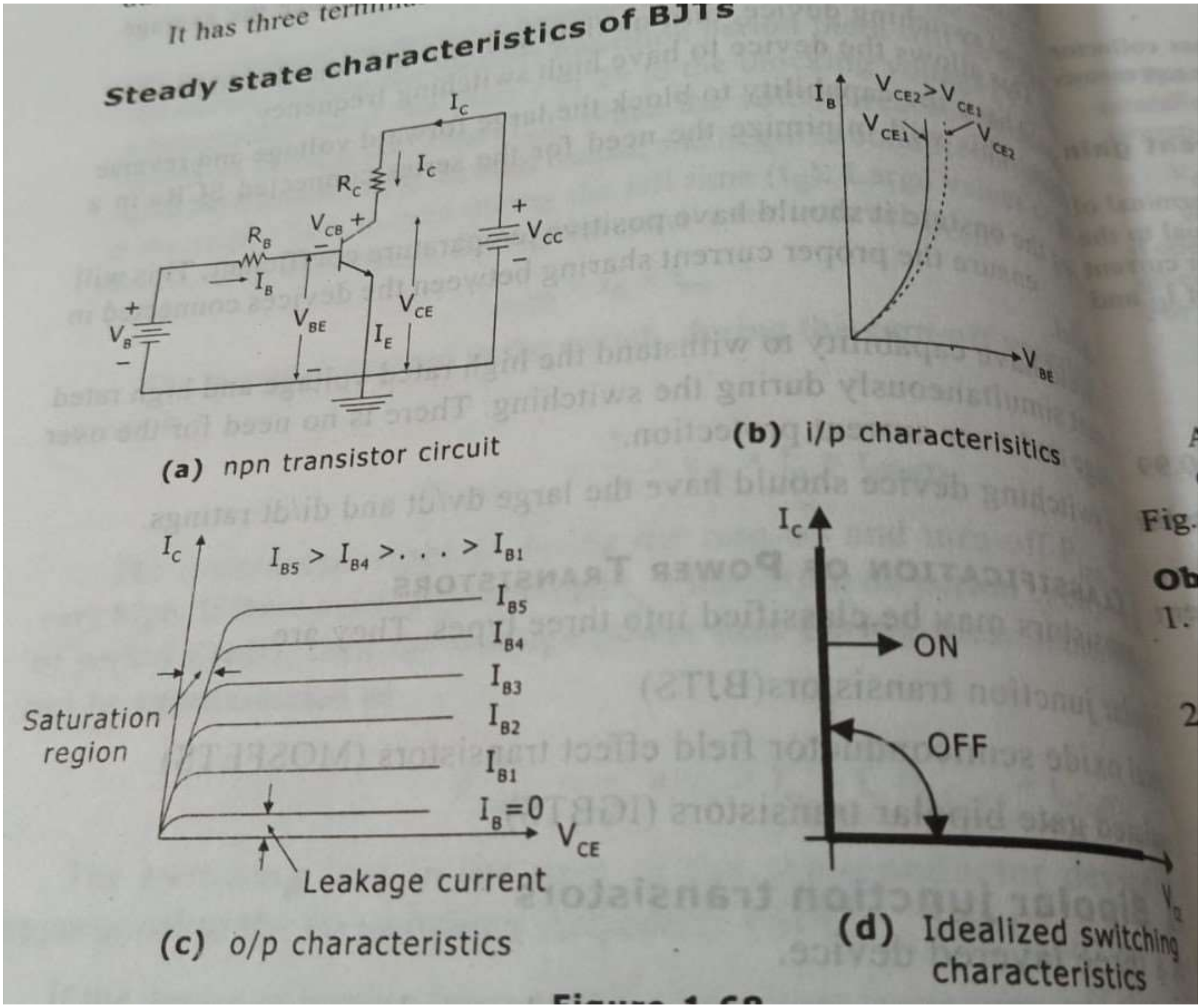
(a) npn type (b) pnp type

Working Principle

- When **base-emitter junction is forward biased**, transistor turns **ON**
- Small **base current** controls large **collector current**
- When base current is zero → transistor **OFF**
- Works in:
    - **Cut-off region** → OFF
    - **Active region** → Amplification
    - **Saturation region** → ON (used in switching)

1.2.2 V–I Characteristics and Uses of Power Transistor
V–I Characteristics

1. **Input characteristics**: Base current vs base-emitter voltage
2. **Output characteristics**: Collector current vs collector-emitter voltage



Key points:

- Collector current increases with base current
- In saturation, voltage drop is small
- Power loss occurs due to heat

Uses

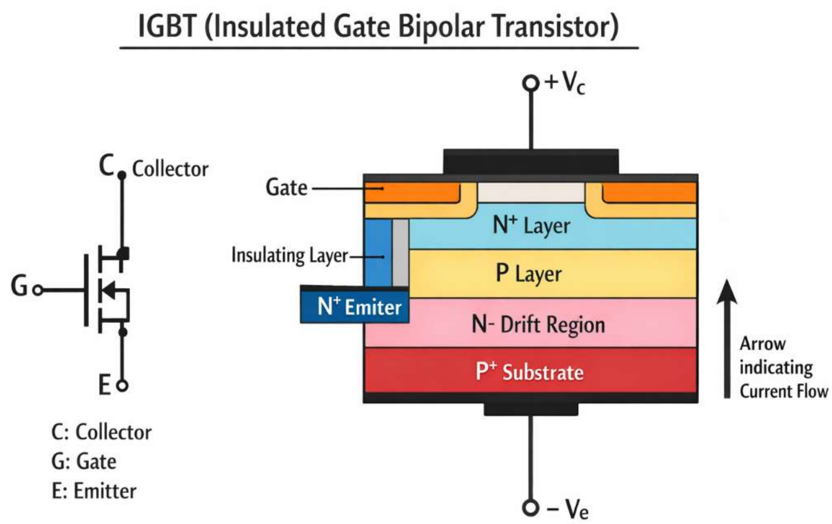
- DC motor control
- Power amplifiers
- Switching regulators
- Relay drivers
- Inverters (low power)

1.3 IGBT (Insulated Gate Bipolar Transistor)

Definition:
IGBT is a **voltage-controlled power device** that combines **MOSFET input** and **BJT output** characteristics.

1.3.1 Construction and Working Principle of IGBT
Construction

- Four layers: **P–N–P–N**
- Three terminals:
    - **Gate (G)**
    - **Collector (C)**
    - **Emitter (E)**
- Gate is **insulated** by silicon dioxide



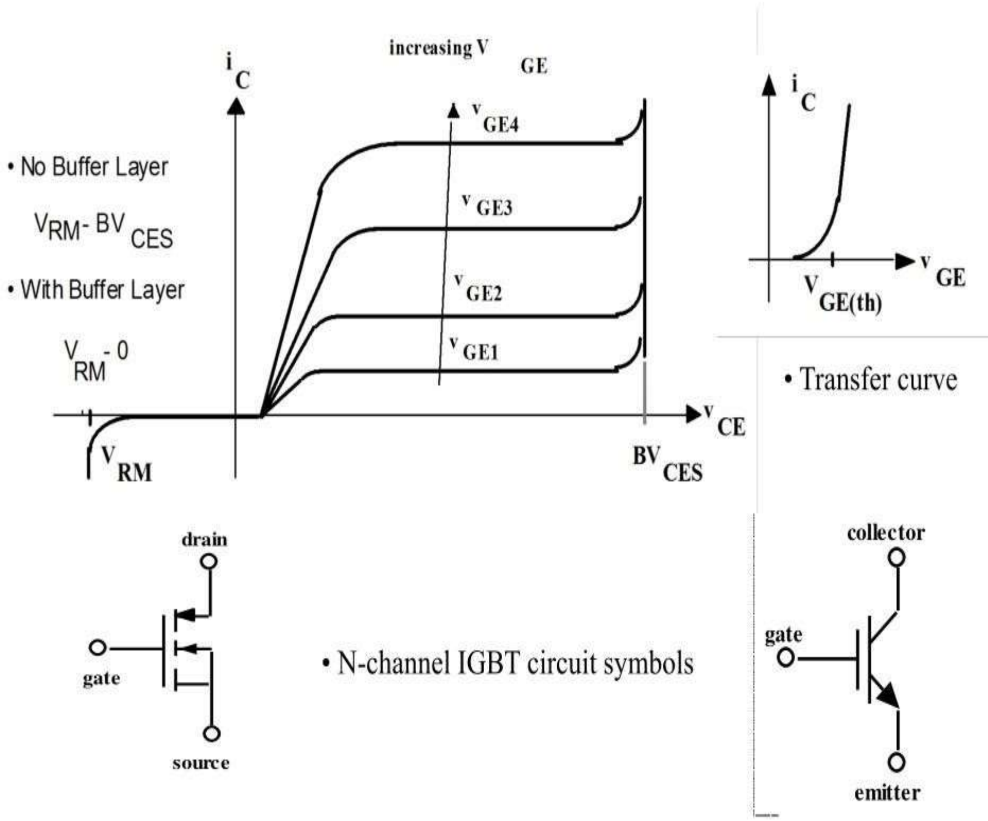
Working Principle

- When **positive gate voltage** is applied → IGBT turns **ON**
- No gate current required
- When gate voltage is removed → IGBT turns **OFF**
- Has **low ON-state losses** and **high input impedance**

1.3.2 V–I Characteristics and Uses of IGBT
V–I Characteristics

- Output curve similar to BJT
- Gate voltage controls collector current
- High blocking voltage capability
- Low switching loss

IGBT I-V Characteristics and Circuit Symbols



Uses

- Variable frequency drives (VFD)
- Inverters
- UPS systems
- Electric vehicles
- Induction heating
- SMPS (high power)

1.4 Concept of Single Electron Transistor (SET)

Definition:
A **Single Electron Transistor (SET)** is a nano-scale device that controls the **movement of single electrons**.

Basic Concept

- Works on **Coulomb blockade principle**
- Consists of:
  - Source
  - Drain
  - Small conducting island

- Electron flow occurs **one electron at a time**

Features

- Extremely **low power consumption**
- Very **small size**
- High sensitivity

Limitation

- Works at **very low temperature**
- Difficult to manufacture

1.5 Aspects of Nano-Technology (Concept Only)

Definition:
Nanotechnology deals with materials and devices having size in **nanometer range (1–100 nm)**.

Key Aspects

- **Miniaturization** of electronic devices
- **High speed** operation
- **Low power consumption**
- **Higher packing density**
- Improved **material properties**

Applications

- Nano-electronics
- Medical diagnostics
- Sensors
- Energy storage devices
- Advanced semiconductor devices

2. Thyristor Family Devices

Thyristors are **four-layer (PNPN) semiconductor devices** used for **control of power** in AC and DC circuits. They act as **controlled switches** and are widely used in **rectifiers, inverters, motor control, and power regulators**.

2.1 SCR (Silicon Controlled Rectifier)

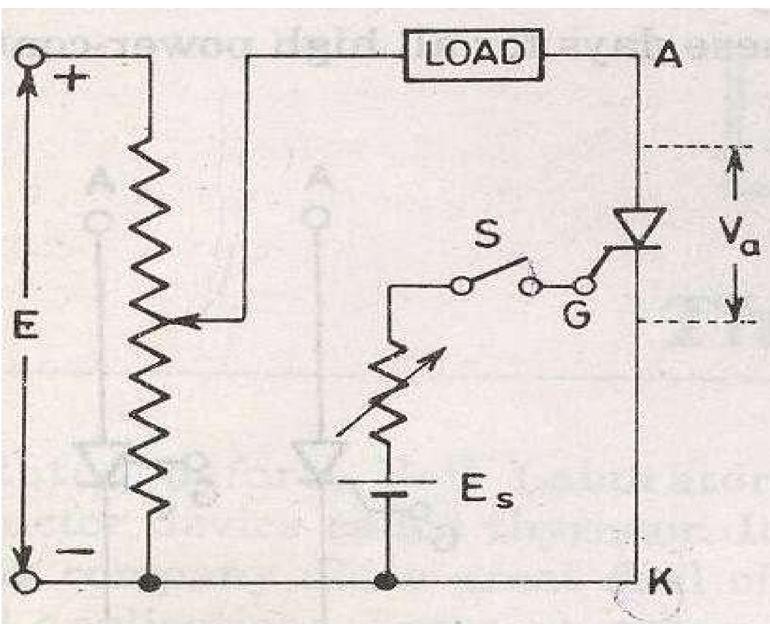
An **SCR** is a **unidirectional thyristor** that conducts current **only after triggering the gate**.

Terminals:

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

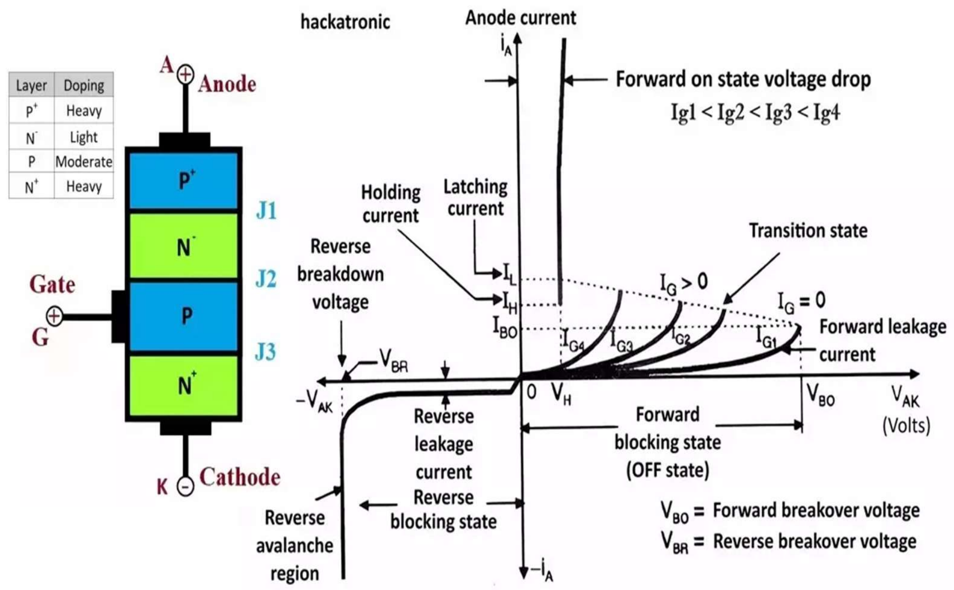
2.1.1 Construction of SCR

- SCR consists of **four alternate layers**: **P–N–P–N**
- Three junctions:
  - **J1 (P–N)**
  - **J2 (N–P)**
  - **J3 (P–N)**
- Gate is connected to the **inner P-layer**
- Anode to outer P-layer
- Cathode to outer N-layer



Important Points:

- Middle junction **J2** controls switching
- SCR remains OFF until **gate signal** is applied



V-I Characteristics of SCR

2.1.2 Two Transistor Analogy of SCR

An SCR can be represented as **two interconnected BJTs**:

- **T1 (PNP transistor)**
- **T2 (NPN transistor)**

Working:

- Collector of T1 → Base of T2
- Collector of T2 → Base of T1
- Gate current increases base current of T2
- Regenerative action causes both transistors to turn ON
- SCR latches ON

Condition for Turn ON:

$\alpha 1 + \alpha 2 \geq 1$ Where:

- $\alpha 1$ = current gain of **PNP transistor (T_1)**
- $\alpha 2$ = current gain of **NPN transistor (T_2)**

- V_{BO}=Forward breakover voltage
- V_{BR}=Reverse breakover voltage
- I_g=Gate current
- V_a=Anode voltage across the thyristor terminal A,K.

- I_a=Anode current
- It can be inferred from the static V-I characteristic of SCR. SCR have 3 modes of operation:

It can be inferred from the static V-I characteristic of SCR. SCR have 3 modes of operation:

1. Reverse blocking mode
2. Forward blocking mode (off state)
3. Forward conduction mode (on state)

1. <u>Reverse Blocking Mode</u>

When cathode of the thyristor is made positive with respect to anode with switch open thyristor is reverse biased. Junctions J_1 and J_2 are reverse biased where junction J_2 is forward biased. The device behaves as if two diodes are connected in series with reverse voltage applied across them.

- A small leakage current of the order of few mA only flows. As the thyristor is reverse biased and in blocking mode. It is called as acting in reverse blocking mode of operation.

- Now if the reverse voltage is increased, at a critical breakdown level called reverse breakdown voltage V_{BR},an avalanche occurs at J_1 and J_3 and the reverse current increases rapidly. As a large current associated with V_{BR} and hence more losses to the SCR.

This results in Thyristor damage as junction temperature may exceed its maximum temperature rise.

2. **<u>Forward Blocking Mode</u>**

When anode is positive with respect to cathode, with gate circuit open, thyristor is said to be forward biased.

Thus junction J_1 and J_3 are forward biased and J_2 is reverse biased. As the forward voltage is increases junction J_2 will have an avalanche breakdown at a voltage called forward breakover voltage V_{BO}. When forward voltage is less then V_{BO} thyristor offers high impedance. Thus a thyristor acts as an open switch in forward blocking mode.

3. **<u>Forward Conduction Mode</u>**

Here thyristor conducts current from anode to cathode with a very small voltage drop across it. So a thyristor can be brought from forward blocking mode to forward conducting mode:

1. By exceeding the forward breakover voltage.
2. By applying a gate pulse between gate and cathode.

During forward conduction mode of operation thyristor is in on state and behave like a close switch. Voltage drop is of the order of 1 to 2mV. This small voltage drop is due to ohmic drop across the four layers of the device.

<u>Switching characteristics of thyristors</u>

The time variation of voltage across the thyristor and current through it during turn on and turn off process gives the dynamic or switching characteristic of SCR.

<u>Switching characteristic during turn on</u>

<u>Turn on time</u>

It is the time during which it changes from forward blocking state to ON state. Total turn on time is divided into 3 intervals:

1. Delay time
2. Rise time
3. Spread time

<u>Delay time</u>

If I_g and I_a represent the final value of gate current and anode current. Then the delay time can be explained as time during which the gate current attains 0.9 I_g to the instant anode current reaches 0.1 I_g or the anode current rises from forward leakage current to 0.1 I_a.

1. Gate current 0.9 I_g to 0.1 I_a.

2. Anode voltage falls from V_a to $0.9V_a$.
3. Anode current rises from forward leakage current to $0.1\ I_a$.

Rise time (t_r)

Time during which

1. Anode current rises from 0.1 I_a to 0.9 I_a
2. Forward blocking voltage falls from $0.9V_a$ to $0.1V_a$. V_a is the initial forward blocking voltage.

Spread time (t_p)

1. Time taken by the anode current to rise from $0.9I_a$ toI_a.
2. Time for the forward voltage to fall from $0.1V_o$ to on state voltage drop of 1 to 1.5V. During turn on, SCR is considered to be a charge controlled device. A certain amount of charge is injected in the gate region to begin conduction. So higher the magnitude of gate current it requires less time to inject the charges. Thus turn on time is reduced by using large magnitude of gate current.

How the distribution of charge occurs?

As the gate current begins to flow from gate to cathode with the application of gate signal. Gate current has a non uniform distribution of current density over the cathode surface. Distribution of current density is much higher near the gate. The density decrease as the distance from the gate increases. So anode current flows in a narrow region near gate where gate current densities are highest. From the beginning of rise time the anode current starts spreading itself. The anode current spread at a rate of 0.1mm/sec. The spreading anode current requires some time if the rise time is not sufficient then the anode current cannot spread over the entire region of cathode. Now a large anode current is applied and also a large anode current flowing through the SCR. As a result turn on losses is high. As these losses occur over a small conducting region so local hot spots may form and it may damage the device.

Switching Characteristics During Turn Off

Thyristor turn off means it changed from ON to OFF state. Once thyristor is oON there is no role of gate. As we know thyristor can be made turn OFF by reducing the anode current below the latching current. Here we assume the latching current to be zero ampere. If a forward voltage is applied across the SCR at the moment it reaches zero then SCR will not be able to block this forward voltage. Because the charges trapped in the 4- layer are still favourable for conduction and it may turn on the device. So to avoid such a case, SCR is reverse biased for some time even if the anode current has reached to zero.

So now the turn off time can be different as the instant anode current becomes zero to the instant when SCR regains its forward blocking capability.

$t_q = t_{rr} + t_{qr}$

Where,

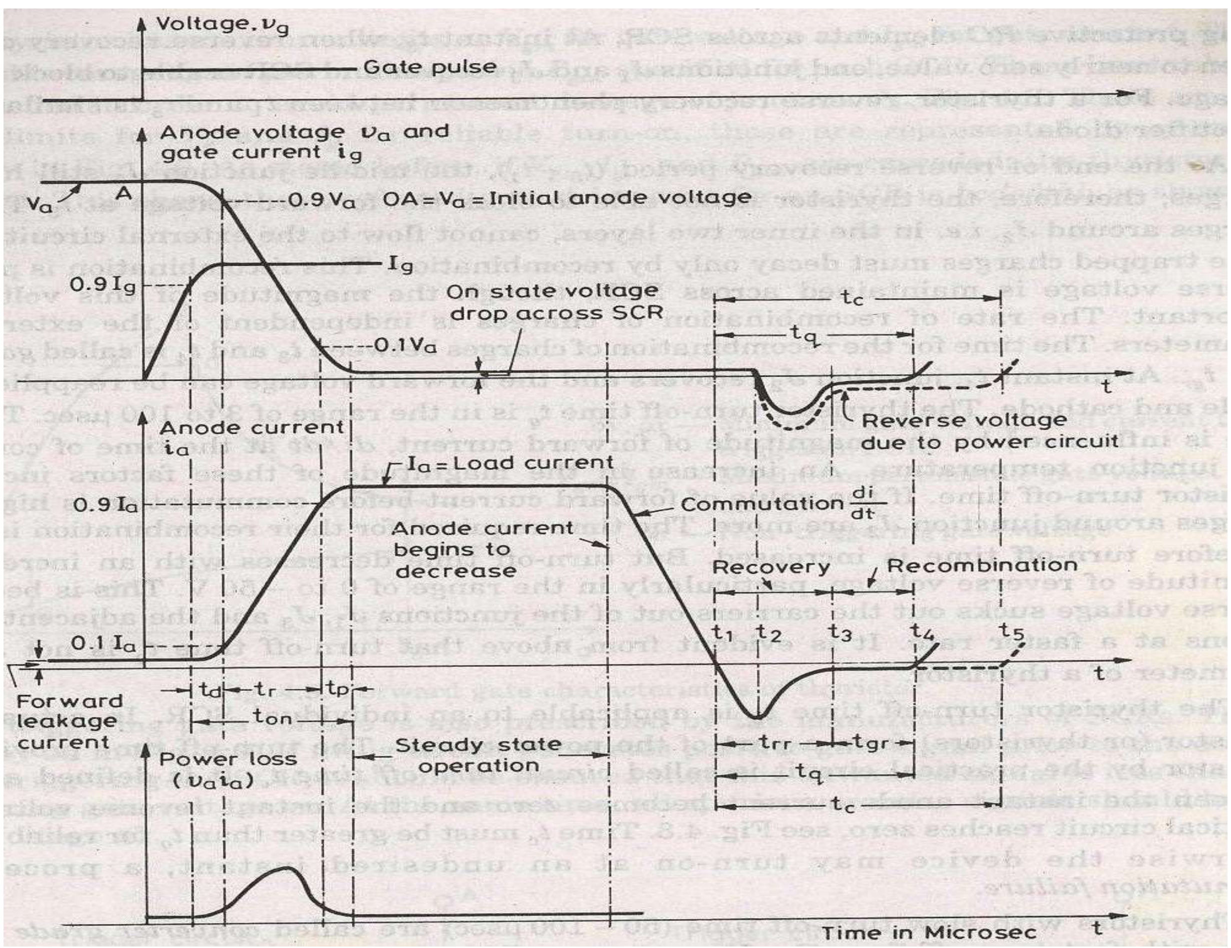
t_q is the turn off time, t_{rr} is the reverse recovery time, t_{qr} is the gate recovery time

At t_1 anode current is zero. Now anode current builds up in reverse direction with same $\frac{dv}{dt}$ slope. This is due to the presence of charge carriers in the four layers. The reverse recovery current removes the excess carriers from J_1 and J_3 between the instants t_1 and t_3. At instant t_3 the end junction J_1 and J_3 is recovered. But J_2 still has trapped charges which decay due to recombination only so the reverse voltage has to be maintained for some more time. The time taken for the recombination of charges between t_3 and t_4 is called gate recovery time t_{qr}. Junction J_2 recovered and now a forward voltage can be applied across SCR.

The turn off time is affected by:

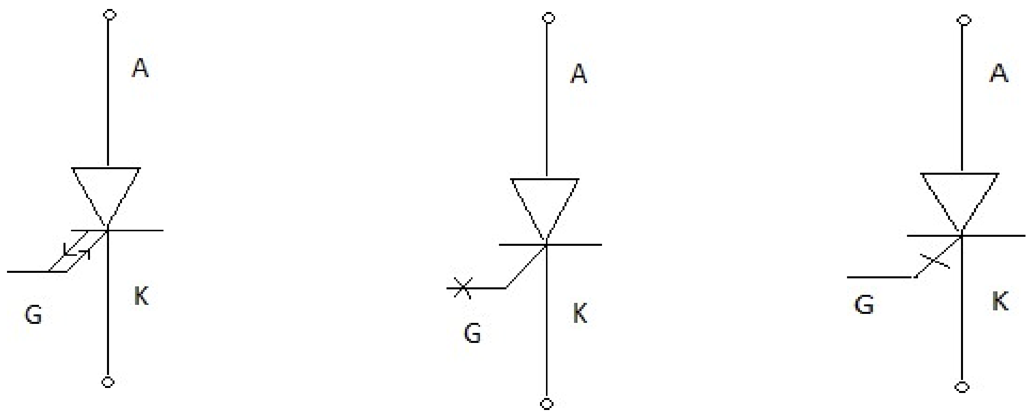
1. Junction temperature
2. Magnitude of forward current $\frac{di}{dt}$ during commutation.

Turn off time decreases with the increase of magnitude of reverse applied voltage.



<u>GTO(Gate turn off thyristor)</u>

A gate turn off thyristor is a pnpn device. In which it can be turned ON like an ordinary SCR by a positive gate current. However it can be easily turned off by a negative gate pulse of appropriate magnitude.



Conventional SCR are turned on by a positive gate signal but once the SCR is turned on gate loses control over it. So to turn it off we require external commutation circuit. These commutation circuits are bulky and costly. So due to these drawbacks GTO comes into existence.

The salient features of GTO are:

1. GTO turned on like conventional SCR and is turned off by a negative gate signal of sufficient magnitude.
2. It is a non latching device.
3. GTO reduces acoustic and electromagnetic noise.

It has high switching frequency and efficiency.

A gate turn off thyristor can turn on like an ordinary thyristor but it is turn off by negative gate pulse of appropriate magnitude.

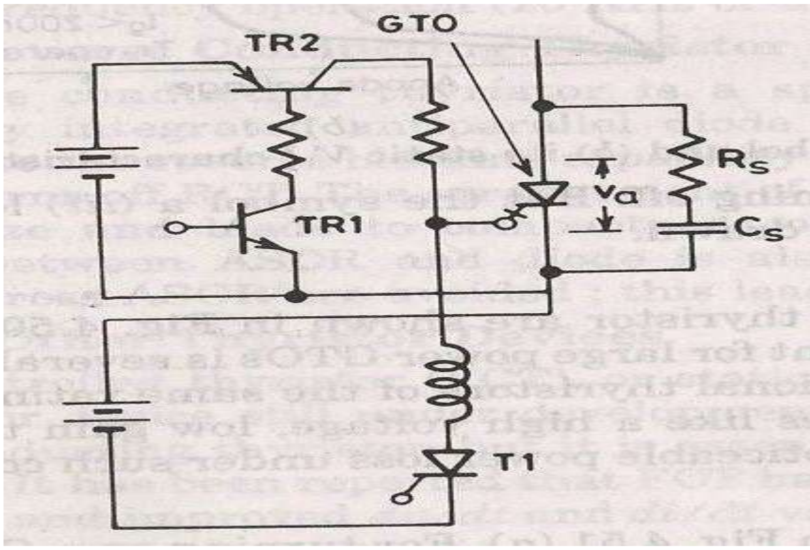
Disadvantage

The negative gate current required to turn off a GTO is quite large that is 20% to 30 % of anode current

Advantage

It is compact and cost less

Switching performance



1. For turning ON a GTO first TR1is turned on.
2. This in turn switches on TR2 so that a positive gate current pulse is applied to turn on the GTO.
3. Thyristor T_1 is used to apply a high peak negative gate current pulse.

Gate turn-on characteristics

1. The gate turn on characteristics is similar to a thyristor. Total turn on time consists of delay time, rise time, spread time.
2. The turn on time can be reduced by increasing its forward gate current.

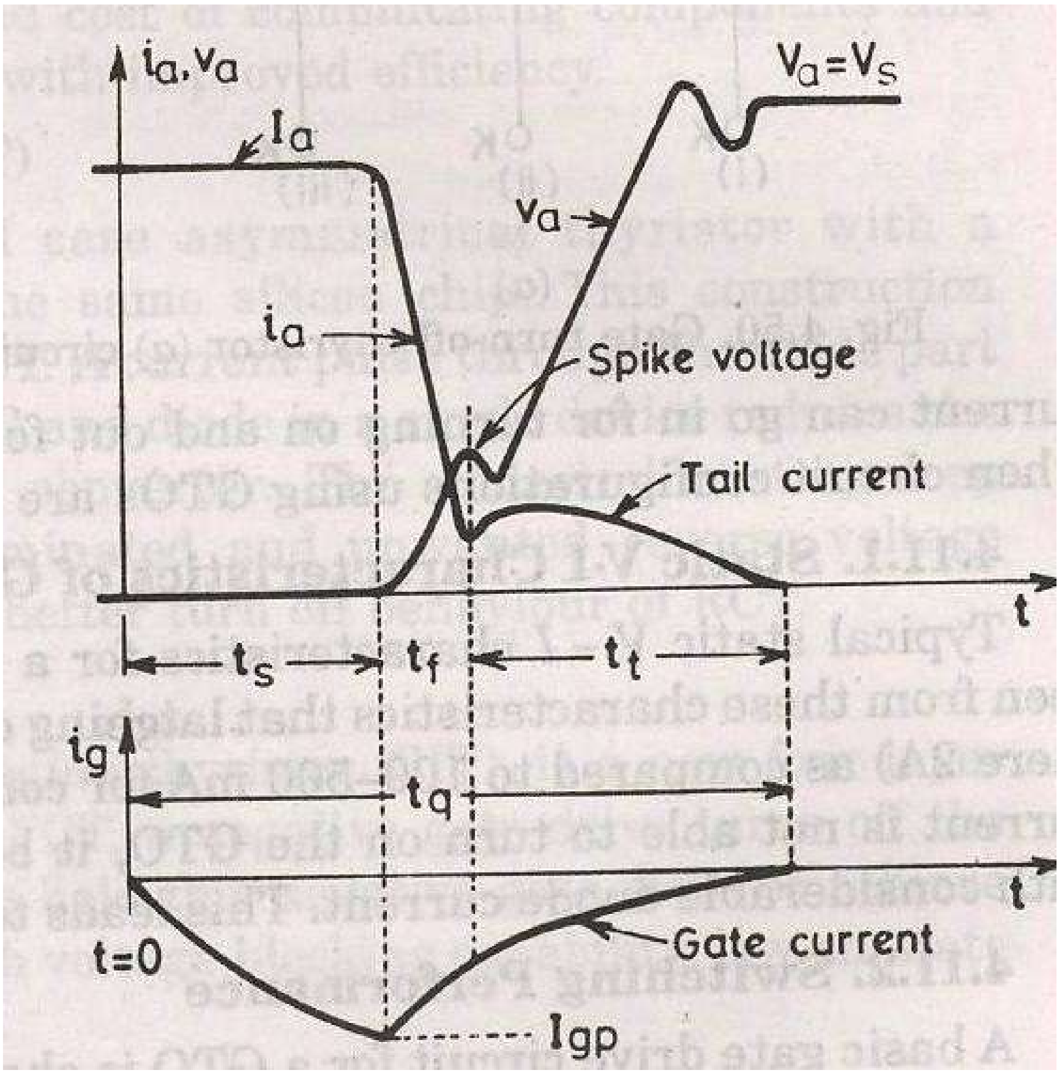
GATE TURN OFF

Turn off time is different for SCR.Turn off characteristics is divied into 3 pd

1. Storage time
2. Fall time
3. Tail time

   $T_q=t_s+t_f+t_t$

   At normal operating condition gto carries a steady state current.The turn off process starts as soon as negative current is applied after t=0.



STORAGE TIME

During the storagepd the anode voltage and current remains constant.The gate current rises depending upon the gate circuit impedance and gate applied voltage.The beginning of pd is as soon as negative gate current is applied.The end of storage pd is marked by fall in anode current and rise in voltage,what we have to do is remove the excess carriers.the excess carriers are removed by negative carriers.

FALL TIME

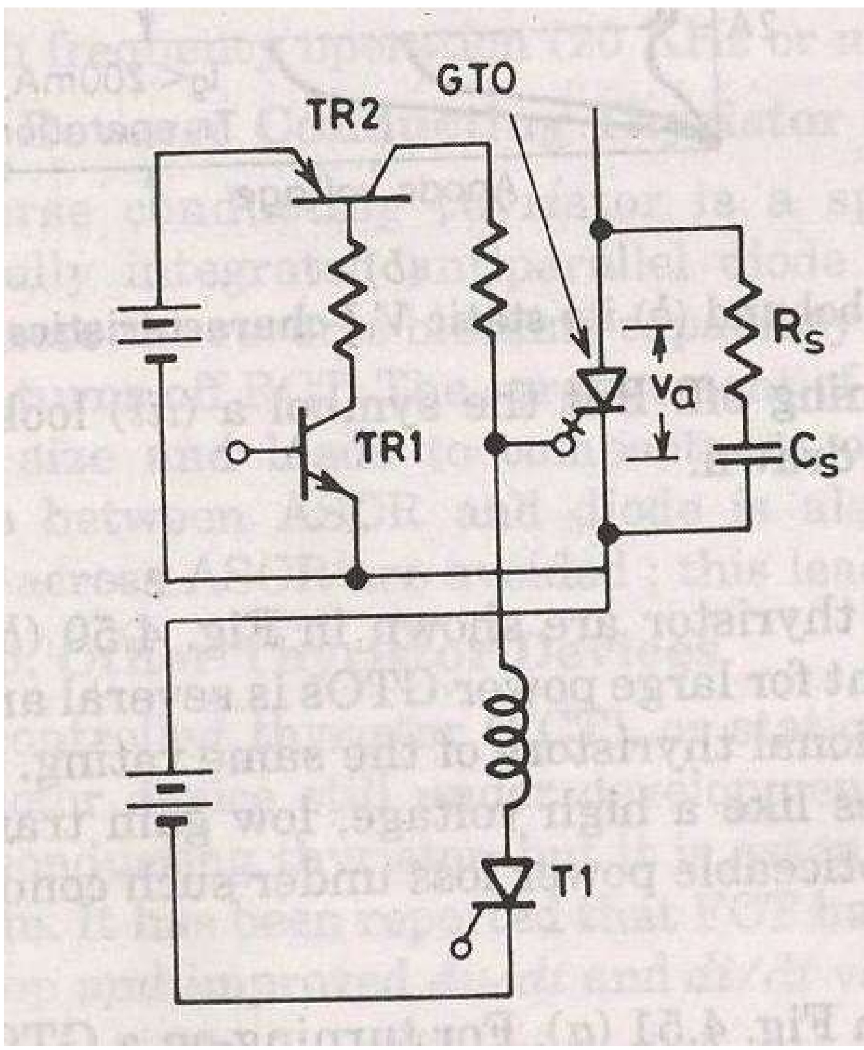
After t_s, anode current begins to fall rapidly and anode voltage starts rising.After falling to a certain value,then anode current changes its rate to fall.this time is called fall time.

SPIKE IN VOLTAGE

During the time of storage and fall timethere is achange in voltage due to abrupt current change.

TAIL TIME

During this time ,the anode current and voltage continues towards the turn off values.The transient overshoot is due to the snubber parameter and voltage stabilizes to steady state value.



2.1.3 Types, Working and Characteristics of SCR

Types of SCR

1. Standard SCR
2. Fast switching SCR
3. Light activated SCR (LASCR)
4. Gate turn-off SCR (GTO)

Working of SCR

(i) Forward Blocking Mode

- Anode positive w.r.t cathode
- No gate signal
- SCR OFF

(ii) Forward Conduction Mode

- Gate pulse applied
- SCR conducts heavily
- Remains ON even after gate removed

(iii) Reverse Blocking Mode

- Anode negative
- Very small leakage current

V–I Characteristics of SCR

Key Parameters:

- **Breakover voltage (VBO)**
- **Holding current (IH)**
- **Latching current (IL)**
- **On-state voltage drop**

2.1.4 SCR Mounting and Cooling

Need for Cooling

- SCR handles **high current and voltage**
- Excess heat reduces life and efficiency

Cooling Methods

1. Natural air cooling
2. Forced air cooling
3. Heat sink mounting
4. Liquid cooling (high power)

Mounting Types

- Stud mounted SCR
- Disc type SCR
- Module type SCR

2.2 Types of Thyristors

Device	Full Form	Key Feature
SCR	Silicon Controlled Rectifier	Unidirectional
LASCR	Light Activated SCR	Triggered by light
SCS	Silicon Controlled Switch	Two gate control
GTO	Gate Turn Off Thyristor	Turn OFF by gate
UJT	Unijunction Transistor	Triggering device
PUT	Programmable UJT	Programmable firing
DIAC	Diode AC switch	Bidirectional
TRIAC	Triode AC switch	AC control

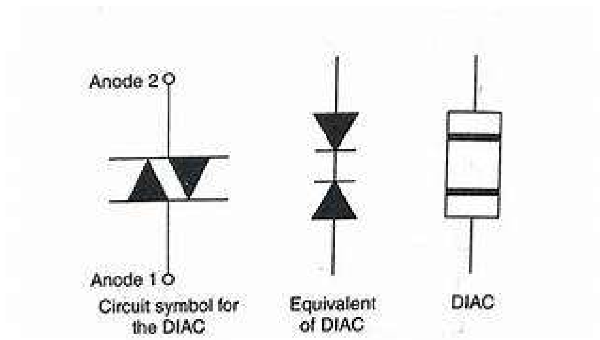
2.3 Thyristor Family Devices

These devices belong to the thyristor group but differ in **structure, triggering and applications**.

2.3.1 Symbol and Construction

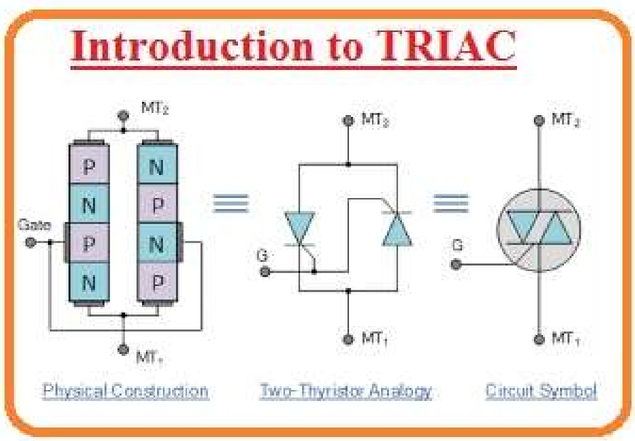
DIAC

- Two-terminal device
- Symmetrical structure
- No gate terminal



TRIAC

- Three terminals: MT1, MT2, Gate
- Equivalent to two SCRs in anti-parallel

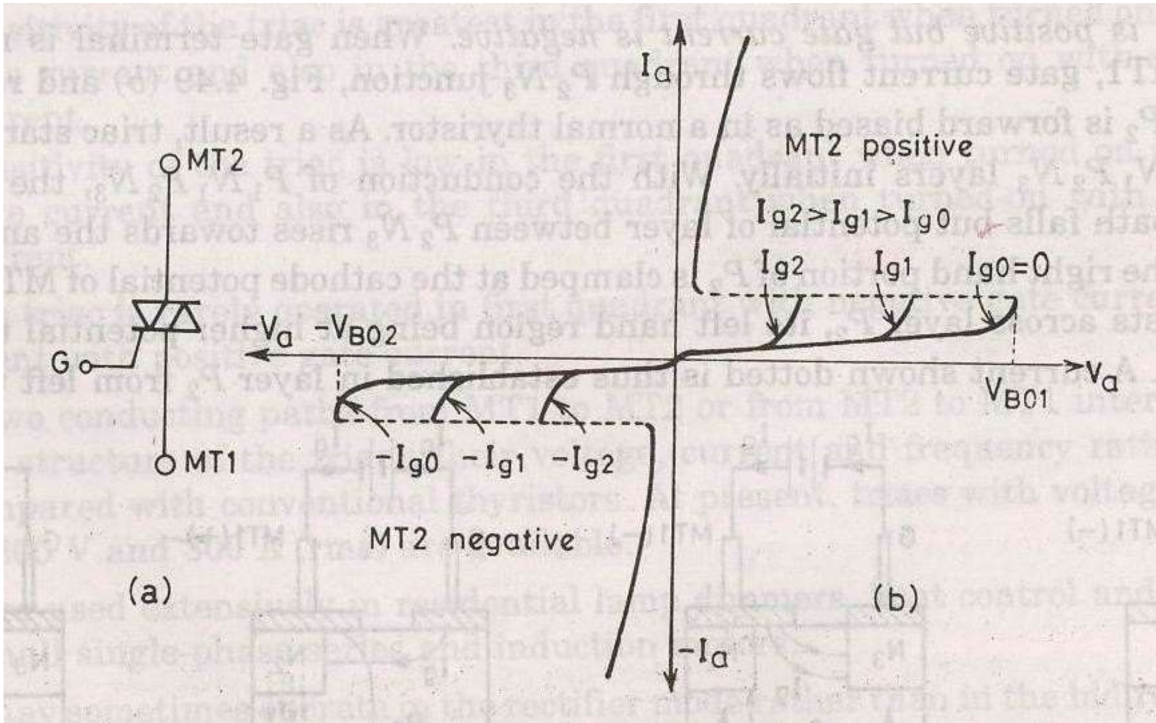


THE TRIAC

As SCR is a unidirectional device,the conduction is from anode to cathode and not from cathode to anode. It conducts in both direction.It is a bidirectional SCR with three terminal.

TRIAC=TRIODE+AC

Here it is considered to be two SCRS connected in anti parallel.As it conducts in both direction so it is named as MT1,MT2 and gate G.



SALIENT FEATURES

1. Bi directional triode thyristor
2. TRIAC means triode that works on ac
3. It conduct in both direction
4. It is a controlled device

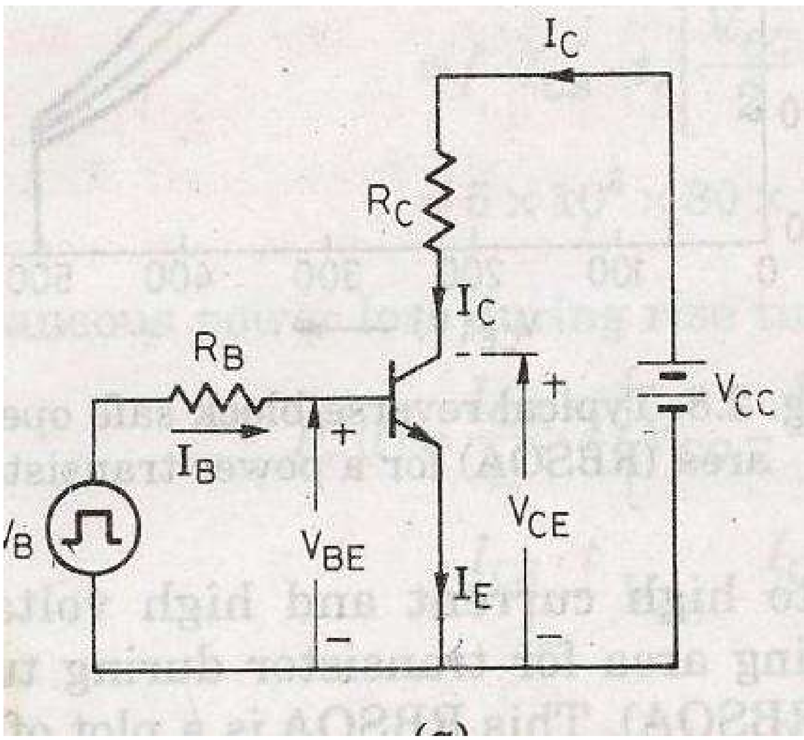
5. Its operation is similar to two devices connected in anti parallel with common gate connection.

6. It has 3 terminals MT1,MT2 and gate G

Its use is control of power in ac.

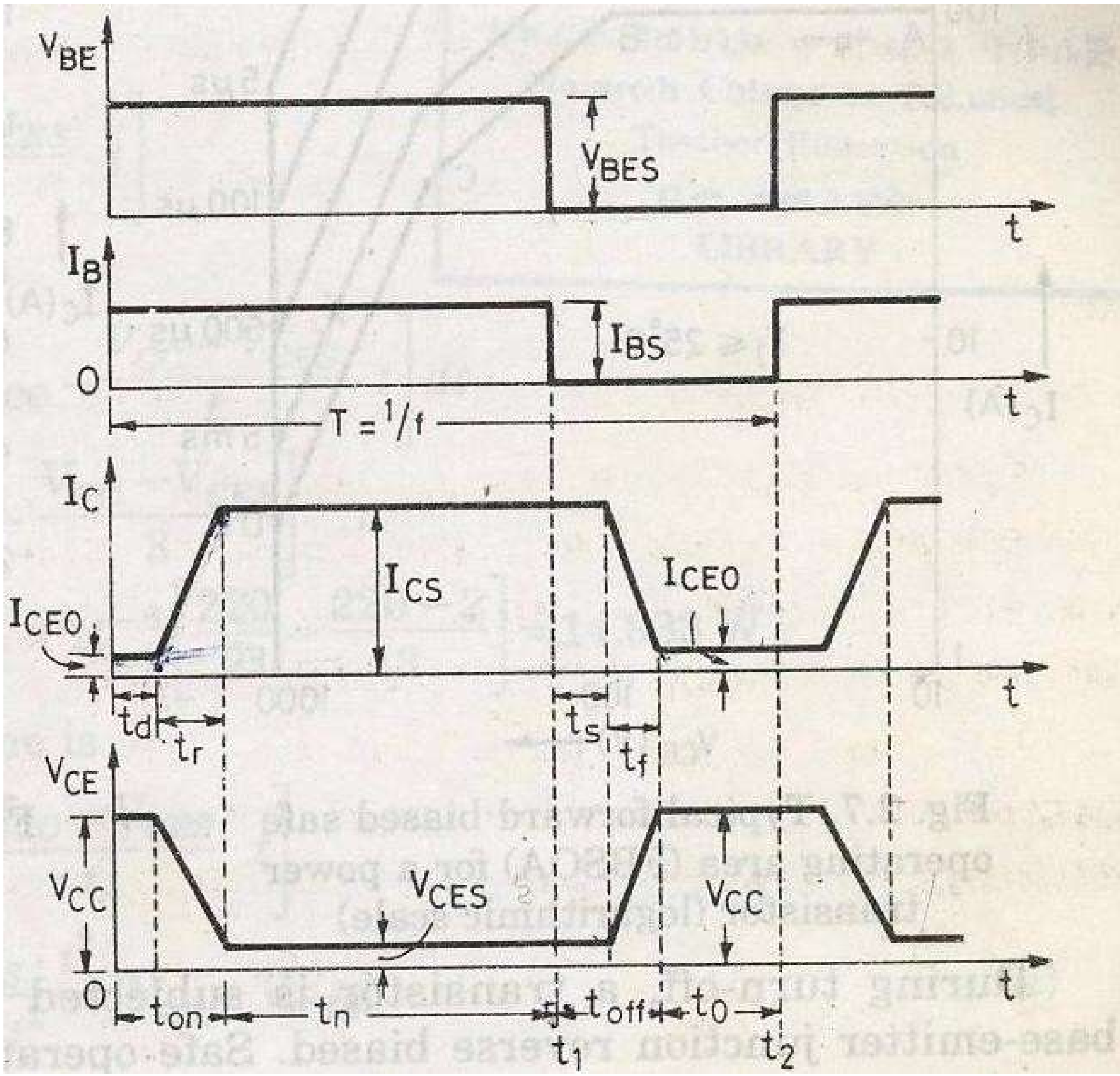
POWER BJT

Power BJT means a large voltage blocking in the OFF state and high current carrying capability in the ON state. In most power application, base is the input terminal. Emitter is the common terminal. Collector is the output terminal.



SIGNAL LEVEL OF BJT

n+ doped emitter layer ,doping of base is more than collector.Depletion layer exists more towards the collector than emitter



POWER BJT CONSTRUCTION

Collector–Emitter and Collector–Base Ratings

- **V_{CEO}**: Maximum collector–emitter voltage with **base open**
- **V_{CBO}**: Collector–base breakdown voltage with **emitter open**

These voltages represent the **maximum safe operating voltages** of the transistor.

PRIMARY BREAKDOWN

Primary breakdown is due to **avalanche breakdown** of the **collector–base (C–B) junction**.

- Breakdown voltage depends on the **width of the depletion region**
- A **thin base** gives:
  - High current gain
  - Lower breakdown voltage
- A **thicker base** gives:
  - Higher breakdown voltage
  - Lower current gain

➡️ Hence, a **compromise** is made between **gain** and **breakdown voltage**.

DOPING LEVELS IN POWER BJT

1. **Emitter**: Heavily doped
2. **Base**: Moderately doped
3. **Collector drift (n^-) region**: Lightly doped
4. **Collector contact (n^+)**: Heavily doped

DRIFT REGION THICKNESS

- Determines **breakdown voltage**
- Thicker drift region → higher breakdown voltage
- Thinner drift region → lower breakdown voltage

SECONDARY BREAKDOWN

Secondary breakdown occurs due to **localized heating** caused by **high power dissipation**.

- Leads to **hot spots**
- Can permanently damage the transistor
- Occurs even when voltage and current are within limits

PHYSICS OF BJT OPERATION (ACTIVE REGION)

- **B–E junction**: Forward biased
- **C–B junction**: Reverse biased
- Electrons injected from **emitter to base**
- Holes injected from **base to emitter**
- Collector drift region is **important mainly in switching operation**

QUASI-SATURATION

- Initially, transistor operates in **active region**
- Increasing base current increases collector current
- Voltage drop across collector load increases
- **C–E voltage decreases**
- Voltage across collector drift region increases
- Reverse bias of C–B junction reduces
- Eventually, C–B junction becomes **forward biased**
- Excess carriers accumulate in drift region
- Device enters **quasi-saturation**

➡️ Quasi-saturation increases **storage time** and **switching losses**

GATE TRIGGERING METHODS OF SCR

Types

The different methods of gate triggering are:

- **Resistance (R) triggering**
- **Resistance–Capacitance (RC) triggering**
- **UJT triggering**

RESISTANCE TRIGGERING

Circuit Description

- **R_1**: Limits the gate current of the SCR
- **R_2**: Variable resistor used to control the firing angle
- **R**: Stabilizing resistor
- **Diode D**: Prevents negative voltage from reaching the SCR gate

This is the **simplest firing circuit**, but it provides **limited control** over the firing angle.

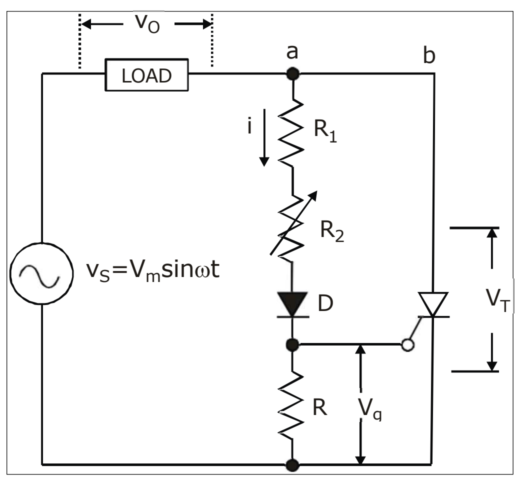
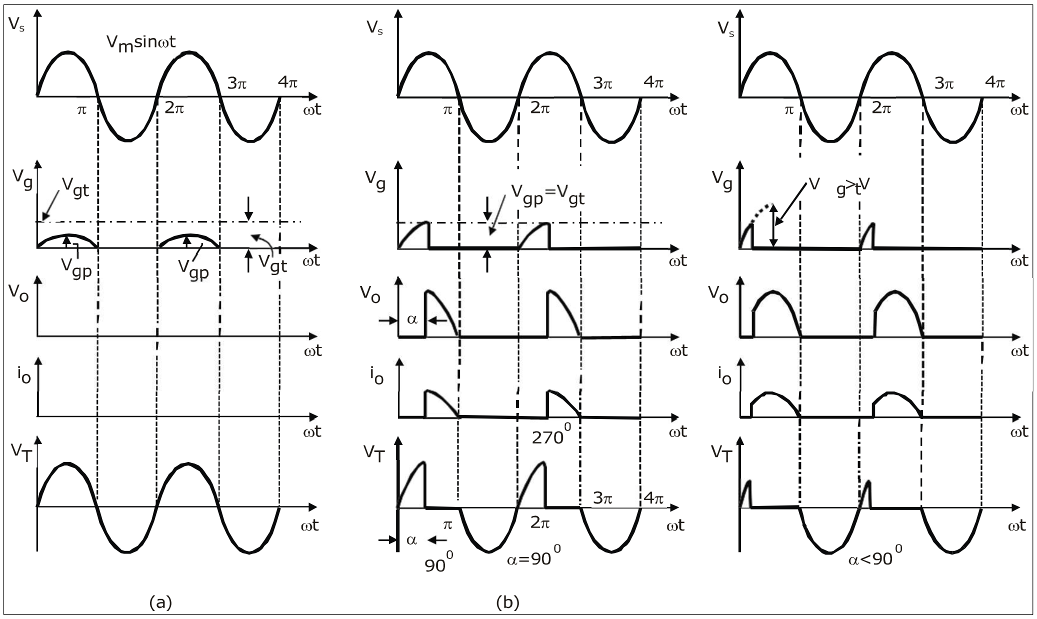


Fig: Resistance firing circuit



Vs
Vmsinωt
π
2π
3π
4π
ωt
Vg
Vgt
Vgp
Vgp
Vgt
Vo
io
VT
Vgp=Vgt
α
270⁰
90⁰
α=90⁰
α<90⁰
(a)
(b)

—

Fig. Resistance firing of an SCR in half wave circuit with dc load

Operation:

Case 1: R2 very large

Gate voltage $V_{gp} < V_{gt}$ → SCR does not trigger.

Case 2: R2 adjusted such that $V_{gp} = V_{gt}$

SCR triggers at $\omega t = 90°$.

Case 3: R2 small

SCR triggers earlier than 90°.

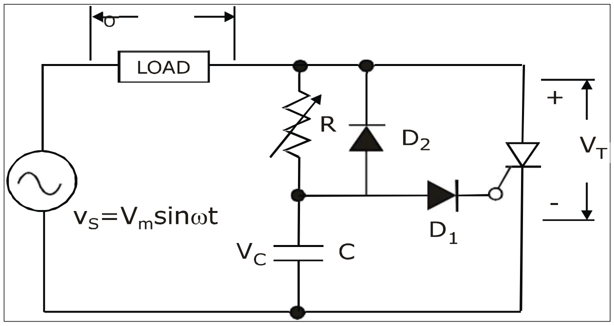
Firing angle:

$\alpha = \sin^{-1}(V_{gt} / V_{gp})$

Gate peak voltage:

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

Resistance Capacitance Triggering



A. RC Half-Wave Triggering

Circuit Description:
• Capacitor C provides phase shift.
• Diode D1 prevents negative gate voltage.
• Diode D2 allows capacitor discharge.

Operation:
• During negative half cycle, capacitor charges to −Vm.
• During positive half cycle, capacitor charges towards Vgt.
• SCR triggers when VC ≥ Vgt.

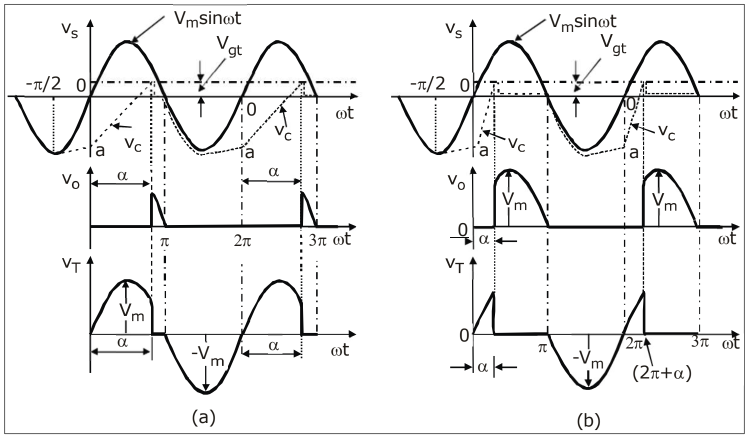
Effect of Resistance:
• Large R → Slow charging → Large firing angle → Low output voltage.
• Small R → Fast charging → Small firing angle → High output voltage.

Design Equation:
SCR fires when:
$Vs \geq Igt\ R + Vgt + Vd$

Therefore:
$R \leq (Vs - Vgt - Vd) / Igt$

For maximum firing angle:
$RC \geq 1.3T$

Fig.: RC half-wave trigger circuit

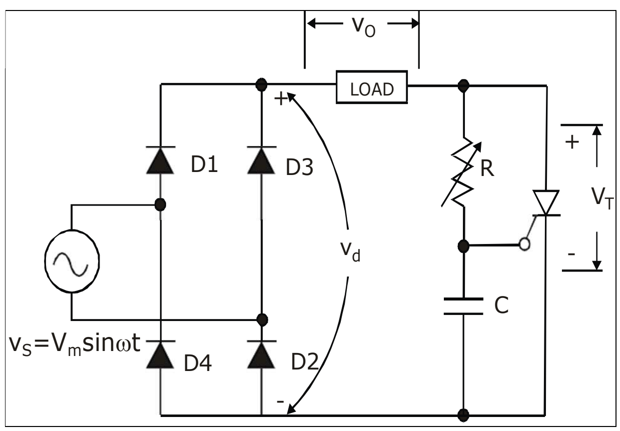


v_s
$V_m \sin\omega t$
V_{gt}
$-\pi/2$
0
ωt
v_c
a
v_o
α
π
2π
3π
v_T
V_m
$-V_m$
$(2\pi+\alpha)$
(a)
(b)

Fig: Waveforms for RC half-wave trigger circuit

A. RC Full Wave

A simple circuit giving full wave output is shown in figure below. In this circuit the initial voltage from which the capacitor 'C' charges is essentially zero. The capacitor 'C' is reset to this voltage by the clamping action of the thyristor gate. For this reason the charging time constant RC must be chosen longer than for half wave RC circuit in order to delay the triggering. The RC value is empirically chosen as $RC \geq \frac{50T}{2}$. Also $R \leq \frac{v_s - V_{gt}}{I_{gt}}$.



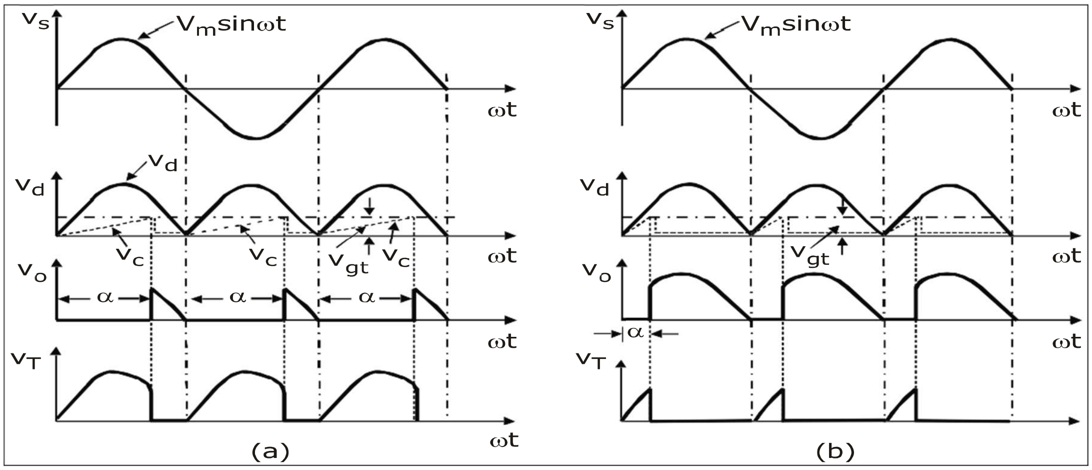


Fig : RC full-wave trigger circuit Fig: Wave-forms for RC full-wave trigger circuit

(a) High value of R **(b) Low value of R**

Numerical Problem:

Given:
Supply voltage Vs = 220 V (rms), 50 Hz
Vgt(min) = 5 V
Igt(max) = 30 mA
Diode drop VD ≈ 0.7 V

Peak voltage:
$Vm = 220\sqrt{2} = 311$ V

Resistance:
$R \leq (311 - 5 - 0.7) / 0.03$
$R \leq 10.18$ kΩ

Choose:
R = 7.1 kΩ

Time period:
T = 1 / 50 = 0.02 s

$RC \geq 1.3T = 0.026$

Capacitance:
$C \geq 0.026 / 7100 \approx 3.66$ μF

Advantages of RC Triggering:
• Wide firing angle control

• Smooth triggering
• Improved performance over R triggering

Applications:
• Controlled rectifiers
• AC voltage controllers
• Speed control of motors

UJT

UJT is highly efficient switch. The switching times is in the range of nanoseconds. Since UJT exhibits negative resistance characteristics it can be used as relaxation oscillator. The circuit diagram is as shown with R_1 and R_2 being small compared to R_{B1} and R_{B2} of UJT.

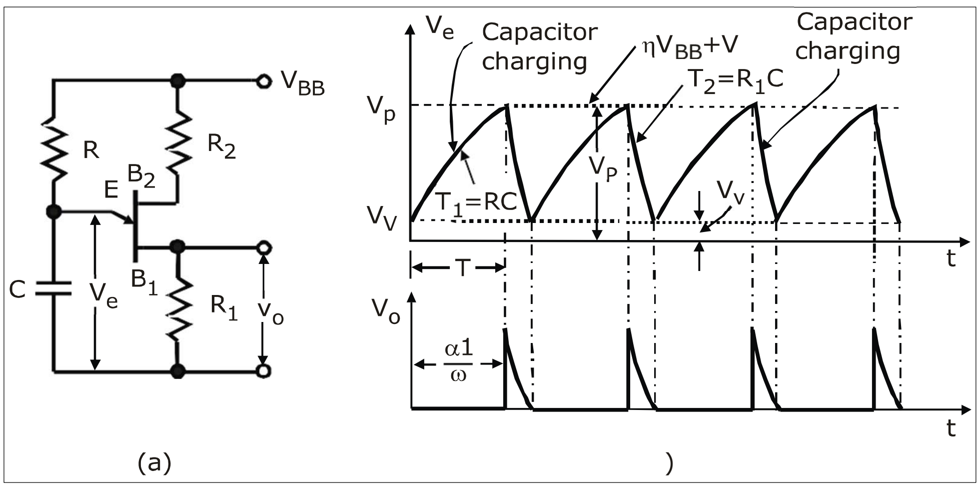


Fig: UJT oscillator (a) Connection diagram and (b) Voltage waveforms

UJT OPERATION

When the **inter-base voltage V_{BB}** is applied across terminals **B2–B1**, and the emitter is left open, the UJT remains in the **OFF state**.

The capacitor **C** starts charging **exponentially** through resistor **R** towards the supply voltage V_{BB}.

- During this charging period, the **emitter-base junction is reverse biased**
- Hence, the UJT behaves like an **open circuit**

Charging Time Constant

$\tau 1=RC$

Turn-ON Condition of UJT

As the capacitor charges, the **emitter voltage V_E** increases.

When the emitter voltage reaches the **peak voltage V_P**, given by:

$V_P = \eta V_{BB} + V_D$

where:

- η = intrinsic standoff ratio
- $V_D \approx 0.7$ V (diode drop)

➡️ At this point:

- The **emitter–base junction becomes forward biased**
- UJT **turns ON**
- Emitter current increases rapidly

Discharging Process

Once the UJT turns ON:

- The capacitor **C discharges rapidly** through **R_{B1}**
- The discharge time constant is:

$\tau 2 = R_{B1} C$

Since $R_{B1} \ll R$

$\tau 2 \ll \tau 1$

Thus, **discharge time is much smaller** than charging time.

Turn-OFF Condition

As the capacitor discharges, the emitter voltage decreases.

When the emitter voltage reaches the **valley voltage V_V**:

- UJT turns **OFF**
- Emitter current drops to valley current I_V

The capacitor again starts charging towards V_{BB} and the cycle repeats.

➡️ This repetitive ON–OFF action produces **relaxation oscillations**.

Effect of Resistance R on Firing Angle

- **Small R** → Capacitor charges faster → V_P reached earlier
  → **Small firing angle**
- **Large R** → Capacitor charges slowly → Delay in reaching V_P
  → **Larger firing angle**

Thus, **firing angle of SCR is controlled by R**.

EXPRESSION FOR PERIOD OF OSCILLATION

Assumption:

Charging time ≫ discharging time

Voltage across capacitor during charging:

$VC=V_{BB}+(V_V-V_{BB})e^{(-t/RC)}$

At:

- $t=T$
- $V_C=V_P$

Substitute:

$VP= V_{BB}+(V_V-V_{BB})e^{(-T/RC)}$

Rearranging:

$(V_{BB}-V_P)/(V_{BB}-V_V)=e^{(-T/RC)}$

Taking natural logarithm:

$T=RC\ln((V_{BB}-V_V)/(VBB-VP))$

Approximation

Since:

$V_V \ll V_{BB}$

$T\approx RC\ln(V_{BB}/V_{BB}-V_P)$

$T=RC\ln(1/1-VP/VBB)$

But:

$V_P=\eta V_{BB}$ (neglect V_D)

$T=RC\ln(1/1-\eta)$

This is the **standard UJT oscillator time period equation**.

DESIGN OF UJT OSCILLATOR

Limits on Resistor R

Upper Limit of R (Turn-ON Condition)

For UJT to turn ON:

$V_{BB} - I_P R > V_P$

$R < V_{BB} - V_P / I_P$

If R is too large, the load line will **not intersect the peak point**, and UJT will not trigger.

Lower Limit of R (Turn-OFF Condition)

At valley point:

$V_{BB} - I_V R < V_V$
$R > V_{BB} - V_V / I_V$

If R is too small, the UJT will **remain ON continuously**.

Practical Range of R

$3 k\Omega \leq R \leq 3 M\Omega$

Supply Voltage Range

$10\ V \leq V_{BB} \leq 35\ V$

Trigger Pulse Width

The width of the triggering pulse applied to the SCR gate is:

$tg = R_{B1} C$

Typical Values of Inter-Base Resistances

- $R_{B1} \approx$ **100 Ω to 1 kΩ**
- $R_{B2} \geq$ **100 Ω**

Approximate estimation:

$$R_{B2} \approx V_{BB} / I_{B2}$$

PROBLEM 1

Design of UJT Triggering Circuit for SCR

Given

- Minimum SCR gate triggering voltage = **6.2 V**
- Intrinsic standoff ratio:

  $\eta=0.66$

- Peak current:

  $I_p=0.5$ mA

- Valley current:

  $I_v=3$ mA

- Interbase resistance:

  $R_{B1}+R_{B2}=5\ k\Omega$

- Leakage current:

  $I_{leakage}=3.2$ mA

- Peak voltage:

  $V_p=14$ V

- Valley voltage:

  $V_v=1$ V

- Oscillation frequency:

  $f=2$ kHz

- Timing capacitor:

  $C=0.04\ \mu F$

Step 1: Time Period

T=1/f=1/2×10^3= 0.5ms

Step 2: Timing Resistance RRR

For a UJT relaxation oscillator:

$T=RC\ln(1/1-\eta)$

$$0.5\times 10\hat{}(-3)=R\times 0.04\times 10\hat{}(-6)\times ln\left(\frac{1}{1-0.66}\right)$$

$\ln(1/0.34)=1.079$

$R=0.5\times10\hat{}(-3)/0.04\times10\hat{}(-6)\times1.079$

$R\approx11.6k\Omega$

Step 3: Interbase Voltage V_{BB}

Peak voltage relation:

$Vp=\eta V_{BB}+V_D$

Assume diode drop:

VD=0.8V
14=0.66VBB+0.8
$V_{BB=}13.2/0.66$
$V_{BB}=20V$

Step 4: Calculation of R2

$R_2=0.7(R_{B1}+R_{B2})/\eta V_B$
$R_2=0.7\times5000/0.66\times20$
$R_2\approx265\Omega$

Step 5: Calculation of R1

Using leakage current:

VBB=Ileakage(R1+R2+RB1+RB2)

$20=3.2\times10\hat{}(-3)(R1+265+5000)$

$R1=(20/(3.2\times10\hat{}(-3)))-5265$

Step 6: Maximum Charging Resistance $R_{C(max)}$

$R_{C(max)} = (V_{BB} - Vp)/I_p$
$R_{C(max)} = (20-14)/(0.5\times10^{(-3)})$
$R_{C(max)}$ **≈12 kΩ**

Step 7: Minimum Charging Resistance $R_{C(min)}$:

$R_{C(min)} = (V_{BB} - V_v)/ Iv$

$R_{C(min)} = (20-1)/(3\times10^{(-3)})$

$R_{C(min)} = 6.33\ k\Omega$

2.3.2 Operating Principle

DIAC

- Remains OFF until **breakover voltage**
- Used for triggering TRIAC

TRIAC

- Conducts in **both half cycles**
- Gate signal can be positive or negative

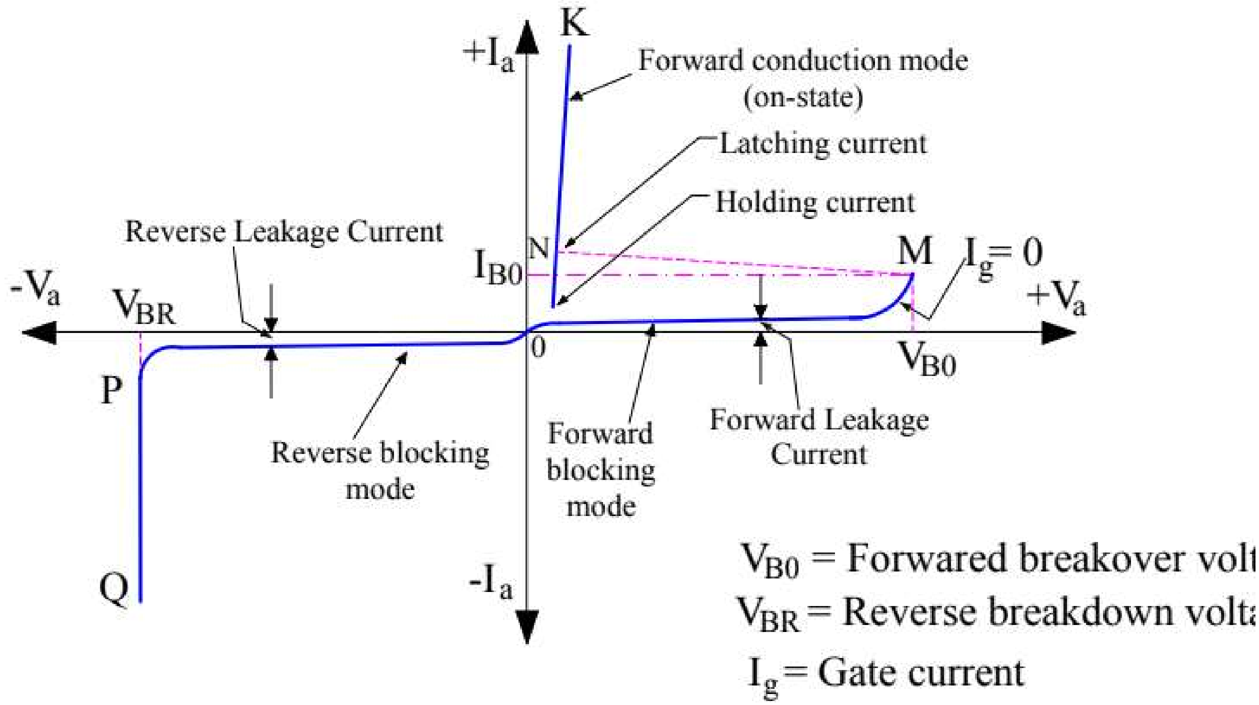
UJT

- Works on **negative resistance principle**
- Used in relaxation oscillators

2.3.3 V–I Characteristics

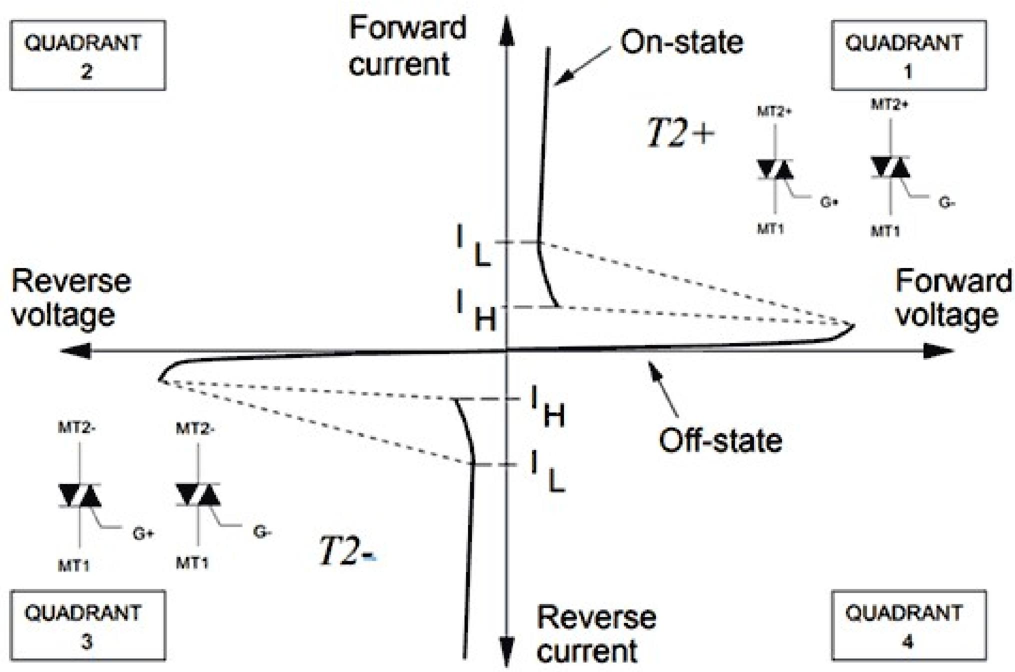
SCR

- Unidirectional
- Latching and holding current present



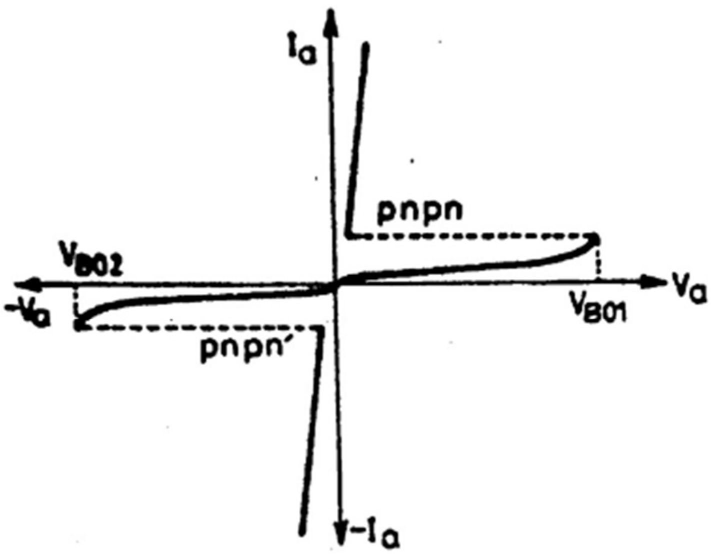
TRIAC

- Bidirectional characteristic
- Four quadrants of operation



DIAC

- Symmetrical V–I curve
- Same breakover voltage in both directions



DIAC V-I characteristics curve

2.4 Protection Circuits

Thyristors are sensitive to **over-voltage, over-current, and high dv/dt**.

2.4.1 Over-Voltage Protection

Methods:

- Metal Oxide Varistor (MOV)
- Zener diode
- RC snubber

Purpose:

- Prevents false triggering
- Protects junctions

2.4.2 Over-Current Protection

Methods:

- Fast acting fuse
- Circuit breaker
- Current limiting reactor

Purpose:

- Prevents SCR damage due to surge current

2.4.3 Snubber Circuit
RC Snubber

- Series combination of **R and C**
- Connected across SCR

Functions:

- Limits **dv/dt**
- Prevents false turn ON
- Absorbs voltage spikes

2.4.4 Crowbar Circuit

- Uses **SCR + Zener diode**
- Connected across load
- When voltage exceeds limit, SCR shorts supply
- Fuse blows and protects load

Applications:

- Power supplies
- Sensitive electronic circuits

3. Turn-ON and Turn-OFF Methods of Thyristors

A thyristor (SCR) cannot turn ON or OFF like a transistor. Special **triggering and commutation methods** are required.

3.1 SCR Turn-ON Methods

An SCR can be turned ON by making **junction J2 conduct**. The following methods are used.

3.1.1 High Voltage (Forward Breakover / Thermal) Triggering Principle:

- SCR is forward biased
- Applied voltage exceeds **breakover voltage (VBO)**
- Junction J2 breaks down

Features:

- No gate signal required
- Excess heat is generated

Disadvantages:

- Not safe
- Poor control
- Device damage possible

Applications:

- Rarely used in practice

3.1.2 Illumination Triggering (LASCR)
Principle:

- SCR is turned ON by **light radiation**
- Light increases charge carriers in junction J2

Features:

- No electrical connection to gate
- High isolation

Advantages:

- Safe triggering
- Suitable for high voltage circuits

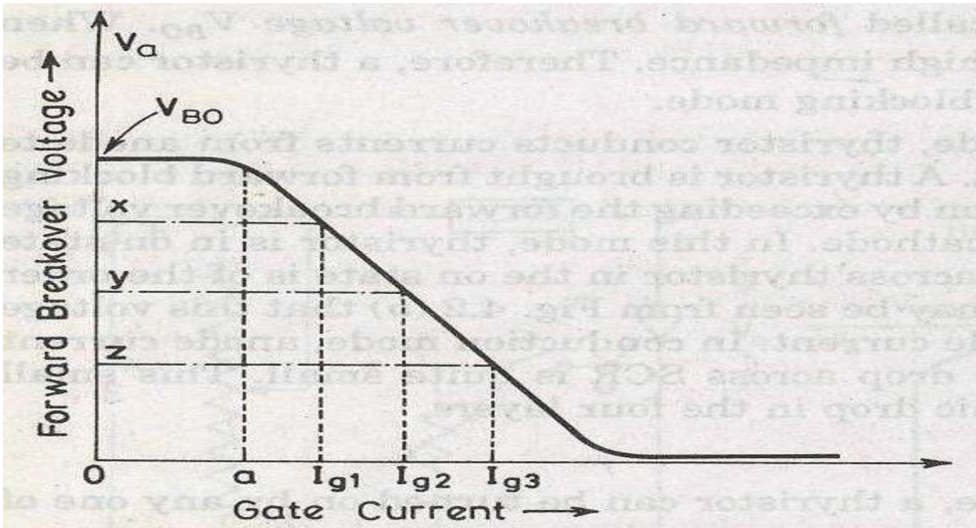
Applications:

- High voltage DC transmission
- Industrial controls

3.1.3 dv/dt Triggering

Principle:

This is a turning ON method but it may lead to destruction of SCR and so it must be avoided.



When SCR is forward biased, junction J_1 and J_3 are forward biased and junction J_2 is reversed biased so it behaves as if an insulator is place between two conducting plate. Here J_1 and J_3 acts as a conducting plate and J_2 acts as an insulator. J_2 is known as junction capacitor. So if we increase the rate of change of forward voltage instead of increasing the magnitude of voltage. Junction J_2 breaks and starts conducting. A high value of changing current may damage the SCR. So SCR may be protected from high dv/dt

$$q = cv$$

$$I_a = c\,(dv/dt)$$

- Capacitive current flows through J2
- SCR turns ON without gate signal

Disadvantage:

- False triggering

Prevention:

- RC snubber circuit

3.1.4 Gate Triggering (Most Common Method)
Principle:

This is the simplest, reliable and efficient method of firing the forward biased SCRs. First SCR is forward biased. Then a positive gate voltage is applied between gate and cathode. In practice the transition from OFF state to ON state by exceeding V_{BO} is never employed as it may destroy the device. The magnitude of V_{BO}, so forward breakover voltage is taken as final voltage rating of the device during the design of SCR application.

First step is to choose a thyristor with forward breakover voltage (say 800V) higher than the normal working voltage. The benefit is that the thyristor will be in blocking state with normal working voltage applied across the anode and cathode with gate open. When we require the turning ON of a SCR a positive gate voltage between gate and cathode is applied. The point to be noted that cathode n- layer is heavily doped as compared to gate p-layer. So when gate supply is given between gate and cathode gate p-layer is flooded with electron from cathode n-layer. Now the thyristor is forward biased, so some of these electron reach junction J_2 .As a result width of J_2 breaks down or conduction at J_2 occur at a voltage less than V_{BO} .As I_g increases V_{BO} reduces which decreases then turn ON time. Another important point is duration for which the gate current is applied should be more then turn ON time. This means

that if the gate current is reduced to zero before the anode current reaches a minimum value known as holding current, SCR can't turn ON.

In this process power loss is less and also low applied voltage is required for triggering.

- Positive gate current is applied
- Reduces width of depletion layer
- SCR turns ON

Gate Signals:

- DC triggering
- AC triggering
- Pulse triggering (preferred)

Advantages:

- Accurate control
- Low power
- Safe operation

3.2 Gate Trigger Circuits

Gate trigger circuits provide **controlled gate pulses** to SCR.

3.2.1 Resistance (R) and Resistance-Capacitance (RC) Trigger Circuits

(a) Resistance Triggering Circuit

- Gate current controlled using variable resistor
- Simple and cheap

Disadvantages:

- Limited firing angle control
- Not suitable for high power

(b) RC Triggering Circuit

- Uses resistor and capacitor
- Phase angle control achieved

Working:

- Capacitor charges gradually
- When gate voltage reaches threshold → SCR turns ON

Advantages:

- Wide firing angle control
- Smooth control

3.3 SCR Triggering Using UJT

Principle:

- UJT works as a **relaxation oscillator**
- Generates sharp trigger pulses

Working:

- Capacitor charges through resistor
- When emitter voltage reaches peak voltage → UJT conducts
- Pulse produced across base resistor
- Pulse applied to SCR gate

Advantages:

- Stable firing angle
- Sharp triggering pulses

Applications:

- AC voltage controllers
- Controlled rectifiers

3.4 PUT: Relaxation Oscillator and Synchronized UJT Circuit
PUT (Programmable Unijunction Transistor)

Relaxation Oscillator:

- PUT turns ON when emitter voltage exceeds reference voltage
- Generates triggering pulses

Synchronized UJT Circuit:

- Synchronization with AC supply
- Uniform firing angle

Advantages:

- Better control than UJT
- Programmable firing voltage

3.5 Pulse Transformer and Opto-Coupler Based Triggering
Pulse Transformer Triggering

- Transfers gate pulses using transformer
- Provides isolation between control and power circuit

Advantages:

- Electrical isolation
- Noise immunity

Opto-Coupler Triggering

- Uses LED and phototransistor
- Light transfers signal

Advantages:

- Complete electrical isolation
- Safe and reliable
- Used in modern circuits

3.6 SCR Turn-OFF Methods (Commutation)

Turning OFF an SCR is called **commutation**.

Condition for Turn-OFF:

- Anode current < **Holding current (IH)**

3.6.1 Class A – Series Resonant Commutation
Principle:

- LC circuit connected in series with SCR
- Current naturally becomes zero

Features:

- Load current oscillates
- Used in low power circuits

3.6.2 Class B – Shunt Resonant Commutation
Principle:

- LC circuit connected parallel to SCR
- Reverse current is applied

Features:

- Faster than Class A
- Requires commutation components

3.6.3 Class C – Complementary Symmetry Commutation
Principle:

- Uses two SCRs
- One SCR turns OFF the other

Applications:

- Inverters
- Choppers

3.6.4 Class D – Auxiliary Commutation
Principle:

- Auxiliary SCR used
- Reverse voltage applied to main SCR

Features:

- Reliable
- High speed commutation

3.6.5 Class E – External Pulse Commutation

Principle:

- External pulse source provides reverse current
- Independent of load

Applications:

- Special industrial circuits

3.6.6 Class F – Line (Natural) Commutation

Principle:

- AC supply current naturally reaches zero
- SCR turns OFF automatically

Applications:

- AC rectifiers
- AC controllers

4. Phase Controlled Rectifiers

Phase controlled rectifiers convert **AC power into controlled DC power** using **thyristors (SCRs)**. By varying the **firing angle**, the average DC output voltage can be controlled.

4.1 Phase Control

Firing Angle (α)

- Angle between **zero crossing of AC input voltage** and **instant of SCR triggering**
- Measured in electrical degrees (°)
- Range: **0° to 180°**

Conduction Angle (θ)

- Angle during which SCR conducts current
- Depends on **firing angle** and **load type**

$$\theta = \pi - \alpha \quad (\text{for R load})$$

Key Points

- Small $\alpha \rightarrow$ high DC output
- Large $\alpha \rightarrow$ low DC output
- Control is achieved by delaying gate pulses

4.2 Single Phase Controlled Rectifiers

Types

1. Half-controlled rectifier
2. Full-controlled rectifier
3. Mid-point controlled rectifier

Each is studied with:

- **R load**
- **RL load**

4.2.1 Single Phase Half-Controlled Rectifier

Circuit Description

- A **single-phase half-controlled rectifier** uses:
  - **One SCR (T)** and
  - **One diode (D)**
- The AC supply is connected to the SCR–diode combination and the **load**.
- Only **one half cycle is controlled** (SCR side), while the other half cycle is **uncontrolled** (diode side).

Working with R Load (Resistive Load)

Positive Half Cycle (0 to π)

- SCR is **forward biased**.
- When a gate pulse is applied at **firing angle α**, the SCR turns ON.
- SCR conducts from **α to π**.
- Load voltage follows the input sine wave during this interval.

Negative Half Cycle (π to 2π)

- SCR is reverse biased and remains OFF.
- Diode becomes **forward biased automatically**.
- Diode conducts for the entire negative half cycle.
- Load current flows in the same direction.

✔ Output is **unidirectional (DC)**.

DC Output Voltage (R Load)

✅ Correct Average Output Voltage Equation

$V_{dc}=(V_m/2\pi)(1+\cos\alpha)$

Where:

- Vdc = Average DC output voltage
- Vm = Peak value of AC input voltage
- α = Firing angle of SCR

Special Cases

- **α = 0°** → Maximum output voltage
- **α = 90°** → Reduced output voltage
- **α = 180°** → Output voltage is zero

Output Current (R Load)

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

- Output current is **in phase** with output voltage.
- Current becomes zero at the end of each half cycle.

Waveforms

- **Input voltage**: Sinusoidal AC
- **Gate pulse**: Applied only in positive half cycle at angle α
- **Output voltage**:
  - Controlled positive half cycle (SCR)
  - Uncontrolled negative half cycle (diode)
- Output is **full-wave rectified but partially controlled**

Working with RL Load (Inductive Load)

- Due to inductance, **current does not fall to zero at π**.
- Energy stored in the inductor causes current to **continue flowing**.
- This can produce **high voltage spikes** across SCR when it turns OFF.
- To avoid this problem, a **freewheeling diode (FD)** is connected across the load.

Effect of Freewheeling Diode (FWD)

Purpose

- Provides an **alternate path** for inductive current

- Prevents sudden interruption of current
- Suppresses **back EMF and voltage spikes**
- Protects SCR from damage

Operation with Freewheeling Diode

- When input voltage becomes zero or negative:
  - SCR turns OFF
  - Inductive current circulates through **freewheeling diode**
- Load voltage becomes nearly **zero during freewheeling**
- Current decays gradually

Effects of Freewheeling Diode

Advantages

- Smoother output current
- Reduced ripple content
- Improved power factor
- Reduced stress on SCR
- Increased efficiency

Output Characteristics

- Load current becomes **continuous**
- Output voltage is more stable
- Better performance for inductive loads

Advantages of Half-Controlled Rectifier

- Simple circuit
- Fewer components
- Lower cost
- Better power factor than full-controlled rectifier

Disadvantages

- Output voltage control is limited
- More ripple compared to full-controlled rectifier
- Cannot operate in inverter mode

Applications

- Battery chargers

- Low-power DC drives
- Heating and lighting control
- DC power supplies

4.2.2 Single Phase Full-Controlled Rectifier Circuit
Circuit Description

- A **single-phase full-controlled rectifier** uses **four SCRs (T_1, T_2, T_3, T_4)** connected in a **bridge configuration**.
- The circuit converts **single-phase AC input** into **controlled DC output**.
- By varying the **firing angle (α)** of the SCRs, the **average DC output voltage** can be controlled.
- Since all devices are SCRs, **both positive and negative half cycles are controlled**.

Working Principle (R Load)

Positive Half Cycle (0 to π)

- AC supply makes terminal A positive with respect to B.
- **SCRs T_1 and T_2** are forward biased.
- When a gate pulse is applied at angle **α**, SCRs **T_1 and T_2 turn ON**.
- Current flows through:
  Source → T_1 → R Load → T_2 → Source
- Load voltage follows the input sine wave from **α to π**.

Negative Half Cycle (π to 2π)

- Polarity of supply reverses.
- **SCRs T_3 and T_4** are forward biased.
- When triggered at angle **π + α**, SCRs **T_3 and T_4 conduct**.
- Current flows through the load in the **same direction**.
- Output voltage again appears from **π + α to 2π**.

➡️ **Two SCRs conduct in each half cycle**.

Output Voltage Control

- The **firing angle α (0°–180°)** controls the conduction period.
- As **α increases**, the **average DC output voltage decreases**.
- For **α = 0°**, maximum output voltage is obtained.
- For **α = 90°**, average output voltage becomes zero.
- For **α > 90°**, output voltage becomes negative (in inverter mode, with appropriate load).

Correct Average Output Voltage Equation (R Load)

✅ Correct equation:

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

✔ This equation is **valid only for R load** and **continuous triggering**.

Where:

- V_{dc} = Average DC output voltage
- V_m = Maximum value of AC input voltage
- α= Firing angle

Output Current

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

Since the load is purely resistive:

- Output current is **in phase** with output voltage.
- Current becomes zero at the end of each half cycle.

Waveforms

- Input voltage: **Sinusoidal AC**
- Gate pulses: Applied at angle **α** in each half cycle
- Output voltage:
    - **Full-wave rectified**
    - Starts at **α** instead of zero crossing
    - Delay increases as α increases
- Output current waveform follows output voltage waveform

Advantages

- Output voltage can be **smoothly controlled**
- Utilizes **both half cycles** of AC input
- Higher average output voltage than half-controlled rectifier

---

Disadvantages

- Requires **four SCRs**
- Circuit complexity is higher
- Output contains **more ripple** than diode rectifier

Applications

- DC motor speed control
- Battery charging circuits

- Controlled DC power supplies
- Industrial heating control

4.2.3 Mid-Point Controlled Rectifier Circuit

- Uses **two SCRs**
- Requires **center-tapped transformer**

Working

- Each SCR conducts for one half cycle
- Output polarity same for both halves

DC Output Voltage:

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

Disadvantages

- Requires bulky transformer
- Higher cost

4.3 Bridge Controlled Rectifier Configurations

4.3.1 Full Bridge Controlled Rectifier

- Four SCRs in bridge
- No center-tapped transformer required
- High output power

Advantages

- Better transformer utilization
- High efficiency

4.3.2 Half Bridge with Common Anode

- Anodes of SCRs connected together
- Cathodes connected to load
- Used in specific converter circuits

4.3.3 Half Bridge with Common Cathode

- Cathodes of SCRs connected together
- Anodes connected to AC source
- Simplifies gate control

4.3.4 SCRs in One Arm and Diodes in Another Arm Configuration

- Two SCRs + two diodes
- Semi-controlled bridge

Features

- Reduced cost
- Less control compared to full-controlled rectifier

DC Output Voltage

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

Comparison Table

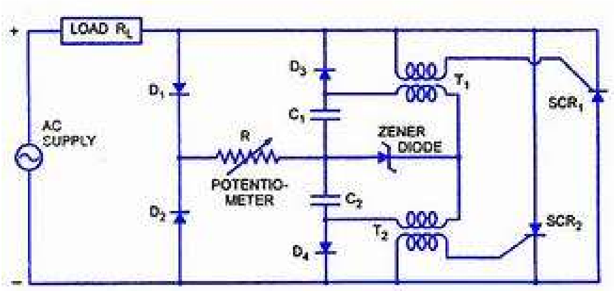
Rectifier	Devices Used	Control	Cost
Half controlled	1 SCR + diode	Limited	Low
Full controlled	4 SCRs	Full	High
Semi-controlled	2 SCR + 2 diodes	Medium	Medium
Mid-point	2 SCR + CT transformer	Full	High

Applications of Phase Controlled Rectifiers

- DC motor speed control
- Battery chargers
- Controlled power supplies
- Electroplating
- Heating control

5. Industrial Control Circuits

Industrial control circuits use **power electronic devices** such as **SCR, TRIAC, DIAC, and SMPS** to control **power, speed, voltage, and protection** in industrial and domestic applications.



Power Control Circuit Using Two SCRs

5.1 Applications of Industrial Control Circuits

5.1.1 Burglar's Alarm System

Principle

- Works on **sensor-based triggering**
- Uses SCR as a **latching switch**

Working

- Sensor (LDR, IR, or switch) detects intrusion
- Trigger signal applied to SCR gate
- SCR turns ON and remains latched
- Alarm (buzzer/siren) sounds continuously
- Reset required to turn OFF alarm

Advantages

- Simple and reliable
- Low power consumption

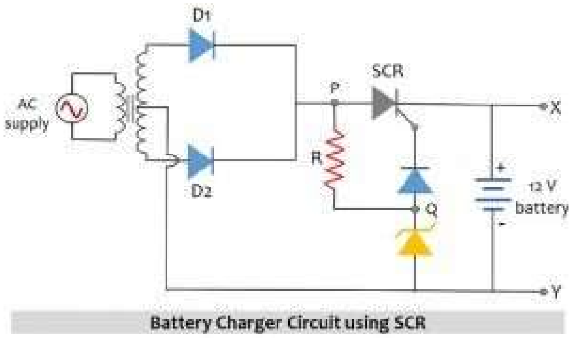
Applications

- Homes
- Banks
- Warehouses

5.1.2 Battery Charger Using SCR

Principle

- Uses **phase-controlled rectification**
- Charging current controlled by firing angle



Working

- AC supply → step-down transformer
- SCR controlled rectifier converts AC to DC
- Battery connected at output
- Charging rate controlled by adjusting gate firing angle

Advantages

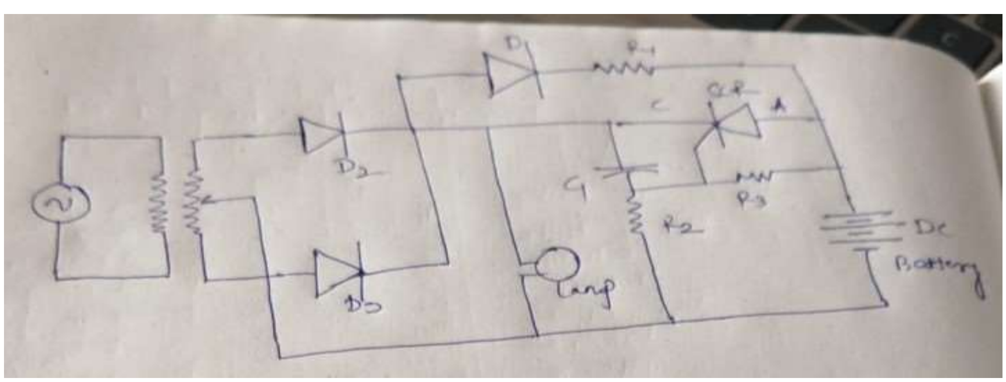
- Controlled charging
- Prevents overcharging

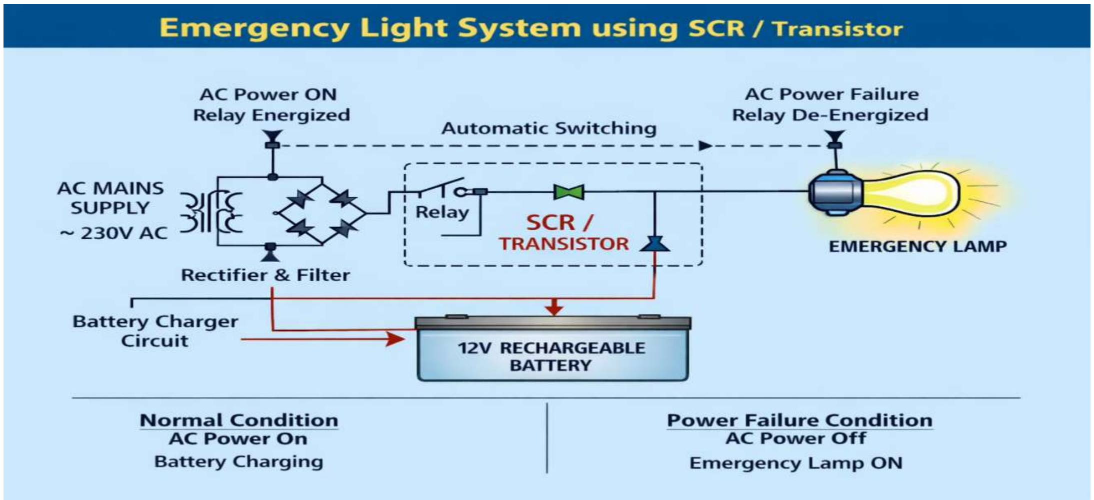
Applications

- Automotive batteries
- Inverters
- UPS batteries

5.1.3 Emergency Light System
Principle

- Automatic switching using SCR or transistor
- Uses rechargeable battery





Working

- Mains ON → battery charging
- Mains OFF → SCR triggers
- Battery supplies power to lamp
- Lamp turns OFF when mains returns

Advantages

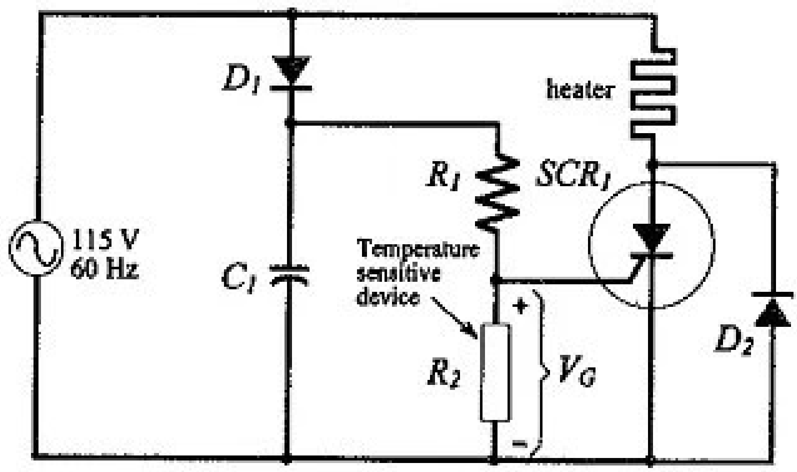
- Automatic operation
- Reliable during power failure

Applications

- Hospitals
- Schools
- Residential buildings

5.1.4 Temperature Controller Using SCR Principle

- Temperature sensor (thermistor/RTD) controls SCR firing
- SCR regulates power to heater



Working

- Sensor detects temperature
- Control circuit varies firing angle
- Power to heater increases/decreases
- Maintains desired temperature

Advantages

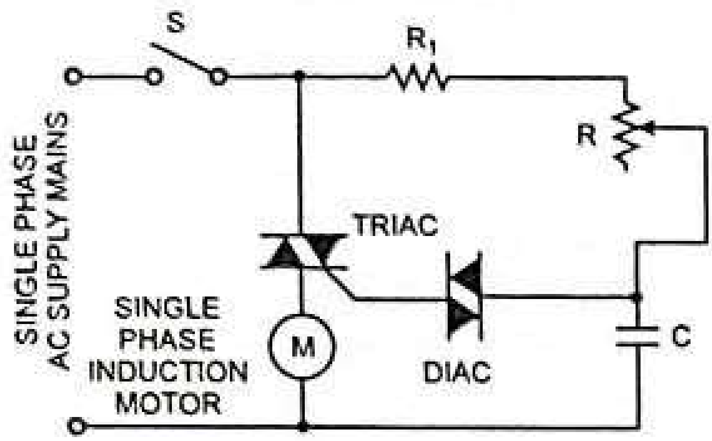
- Accurate temperature control
- High efficiency

Applications

- Industrial furnaces
- Ovens
- Process heating

5.1.5 Illumination Control / Fan Speed Control Using TRIAC Principle

- Uses **phase angle control**
- TRIAC controls both half cycles



Working

- DIAC triggers TRIAC at adjustable firing angle
- Varying firing angle controls RMS voltage
- Lamp brightness / fan speed changes

Advantages

- Smooth control
- Compact circuit

Applications

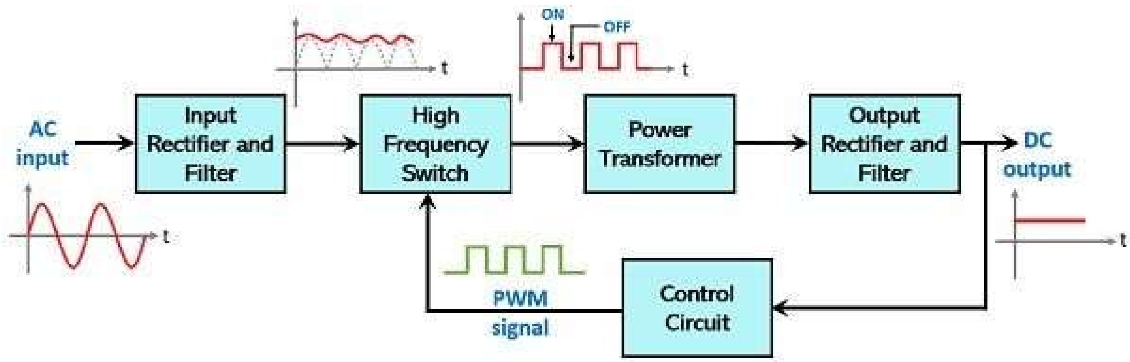
- Light dimmers
- Ceiling fan regulators
- AC motor control

5.2 SMPS (Switched Mode Power Supply)
Definition

An SMPS converts AC to DC using **high-frequency switching devices** instead of linear regulators.

Block Diagram

AC Input → Rectifier → Filter → High-frequency switch → Transformer → Rectifier → DC Output



Block diagram of Switch Mode Power Supply

Working

- AC is rectified to DC
- DC chopped at high frequency
- Voltage transformed and rectified
- Regulated DC output obtained

Advantages

- High efficiency (80–90%)
- Compact and lightweight
- Low heat loss

Applications

- Computers
- Mobile chargers
- TVs
- Industrial control systems

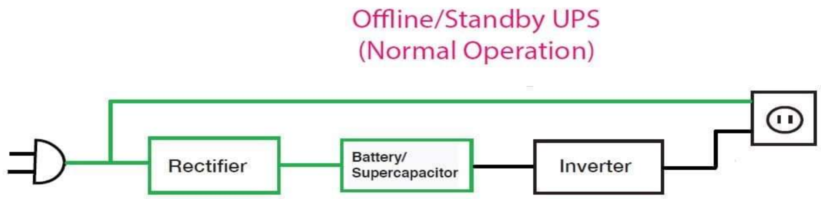
5.3 UPS (Uninterruptible Power Supply)

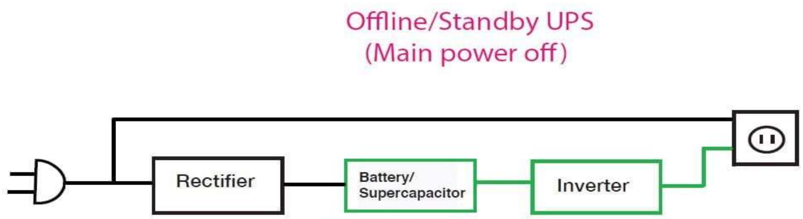
UPS provides **continuous power** during mains failure.

5.3.1 Offline UPS

Working

- Mains ON → load powered from AC
- Mains OFF → battery + inverter supply load
- Switching time: few milliseconds





Advantages

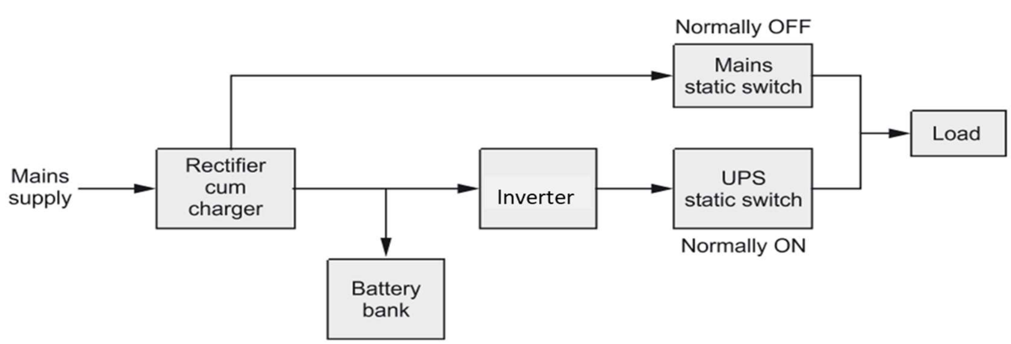
- Low cost
- Simple circuit

Disadvantages

- Small switching delay
- Not suitable for sensitive loads

5.3.2 Online UPS
Working

- Load always powered through inverter
- Battery always connected
- No switching time



Advantages

- No interruption
- High reliability

Disadvantages

- Costly
- Lower efficiency than offline UPS

Comparison of UPS

Feature	Offline UPS	Online UPS
Switching time	Present	Zero
Cost	Low	High
Power quality	Moderate	Excellent
Applications	Home, office	Hospitals, servers

5.4 SCR Based AC and DC Circuit Breakers

5.4.1 SCR Based DC Circuit Breaker Principle

- SCR acts as a **fast electronic switch**
- Turns OFF during fault using commutation circuit

Working

- Normal condition → SCR conducts
- Fault → control circuit triggers commutation
- SCR turns OFF
- Circuit disconnected instantly

Advantages

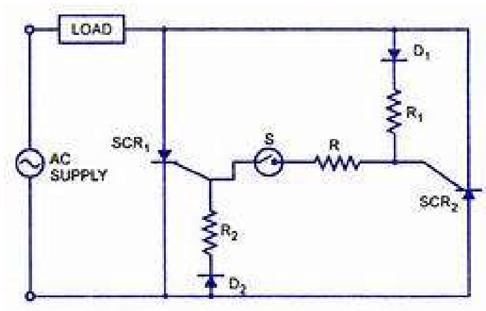
- Fast operation
- No mechanical wear

5.4.2 SCR Based AC Circuit Breaker Principle

- Uses natural (line) commutation
- SCR turns OFF at zero crossing

Working

- SCR conducts during normal operation
- Fault detected → gate pulses stopped
- SCR turns OFF at next current zero



Static AC Circuit Breaker

Advantages

- Fast and reliable
- Less arcing

Advantages of SCR Circuit Breakers

- High speed protection
- Long life
- Suitable for high power systems