Power Electronics

Power electronics circuits can be classified as

- Diode Rectifiers
- AC to DC Converter (Controlled Rectifier)
- DC to DC Converter (DC Chopper)
- AC to AC Converter (AC Voltage Regulator, cyclo-converter)
- DC to AC Converter (Inverter)
- Static switches

- Diode rectifier converts ac voltage into fixed dc voltage.
- Controlled Rectifier converts fixed A.C voltage to a variable DC voltage.
- Inverter converts a fixed a DC voltage to AC voltage of variable frequency with fixed or variable magnitude.
- Chopper converts a fixed dc voltage to a variable dc voltage.
- Cyclo converter converts input power at one frequency to output power at a attaining low frequency ac voltage.
- AC v/g controller is device which converts fixed ac v/g to variable ac v/g at same frequency.

- **Latching Current:** Latching Current is minimum I_a (anode current) that must flow through SCR to latch it into the ON state.
- **Holding current :** Holding Current is the minimum current that can flow through SCR and still hold in the on state.

- High rating SCR : $I_L = 2$ to $3\ I_H$
- low rating SCR : $I_L = 1.2$ to $1.8\ I_H$

Switching Characteristics of SCR during Turn ON

- Forward bias thyristor is usually turn ON by apply +ve gate v/g b/w gate and cathod.
- There is transition time from forward off state to forward on state , this transition time called thyristor turn on time define as time during which the change from forward blocking state to final on state.

Total Turn-on Time of SCR is subdivided into three distinct period:

- Delay Time : This is time b/w the instant at which the gate current reaches 90% of its final value and instant at which the anode current reaches 10% of its final value. It can also be defined as the time during which anode v/g falls from Va to 0.9Va where Va is the initial value of the anode v/g.
- Rise Time : This is the time required for the anode current to rise from 10-90% of its final value. It can also defined as the time required for the forward blocking off-state v/g to fall from 0.9 to 0.1 of its value-OP.

- Spread Time: It is the time required for forward blocking v/g to fall from 0.1 to its value to the on state v/g drop (1 to 1.5 V).
- Turn on Time : Sum of delay time, rise time and spread time. This is typically of order of 1 to 4 μs.

Turn on Triggering Methods of SCR

- Switching the SCR from forward blocking state (OFF state) to forward conduction state (ON-state) is known as turning ON of SCR (Triggering).

1. Forward Voltage Triggering
2. dv/dt Triggering
3. Light triggering
4. Temperature Triggering
5. Gate Triggering

Turn off characteristic of SCR

- The process of turn off is called Commutation.
- $t_{off} = t_r + t_g$
- t_r =Reverse Recovery Time
- t_g = Gate Recovery Time

- Circuit turn off time must be greater than device turn off time by suitably safe margin, otherwise the device will turn on at an undesired instant a process known as commutation failure.
- Large turn-off time (50-100 μs) called slow switching or phase control type thyristors.
- Low turn-off time (10-50 μs) are called fast switching or inverter type thyristors.

Turn off Process of SCR

- The process of turning off a conducting SCR is known as "Commutation".
- Depending on the nature of the source (ac or dc) the commutation can be natural or forced.
- Commutation Techniques:
- Natural commutation & Forced Commutation
- Forced Commutation : Current commutation & Voltage commutation.

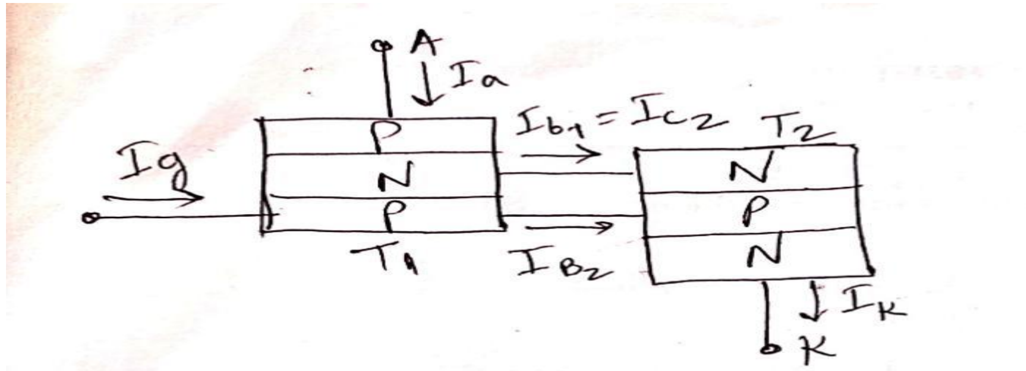
- Forced commutation : In case of D.C circuits, for switching off the thyristors , the forward current should be forced to be zero by means of some external Circuit. The process is called forced commutation and external circuits required for it are known as commutation circuits.
- Natural Commutation : As the current passes through natural zero, reverse v/g will simultaneously appear across the device. This immediately turns-off the device. This process is called as natural commutation. No external ckt is required.

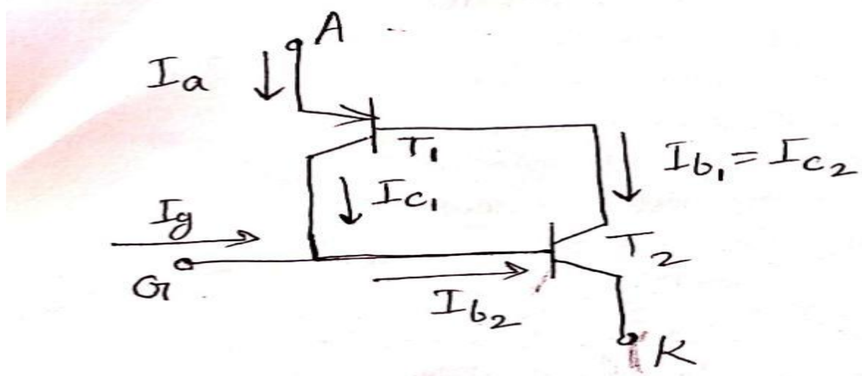
Forced Commutation

- Six basic methods of commutation

1. Class A
2. Class B
3. Class C
4. Class D
5. Class E
6. Class F

Two Transistor Analogy





Collector Current of T_1 → base current of T_2 & vice versa

$$I_{C_1} = I_{b_2} \quad \& \quad I_{b_1} = I_{C_2}$$

$$I_K = I_a + I_g \quad \text{--- (1)}$$

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Transistor Analysis

$$I_{b_1} = I_{e_1} - I_{C_1} \quad \text{—} \ (2)$$

$$I_{C_1} = \alpha_1 I_{e_1} + I_{CO1} \quad \text{—} \ (3)$$

↓ Reverse leakage Current of the reverse biased junction J_2

Substituting (3) in (2)

$$I_{b_1} = I_{e_1} - \alpha_1 I_{e_1} - I_{CO1}$$

$$I_{b_1} = (1 - \alpha_1) I_{e_1} - I_{CO1}$$

$\therefore I_a = I_{e_1}$

$$I_{b_1} = (1-\alpha_1) I_a - I_{co_1} \quad \text{--- (4)}$$

$$I_{c_2} = \alpha_2 I_{e_2} + I_{co_2}$$

$$\therefore I_K = I_{e_2}$$

$$I_{c_2} = \alpha_2 I_K + I_{co_2} \quad \text{--- (5)}$$

$$I_{b_1} = I_{c_2} \quad \text{--- (6)}$$

Substituting (6) & (5) in (6)

$$(1-\alpha_1) I_a - I_{co_1} = \alpha_2 I_K + I_{co_2} \quad \text{--- (7)}$$

Substituting ([redacted]) in (7)

$$(1-\alpha_1) I_a - I_{co_1} = \alpha_2 (I_a + I_g) + I_{co_2}$$

$$(1-\alpha_1-\alpha_2) I_a = \alpha_2 I_g + I_{co_2} + I_{co_1}$$

$$I_a = \frac{\alpha_2 I_g + I_{co_1} + I_{co_2}}{[1 - (\alpha_1+\alpha_2)]}$$

As $I_g \uparrow \longrightarrow (\alpha_1+\alpha_2)$ will go towards 1

$\downarrow$

$I_a \uparrow \longrightarrow$ SCR will ON

$(I_a > I_L)$

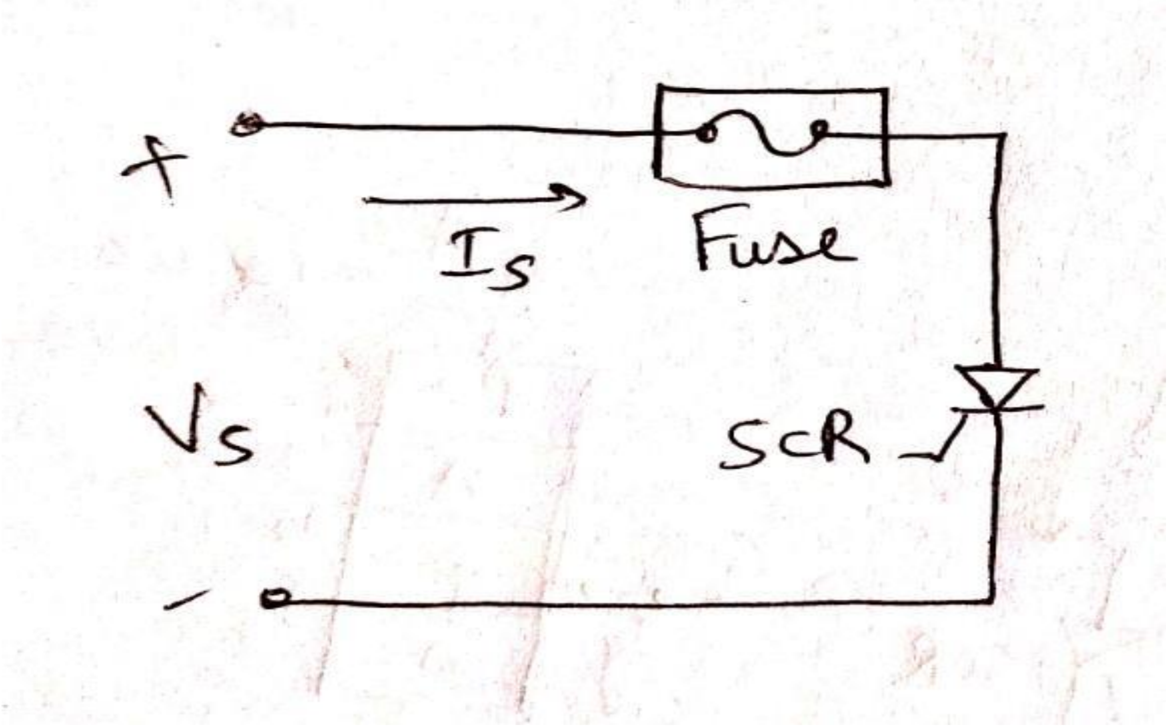
SCR Protection

- Various protection scheme available for satisfactory operation of SCR are

1. Over Current Protection
2. Over v/g Protection
3. di/dt Protection
4. dv/dt Protection
5. Thermal protection

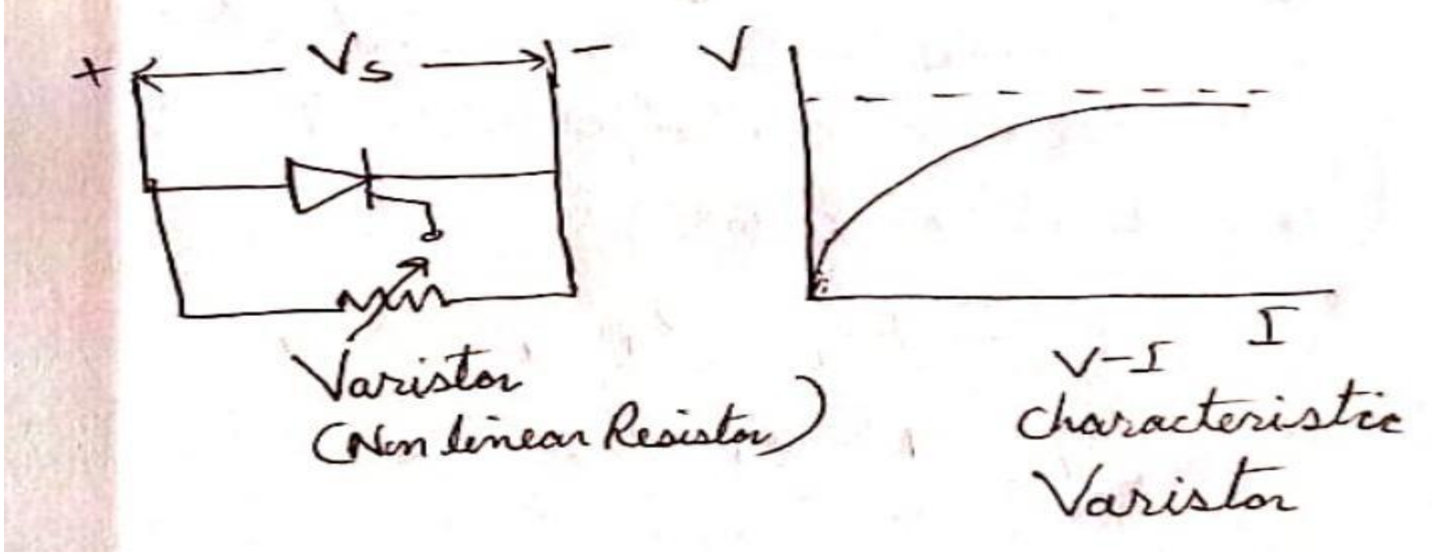
Over Current Protection

- Is>Irated
- In SCR due to over current , the junction temperature exceeds the rated value and the device gets damaged.



Over Voltage Protection

- Vs>Vrated
- Overvoltage may result in false turn ON of device (or) damage the device .
- The effect of over voltage is reduced by using non-linear resistors called Varistor.



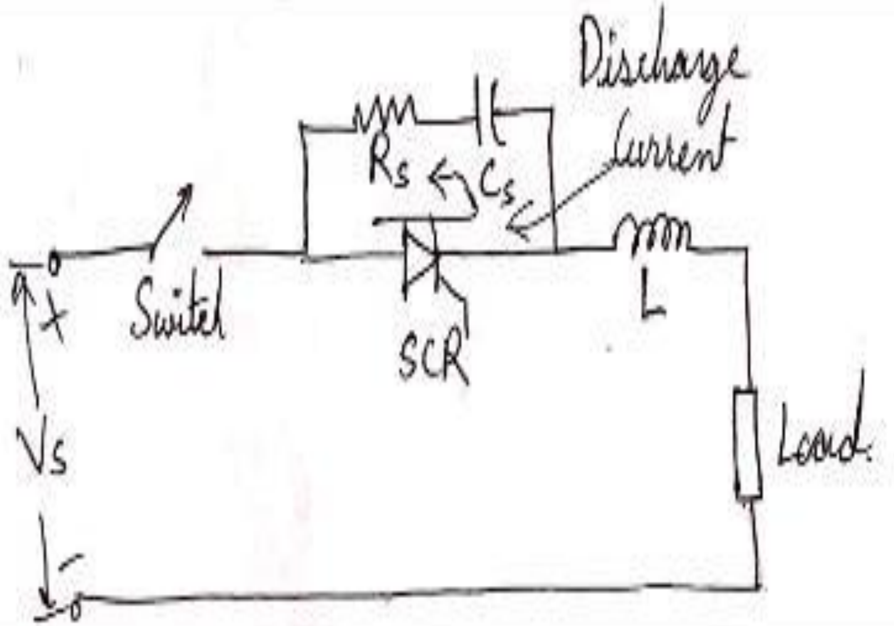
di/dt Protection

- di/dt is rate of change of current in a device.

- The device protection is done by means of connecting an inductor in series with the thyristor.
- di/dt (increases or more) heat up and demage the SCR.

dv/dt Protection

- dv/dt is the rate of change of v/g across SCR. To protect the thyristor against false turn ON or against high dv/dt a “Snubber ckt” is used.
- The snubber ckt is a series combination of resistor ‘R’ and ‘C’.



Charging Current across Capacitor

$$I = C\frac{dV}{dt}$$

Thermal Protection

- With the increase in the temperature of the junction , insulation may get failed and SCR may damage . So thermal protection achieve by monitoring heat sink over SCR.

$$\text{String efficiency} = \frac{\text{Total V/g or Current rating of the whole string}}{(\text{No. of SCRs}) \times (\text{Individual V/g or Current rating of SCR})}$$

$$= \frac{V_1 + V_2}{2V_1}$$

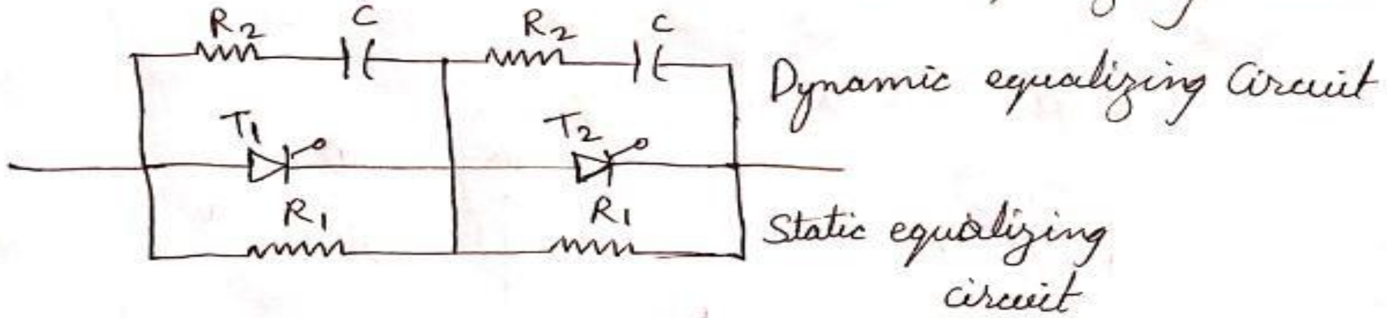
This show even SCR having identical rating, V/g shared by each device is not same, so String $\eta < 1$

To get 100% String η make $V_1 = V_2$ by using external equalizing Circuits.

Static Equalization & Dynamic Equalization

→ A uniform V/g distribution is achieved by Connecting a suitable resistance across each SCR such that each parallel combination has the same resistance.

→ This shunt Resistance R is called a static equalizing Circuit.

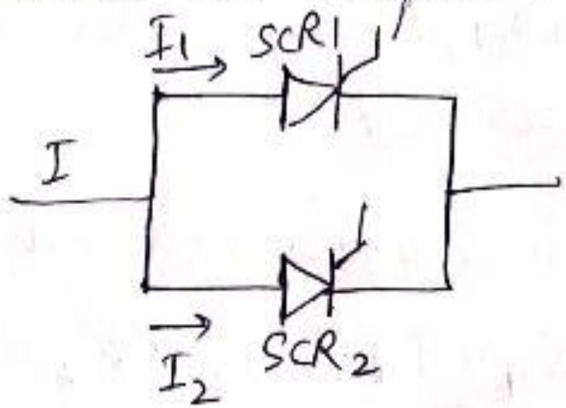


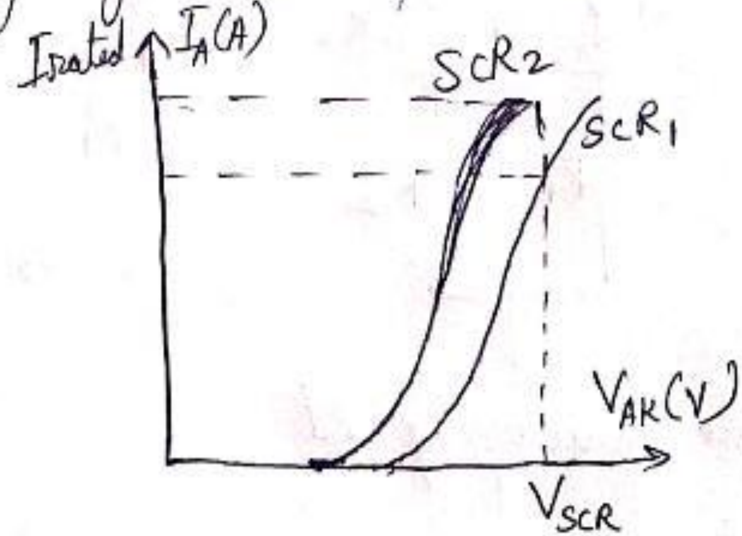
→ During the turn-off process, due to the difference in junction Capacitance, there is the differences in stored charge for the series connected SCRs.

→ It will cause unequal reverse V/g sharing among the thyristors. This problem is solved by connecting Capacitor across each thyristor.

Parallel operation of SCR

When the load Current exceeds the rating of a single SCR, SCR's are Connected in parallel to increase their Common Current capability. In SCR's are not perfectly matched, this results in an unequal sharing of Current b/w them.





The device having lower dynamic resistance will tend to share more current. If R_{T_1} is the resistance across SCR_1 & R_{T_2} is the resistance across SCR_2 if,

$$R_{T_1} < R_{T_2}$$

$$I_1 > I_2$$

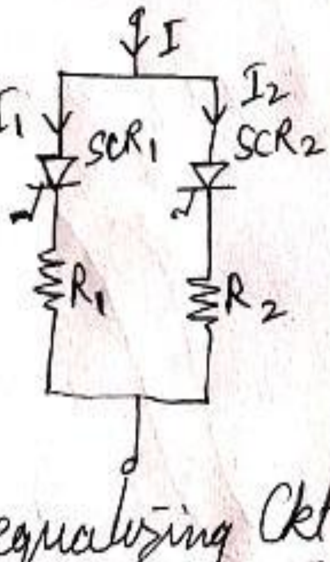
$$\text{String efficiency} = \frac{I_1 + I_2}{2 I_1}$$

This show even SCR having identical rating, V/g shared by each device is not same, so string $\eta < 1$

To get 100% string η make $I_1 = I_2$

Static & Dynamic equalization

Resistors are used in case of static current sharing. When resistances are used in series, the losses may become high



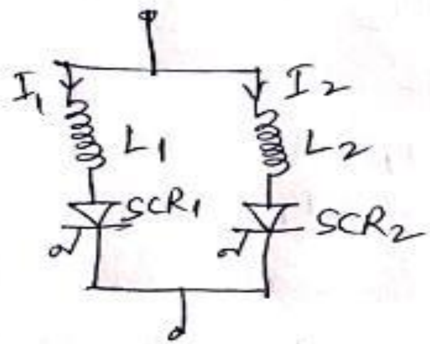
Static equalizing Ckt

If the internal Resistance across SCR_1 is R_{T_1} & SCR_2 is R_{T_2}. So we choose the value of R_1 & R_2 such that

The total resistance across each branch is

$$R_{T_1} + R_1 = R_{T_2} + R_2$$

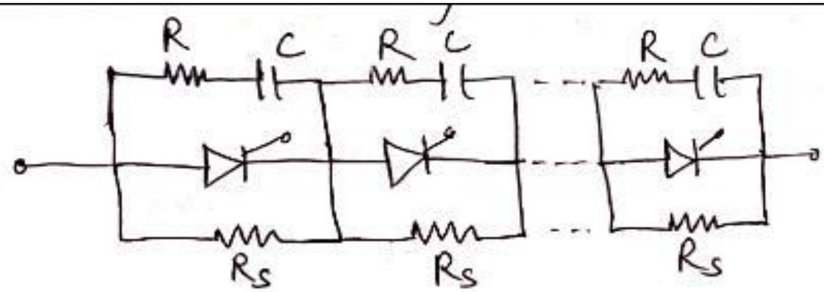
→ If annode Current are such that $I_1 = I_2$ then flux produce by two equal halves of the reactor oppose each other, opposite flux canceled each other & therefore no V/g drop across reactor.



Dynamic equalizing ckt

→ But if I_1 & I_2 are unequal such that $I_1 > I_2$, the resultant flux is not zero. These flux linkage induce EMF in L_1 & L_2. EMF across reacter L1 is high it oppose the flow of I_1 where as L_2 aids the flow of I_2.

→ Thus L_1 buck I_1 & L_2 boost I_2. So it balance the current in the parallel unit.



$$(R_s)_{max} \leq \frac{nV_D - V_S}{(n-1)\,\Delta I_{b\,max}}$$

n = no. of SCRs are Connected in series

V_S = Supply V/g

V_D = max. blockage V/g of SCR

$$C_{min} \geq \frac{(n-1)\Delta Q_{max}}{nV_D - V_S}$$

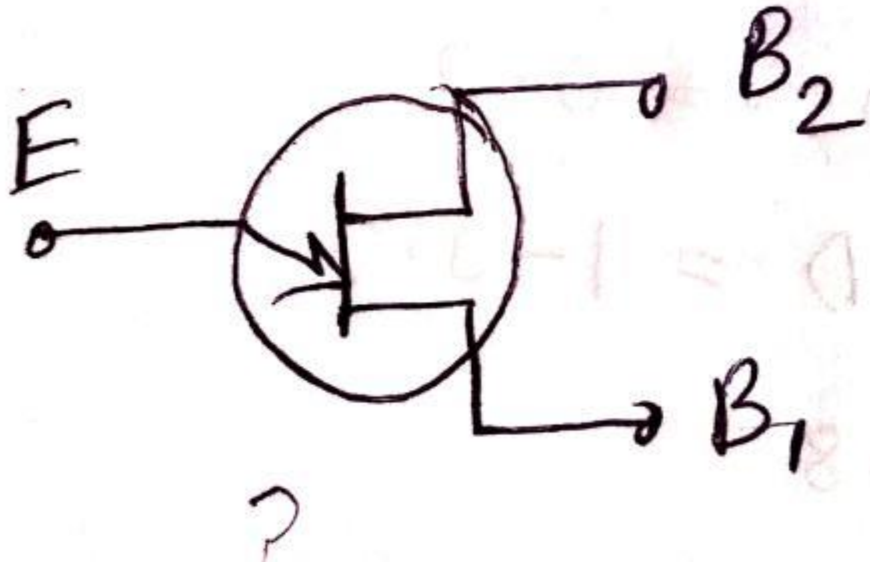
$$\eta = \frac{V_s}{nV_D} = \frac{\text{Supply Voltage}}{(\text{No. of SCR})\ (\text{Rating of one SCR})}$$

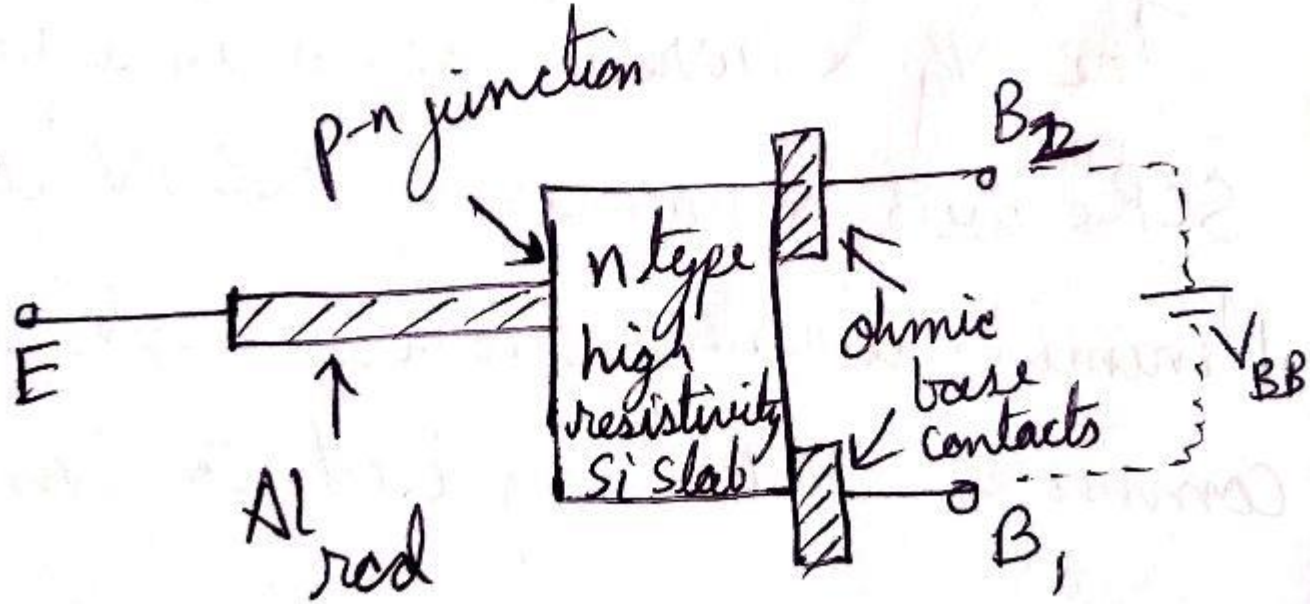
$$D = 1 - \eta$$

Unijunction Transistor (UJT)

- One PN junction.
- Three terminal device.
- Emitter, base1, base2 -----3-Terminal.
- The most popular device used for SCR Triggering in UJT.

Symbol





UJT Construction