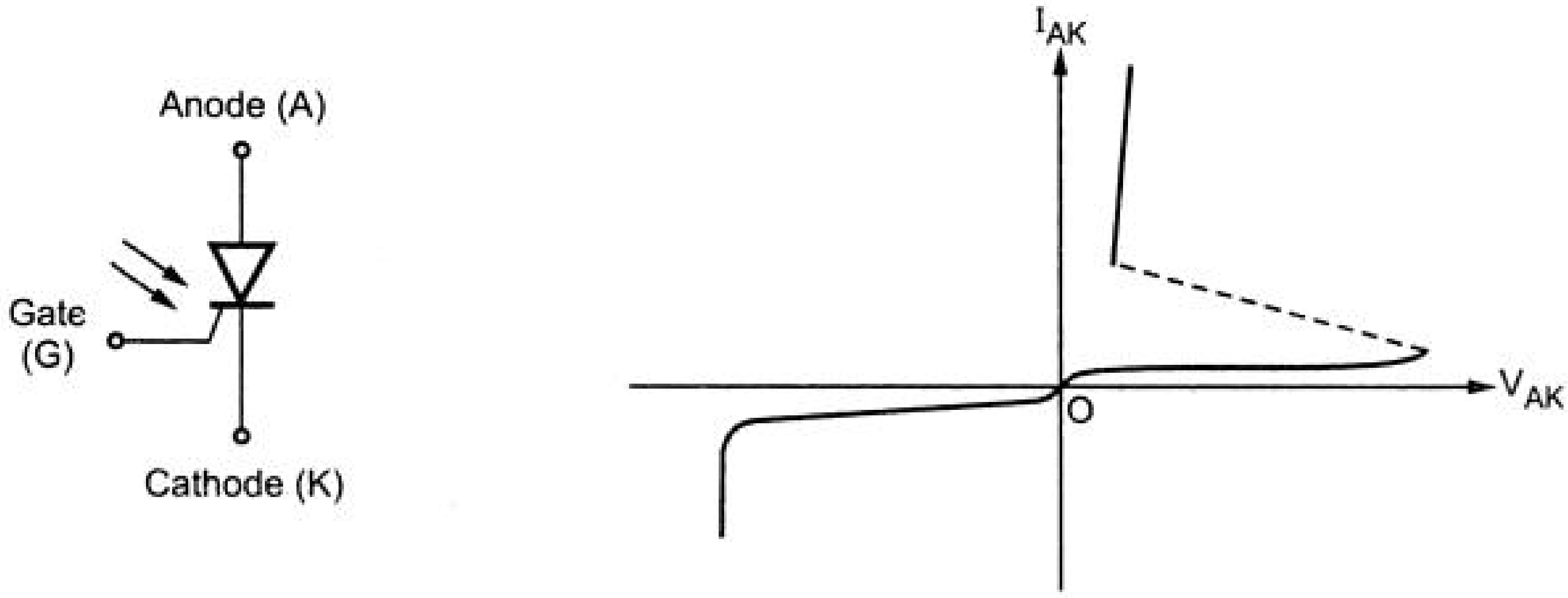
Applications

i.GTOs are suitable mainly for low power applications.

ii.Induction heating and motor drives.

1.10.2 Light Activated SCR (LASCR)

The light activated SCRs can be triggered using a beam of light. Their gate region is photosensitive. Fig. 1.10.4 shows the symbol and V-I characteristics of LASCR.



(a) Symbol of LASCR (b) V-I characteristics of LASCR

Fig. 1.10.4

The photons of light induce electrons in the gate-cathode junction. Because of these electrons, current starts flowing across J_3 and SCR turns-on. Once the SCR is turned on, gate has no control over its operation.

Advantages

i. It can be turned-on by a beam of light. Hence isolation is provided between control circuit and SCR.

ii. Because of optical triggering, effects of noise are reduced.

Applications

i. Used in high power applications like HVDC transmission, VAR compensation etc.

ii. Used in noise environments for better triggering control.

1.10.3 Reverse Conducting Thyristor (RCT)

In most of the applications, an antiparallel diode is connected across the thyristor. For example in chopper and inverter circuits, the antiparallel diode improves the turn-off requirement of the circuit. The antiparallel diode is also useful in case of inductive loads to provide the path for feedback currents. A reverse conducting thyristor (RCT) is similar to an SCR with antiparallel diode. Fig. 1.10.5 shows the equivalent circuit of RCT. The RCT is also called as asymmetrical thyristor or ASCR. It conducts in the reverse direction without any control. The conduction in the forward direction is controlled by the gate. The characterictics are similar to SCR in the forward direction. And the characteristics are similar to diode in reverse direction. It has the capability of upto 2000V/500A in the forward direction. The reverse blocking voltage is upto 40V.

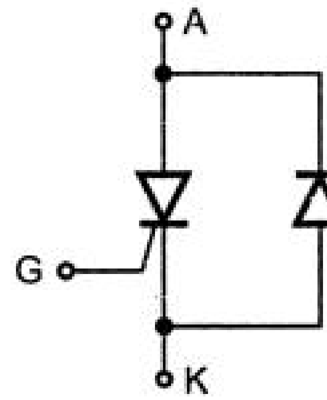
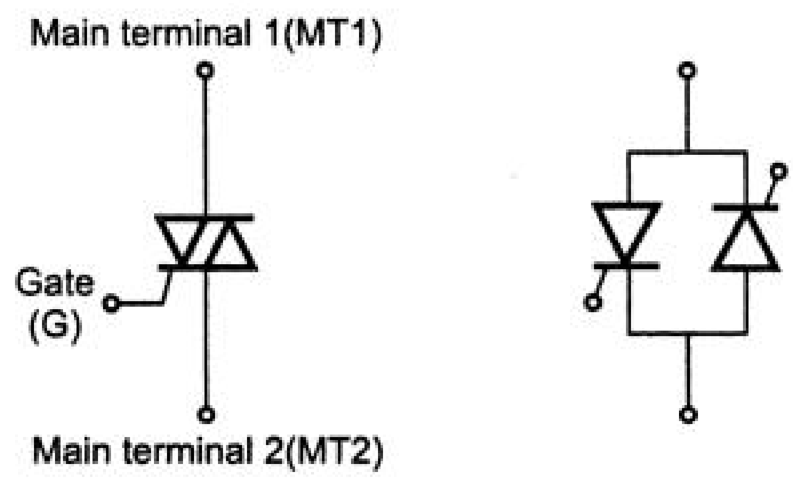


Fig. 1.10.5 RCT

1.10.4 Triac (Bidirectional Triode Thyristors)

The triac is the bidirectional device. It conducts in both the directions. We know that SCR conducts only in one direction. The triac is equivalent to the two antiparallel SCRs as shown in Fig. 1.10.6.



(a) Triac symbol **(b) Triac equivalent circuit**

Fig. 1.10.6 Triac symbol and equivalent circuit

The triac has three terminals : Main Terminal 1 (MT 1), Main Terminal 2 (MT2) and gate (G). Observe that the symbol also consists of antiparallel devices. The current can flow from MT1 to MT2 when MT1 is forward biased with respect to MT2. Similarly current flows from MT2 to MT1 when MT2 is forward biased with respect to MT1. The current flows (i.e. triac is switched 'on') whenever gate drive is applied. The triac is the best device for AC phase control. The input is AC and the load is also AC. The power is to be controlled in positive as well as negative half cycles. The triac is then triggered in every half cycle. The triac turns-off when current falls to zero in every half cycle. Thus the necessity of antiparallel SCRs is eliminated by triac. The word *triac* is abbreviated from *Tri* of triode and *AC*. It is mainly used for AC phase control and similar applications.

In the equivalent circuit observe that drains(D) of both the MOSFETs are connected to anode. The source(s) of ON-FET is connected to base region (p^-) of the npn transistor.

1.10.5.2 Turn-on and Turn-off MCT

MCT can be turned-on by applying negative gate-anode voltage. Because of this voltage the p-channel is induced as shown in Fig. 1.10.10. Hence ON-FET starts conducting the current of ON-FET goes to base of the npn transistor and the device turns on by regeneration.

The MCT can be turned-off by applying positive gate-anode voltage. This induces the n-channel in the device as shown in Fig. 1.10.10. The OFF-FET then starts conducting. In Fig. 1.10.11(a) observe that the OFF-FET is connected across emitter base of pnp transistor. Since OFF-FET is turned on, the base-emitter of pnp transistor is shorted. Hence it comes out of saturation and starts turning OFF. Therefore npn transistor also turns-off and the MCT is turned off.

1.10.5.3 Characteristics of MCT

The VI characteristics of MCT are similar to that of GTO.

1.10.5.4 Advantages and Disadvantages of MCT

Advantages

i. MCT can be truned-on and turned-off by low gate voltages.

ii. MCT has fast switching times (typically $t_{on} = 0.3$ μs and $t_{off} = 1$ μsec).

iii. MCT has low switching losses.

iv. MCT has high gate input impedance due to its MOS gates.

v. Paralleling of MCTs is easier.

Disadvantages

i. If current through MCT is greater than gate controllable current then it cannot be turned off. Then MCT has to be commutated externally like SCR.

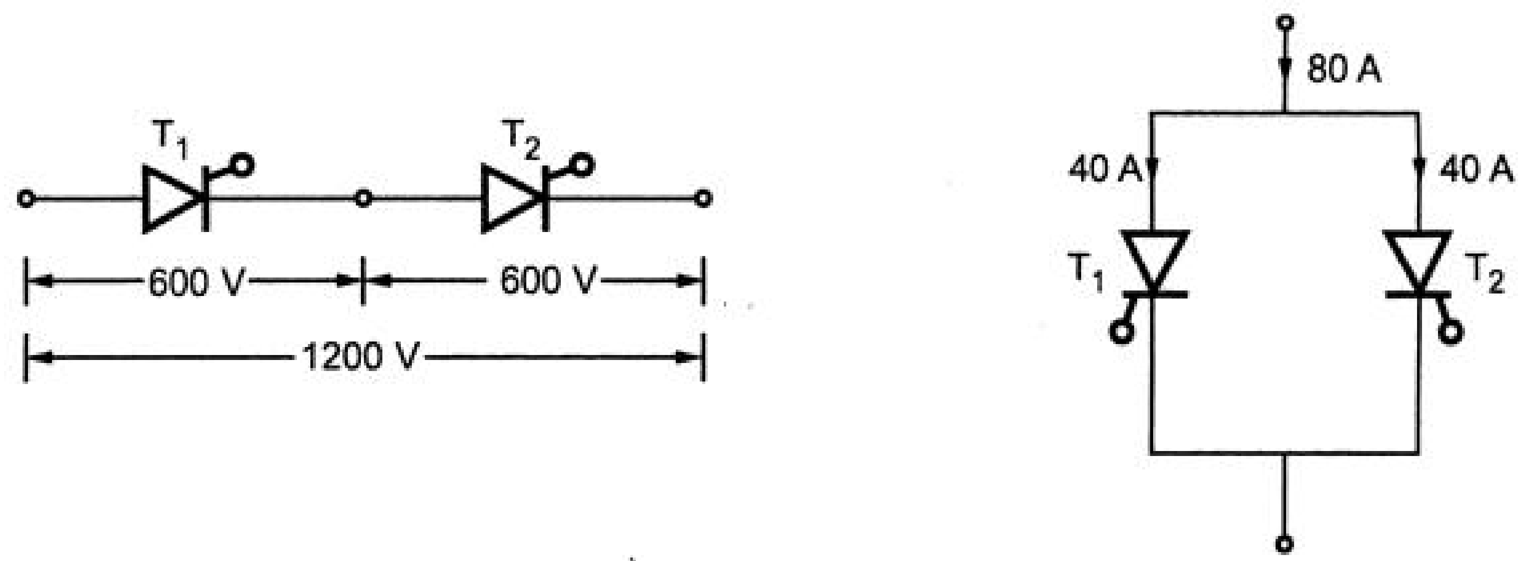
ii. For larger anode currents, the gate pulses of longer duration are required.

iii. Gate draws peak current during turn-off.

1.11 Series and Parallel Operation of Thyristors

1.11.1 Necessity of Series and Parallel Connection

Series connection of the devices is often required to increase the overall voltage rating. For example the thyristor is to be operated at 1000 volts. But we have thyristors of rating 600 volts. Then the circuit can be implemented by connecting two thyristors in series.



(a) Series connection (b) Parallel connection

Fig. 1.11.1 Series and parallel operations

Similarly parallel connection is used to increase current ratings. For example, current in the circuit is 80 A. But we have a thyristor of rating 50 A. Then the problem can be solved by connecting two thyristors in parallel as shown in Fig. 1.11.1 (b). This makes the current sharing among two thyristors and each one carries $\frac{80}{2}$ = 40 A. Thus series and parallel connections are most widely used to cater the need of higher voltage and currents.

1.11.2 Series Connection of Thyristors

1.11.2.1 Problems Encountered in Series Connection

When the thyristors are connected in series, they have small differences in their ratings. For example Fig. 1.11.2 shows the V-I characteristics of two thyristors of same ratings. Observe that there are minor differences between the characteristics. Forward break-over voltages, internal resistance, leakage current etc are not exactly same. The thyristor with highest internal resistance will have minimum leakage current. Hence high voltage will appear across it in off state. This creates voltage imbalance in the series connection. Hence equalization is necessary in the series connection.

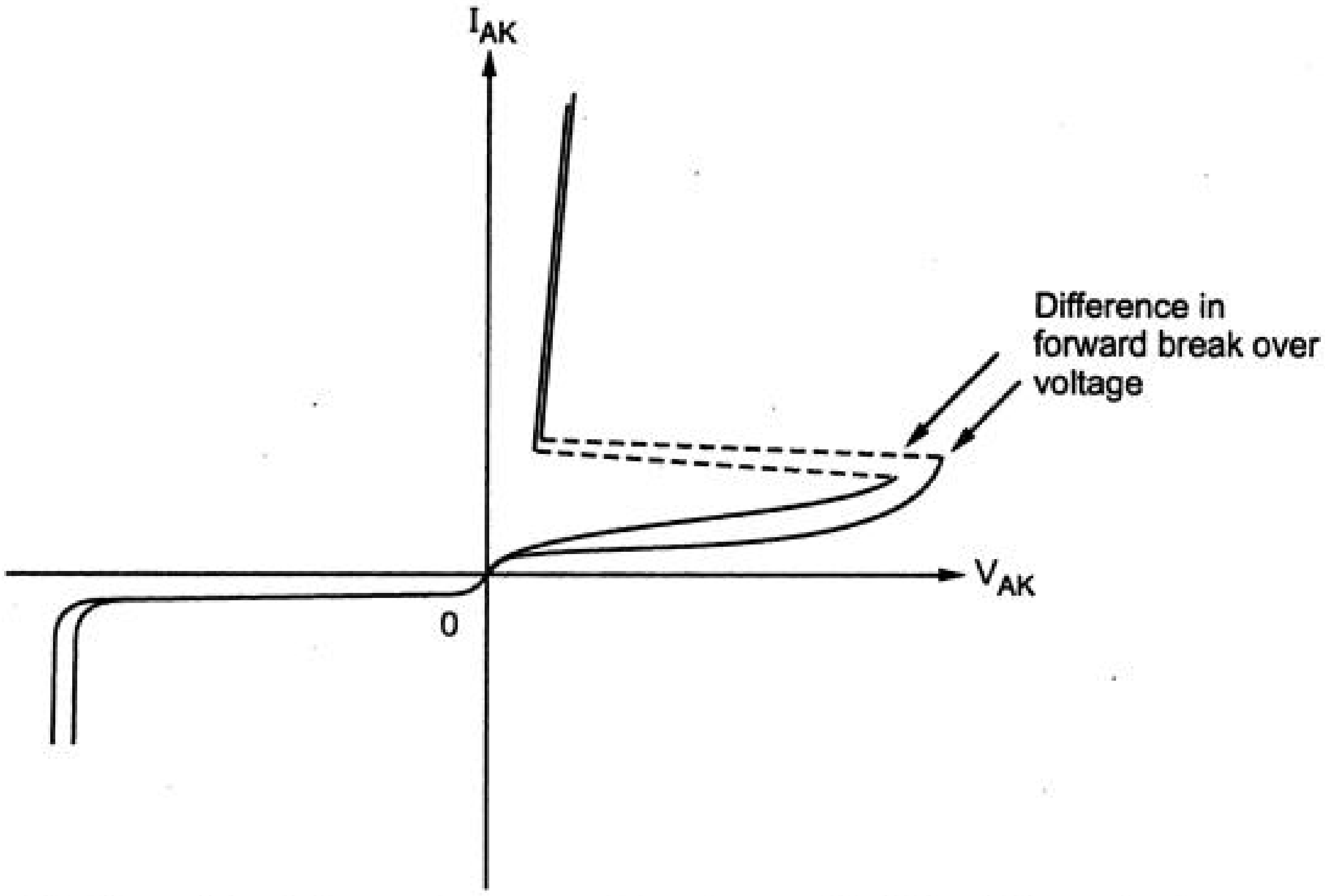


Fig. 1.11.2 Two thyristors of same rating have slightly different characteristics

1.11.2.2 Equalizing Components

Let us consider that 'n' number of thyristors are connected in series. An equalizing resistance 'R' is connected across each thyristor as shown in Fig. 1.11.3. Let us assume that T_1 has maximum internal resistance in off state. Hence its leakage current I_{D1} is minimum. Let the internal resistance of other devices is same. Hence their leakage current is also same, i.e. I_{D2} current I_1 flows through R. Since other thyristors have same internal resistance, current through their parallel resistors will be same, i.e. I_2. From above circuit we can write,

$$I_{D1} + I_1 = I_{D2} + I_2$$

$$\therefore \quad I_2 = I_1 - I_{D1} - I_{D2}$$

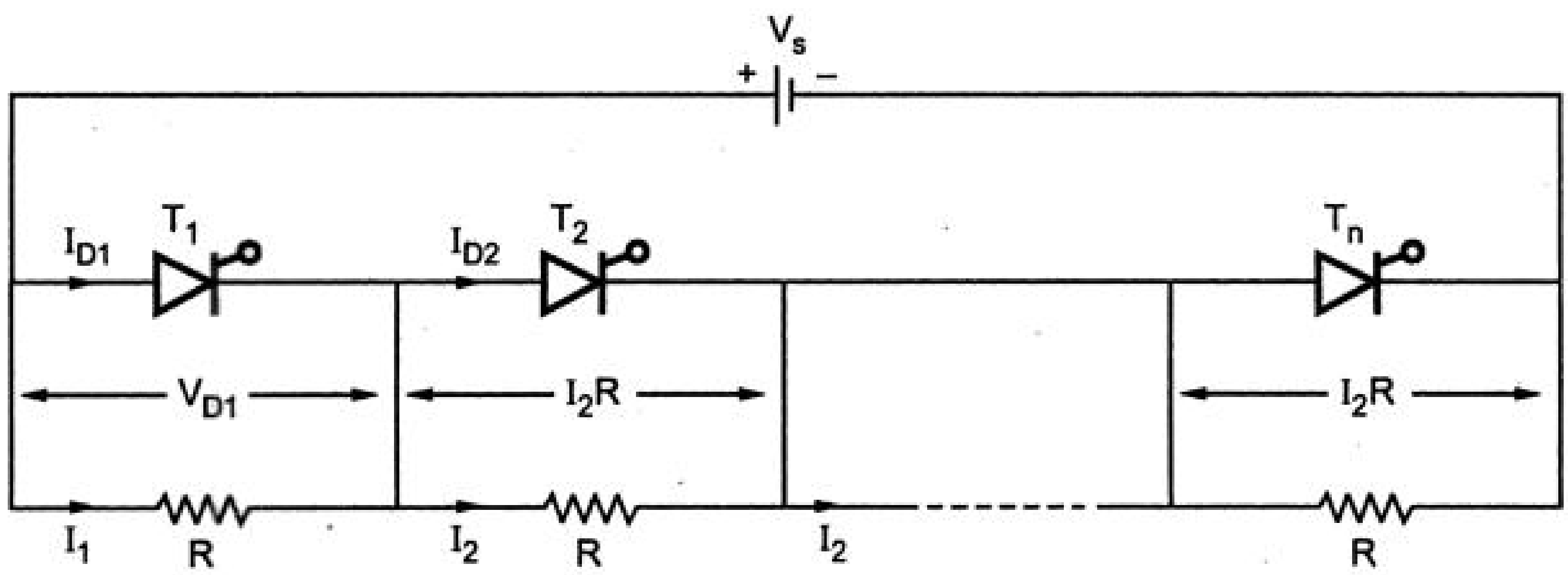


Fig. 1.11.3 Static equalization circuit

$$= I_1 - \Delta I_D \quad \text{... (1.11.1)}$$

Here ΔI_D is the difference in leakage currents of two thyristors. Voltage across T_1 is $V_{D1} = I_1$, R and voltage across T_2, T_3, ... T_n is same, i.e. I_2R. Therefore we can write,

$$V_s = I_1 R + I_2 R(n-1)$$

$$= V_{D1} + (n-1) I_2 R$$

Putting for I_2 from eq. 1.11.1,

$$V_s = V_{D1} + (n-1)(I_1 - \Delta I_D) R$$

$$= V_{D1} + n I_1 R - n \Delta I_D R - I_1 R + \Delta I_D R$$

$$= V_{D1} + n V_{D1} - V_{D1} - (n-1) \Delta I_D R$$

$$= n V_{D1} - (n-1) \Delta I_D R$$

$$\therefore \quad \boxed{V_{D1} = \frac{V_s + (n-1) \Delta I_D R}{n}} \quad \text{... (1.11.2)}$$

Maximum value of V_{D1} will occur when ΔI_D is maximum. Value of R can be obtained from above equation as,

$$R = \frac{n V_{D1} - V_s}{(n-1) \Delta I_D} \quad \text{... (1.11.3)}$$

1.11.2.3 Dynamic Equalization Circuit

We studied the equalization when all thyristors are in forward blocking state. There can be some difference in the turn-on and turn-off times of the thyristors. When trigger is given to all the thyristors, they start turning-on. Higher voltage will appear across the thyristor which turns-on late. Hence its maximum voltage rating may be exceeded. This problem can be overcome by dynamic equalizing circuit. Fig. 1.11.4 shows the dynamic equalizing circuit. It is R-C circuit across each thyristor. Static equalization resistors are also shown in this circuit. An RC circuit is placed across

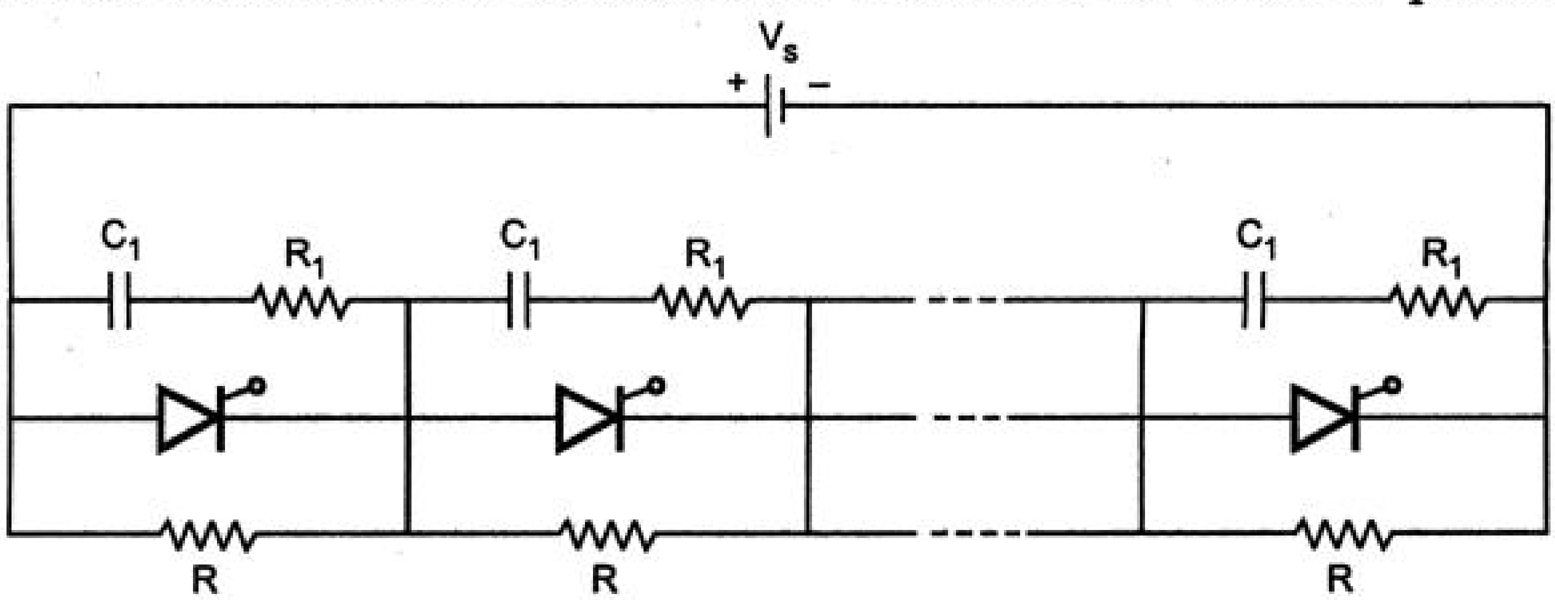


Fig. 1.11.4 Complete equalization circuit

each thyristor. C_1 provides the equalization during turn-on and turn-off. Resistance R_1 is used to limit discharge current of C_1.

Value of C_1

We know that the relationship between charge on the capacitor, voltage on the capacitor and value of the capacitor is,

$$V = \frac{Q}{C}$$

If V is ΔV, then,

$$\Delta V = \frac{\Delta Q}{C}$$

Consider equation 1.11.2, $V_{D1} = \frac{V_s + (n-1)\Delta I_D R}{n}$

If ΔQ indicates the difference in charge stored in C_1 and C_2, then ΔV will indicate the voltage difference across T_1 and T_2. Hence we have $\Delta V = \Delta I_D R$. Therefore above equation becomes,

$$V_{D1} = \frac{V_s + (n-1)\Delta V}{n}$$

Since $\Delta V = \frac{\Delta Q}{C_1}$, $$V_{D1} = \frac{V_s + (n-1)\Delta Q / C_1}{n} \quad \dots (1.11.4)$$

This equation gives the voltage imbalance across T_1. Value of C_1 can be obtained as,

$$\boxed{C_1 = \frac{(n-1)\Delta Q}{nV_{D1} - V_s}} \quad \dots (1.11.5)$$

Derating factor of the string

The derating factor (D) indicates the amount by which string is derated. It is given by

$$\% D = \left[1 - \frac{V_s}{nV_{D1}}\right] \times 100 \quad \dots (1.11.6)$$

String efficiency (η)

String efficiency indicates the amount by which the string is utilized. It is given as,

$$\% \eta = (1 - D) \times 100 \quad \dots (1.11.7)$$

$$= \frac{V_s}{n V_{D1}} \times 100 \quad \dots (1.11.8)$$

Example 1.11.1 : *How many SCRs are required in a series string to withstand a DC voltage of 3500 volts in steady state, if the SCRs have steady state voltage rating of 1000 V and steady state derating factor of 30% ? Assuming maximum difference in leakage current of SCRs to be 10 mA, calculate the value of voltage sharing resistances to be used. Draw the circuit showing the SCRs and the voltage sharing resistances.*

Solution : Given data

$$V_S = 3500 \text{ V}$$

$$V_{D1} = 1000 \text{ V}$$

$$\%D = 30$$

$$\Delta I_D = 10 \text{ mA}$$

i) To obtain number of SCRs

By eq. 1.11.6 we have,

$$\%D = \left[1 - \frac{V_S}{nV_{D1}}\right] \times 100$$

$$\therefore \quad 30 = \left[1 - \frac{3500}{n \times 1000}\right] \times 100$$

$$\therefore \quad n = 5$$

ii) To obtain voltage sharing resistance

By eq 1.11.3 such resistance is given as,

$$R = \frac{nV_{D1} - V_S}{(n-1)\Delta I_D} = \frac{5 \times 1000 - 3500}{4 \times 10 \times 10^{-3}}$$

$$= 37.5 \text{ k}\Omega$$

The circuit will be similar to Fig. 1.11.3 having 5 SCRs in series and each resistance of 37.5 kΩ.

Example 1.11.2 : *A 3ϕ converter is used for HVDC transmission system and is operated from 3ϕ 25 kV supply. Thyristor each of 1600 V/16 A are available. The forward leakage current difference of the device is 35 mA. The string efficiency can be assumed to be 85% and $\Delta Q_{max} = 25 \mu C$.*

a) Determine the number of devices to be connected in series.

b) Equalizing components

Solution : **Given data**

$$V_{line} = 25 \text{ kV}$$

$$\therefore \quad V_s = PIV = \sqrt{2} \times V_{line}$$

$$= \sqrt{2} \times 25 \text{ kV} = 35.35 \text{ kV}.$$

$$V_{D1} = 1600 \text{ V}$$

$$\Delta Q_{max} = 25 \mu C$$

$$\Delta I_D = 35 \text{ mA}$$

String efficiency, $\eta = 0.85$

a)To obtain number of devices

Form equation 1.11.8,

$$\eta = \frac{V_s}{n V_{D1}}$$

$$\therefore \quad n = \frac{V_s}{\eta V_{D1}} = \frac{35.35 \times 10^3}{0.85 \times 1600}$$

$$= 26$$

b) To obtain equalizing components

Value of R is given by equation 1.11.3 as,

$$R = \frac{n V_{D1} - V_s}{(n-1) \Delta I_D}$$

$$= \frac{26 \times 1600 - 35.35 \times 10^3}{(26-1) 35 \times 10^{-3}}$$

$$= 7.142 \text{ k}\Omega$$

Value of C_1 is given by equation 1.11.5 as,

$$C_1 = \frac{(n-1) \Delta Q}{n V_{D1} - V_s} = \frac{(26-1) 25 \times 10^{-6}}{26 \times 1600 - 35.35 \times 10^3}$$

$$= 0.1 \mu F$$

1.11.3 Parallel Connection of Thyristors

We know that parallel connection of thyristors is used to cater higher current demands.

1.11.3.1 Problems Occurred in Parallel Connection

The devices used in parallel connection donot have exactly similar characteristics. The thyristor carrying higher current will have more power dissipation. This will increase its temperature and reduce the internal resistance. Therefore the current further increases. This process continues till thyristor damages.

1.11.3.2 Equalizing Arrangements

Heat sharing can be done by using common heat sinks for all the devices. This will maintain all the devices at same temperature.

Static Current Sharing

Fig. 1.11.5 shows the static current sharing arrangement. Two resistors connected in series with the thyristors.

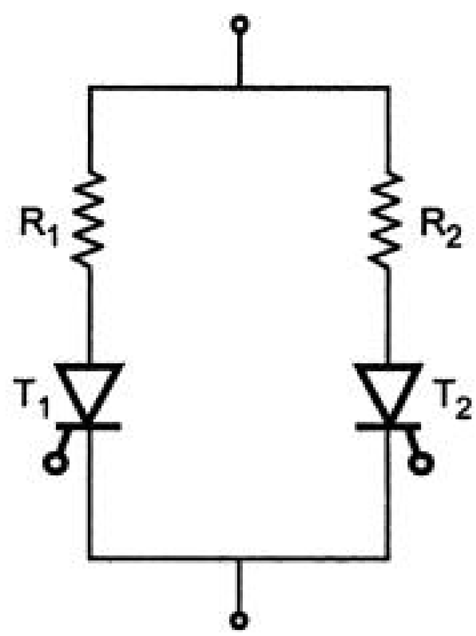


Fig. 1.11.5 Static current sharing

R_1 and R_2 try to equalize the currents through T_1 and T_2. But power dissipation in R_1 and R_2 is very high.

Dynamic Current Sharing

Fig. 1.11.6 shows an arrangement for dynamic current sharing. The inductors are placed in series with thyristors. These inductors are magnetically coupled. But they are connected in opposite direction. Hence if current in T_1 tries to increase, then a voltage of opposite polarity will be induced in L_2. This increases the current in T_2. Thus current balance is maintained.

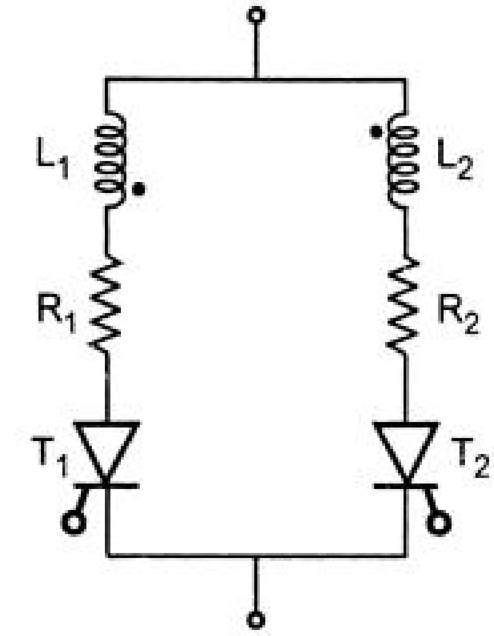


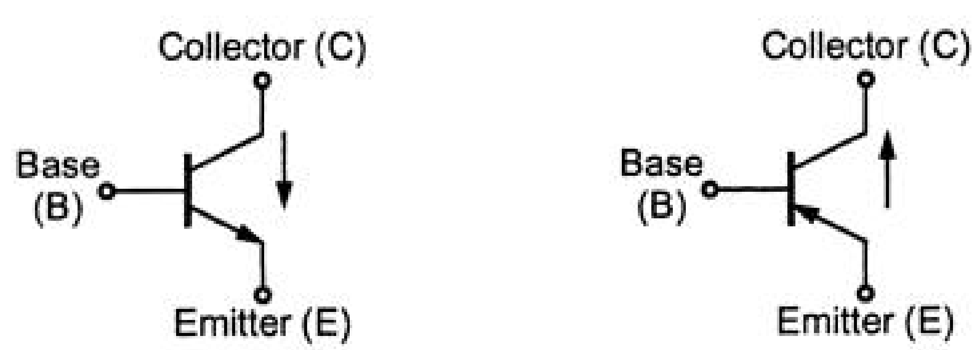
Fig. 1.11.6 Dynamic current sharing

Review Questions

1. *Derive an equation for components of dynamic equalization circuit of SCRs connected in series.*
2. *What is the necessity of series and parallel connection of SCRs?*

1.12 Power BJT

The power BJT is the bipolar device. Fig. 1.12.1 shows the symbols of BJT. The BJT is also called as power transistors in general. The BJTs are of two types : npn and pnp. BJT has collector (C) base (B) and emitter (E). In the npn BJT, when the base emitter junction is forward biased to saturation, the transistor turns 'on' and current flows from collector to emitter. When the BJT turns 'on', the collector emitter drop becomes negligible. The BJT turns-off as soon as base emitter drive is removed. Similarly in case of pnp BJT, when base emitter junction is forward biased to saturation, the transistor turns 'on' and current flows from emitter to collector. The transistor turns-off as soon as base emitter drive is removed. Thus the drive has full control over the conduction of BJT. No commutating components are required by BJT for turn-off.



(a) npn BJT (b) pnp BJT

Fig. 1.12.1 Symbols of BJT