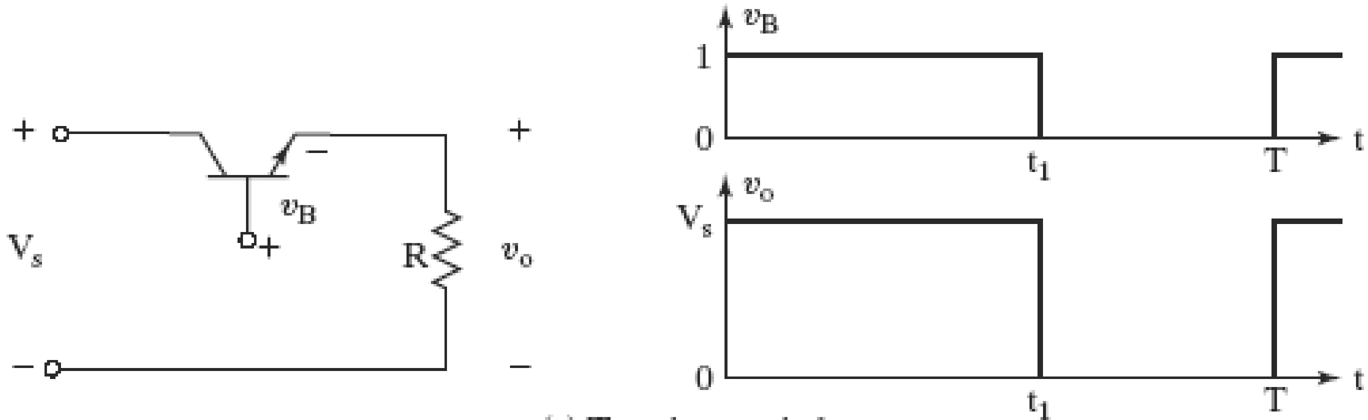
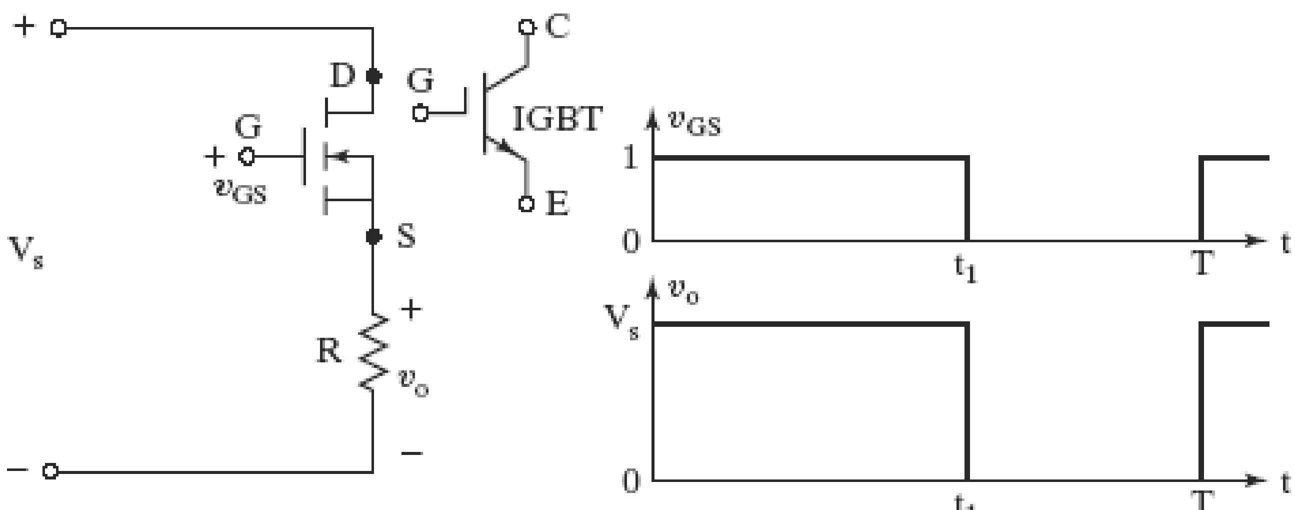
Lecture 3

Control Characteristics of Devices

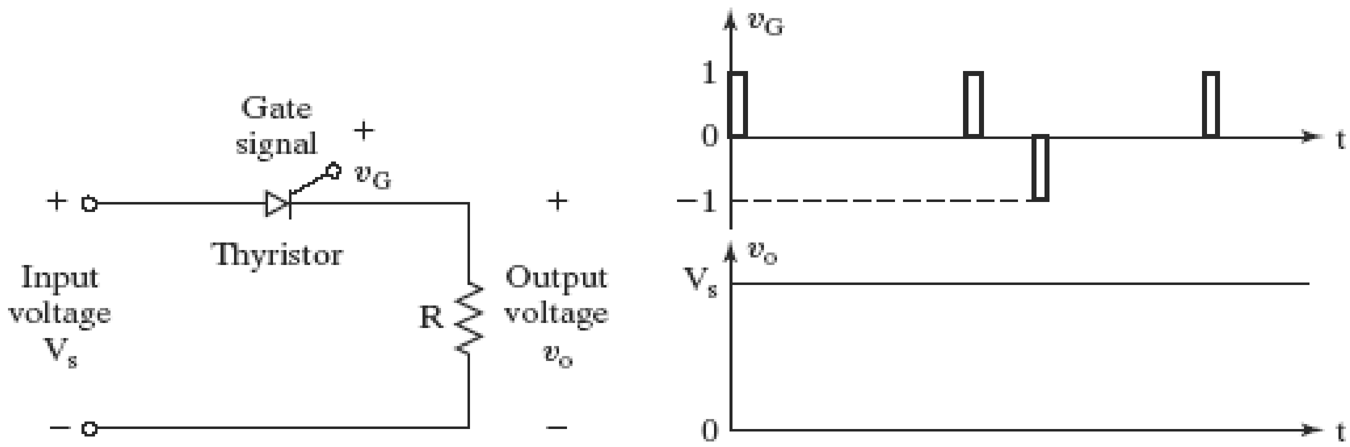


(c) Transistor switch

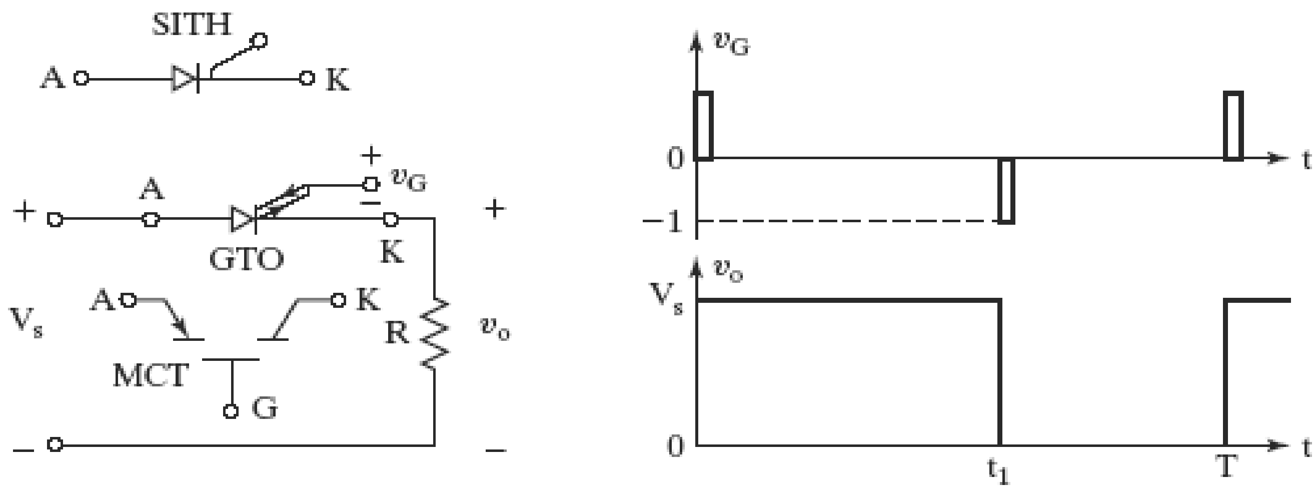


(d) MOSFET/IGBT switch

Control Characteristics of Devices



(a) Thyristor switch



(b) GTO/MTO/ETO/IGCT/MCT/SITH switch (For MCT, the polarity of V_G is reversed as shown)

SILICON-CONTROLLED RECTIFIER (SCR)

The ***silicon-controlled rectifier or semiconductor controlled rectifier*** is a two-state device used for efficient power control.

SCR is the parent member of the ***thyristor family*** and is used in ***high-power electronics. Its*** constructional features, physical operation and characteristics are explained in the following sections.

Constructional Features

The SCR is a ***four-layer structure***, either ***p–n–p–n or n–p–n–p****, that effectively blocks current through two* terminals until it is turned ***ON*** by a small-signal at a third terminal.

The SCR has ***two states***: a ***high-current low-impedance ON state*** and ***a low-current high-impedance OFF state.***

The basic transistor action in a ***four-layer p–n–p–n structure*** *is analysed first with only two terminals,*and then the third control input is introduced.

Physical Operation and Characteristics:

- The physical operation of the SCR can be explained clearly with reference to the current–voltage characteristics.
- The forward-bias condition and reverse-bias condition illustrate the conducting state and the reverse blocking state respectively. Based on these two states a typical I –V characteristic of the SCR is shown in Fig. 8-2.

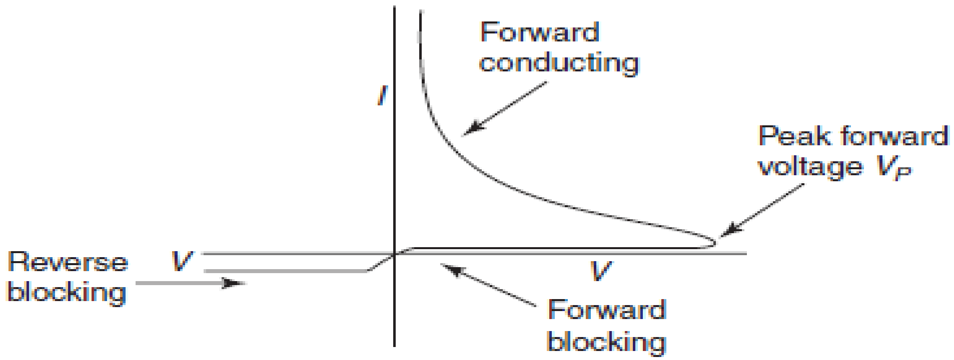


Figure 8-2 I–V characteristics of a two terminal *p–n–p–n* device

SCR in Forward Bias:

- There are two different states in which we can examine the SCR in the forward-biased condition:

  (i) The high- impedance or forward-blocking state

  (ii) The low-impedance or forward-conducting state

  At a critical peak forward voltage *Vp, the SCR switches from the blocking state to the conducting state, as* shown in Fig. 8-2.
- A positive voltage places junction *j1 and j3 under forward-bias, and the centre junction j2 under reverse-bias.*
- The for ward voltage in the blocking state appears across the reverse-biased junc tion *j2 as the applied voltage V is increased. The voltage from the anode A to cathode C, as shown in Fig. 8-1, is very small after switching* to the forward-conducting state, and all three junctions are forward-biased. The junction *j2 switches from* reverse-bias to forward-bias..

SCR in Reverse Bias:

- In the reverse-blocking state the junctions *j1 and j3 are reverse-biased, and j2 is forward-biased.*
- The supply of electrons and holes to junction *j2 is restricted, and due to the thermal generation of* electron–hole pairs near junctions *j1 and j2 the device current is a small saturation current.*
- *In the reverse blocking* condition the current remains small until avalanche breakdown occurs at a large reverse-bias of several thousand volts.
- An SCR *p–n–p–n structure is equivalent to* one *p–n–p transistor and one n–p–n transistor sharing some common terminals.*

- Collector current $I_{C1} = \alpha_1 i + I_{CO1}$ *having a transfer ratio* α_1 *for the p–n–p.*
- Collector current $I_{C2} = \alpha_2 i + I_{CO2}$ *having a transfer ratio a2 for the n–p–n.*
- I_{CO1} *and* I_{CO2} *stand for the respective* collector-saturation currents.

$$I_{C1} = \alpha_1 i + I_{CO1} = I_{B2} \qquad \text{(8-1)}$$

$$I_{C2} = \alpha_2 i + I_{CO2} = I_{B1} \qquad \text{(8-2)}$$

SCR in Reverse Bias:

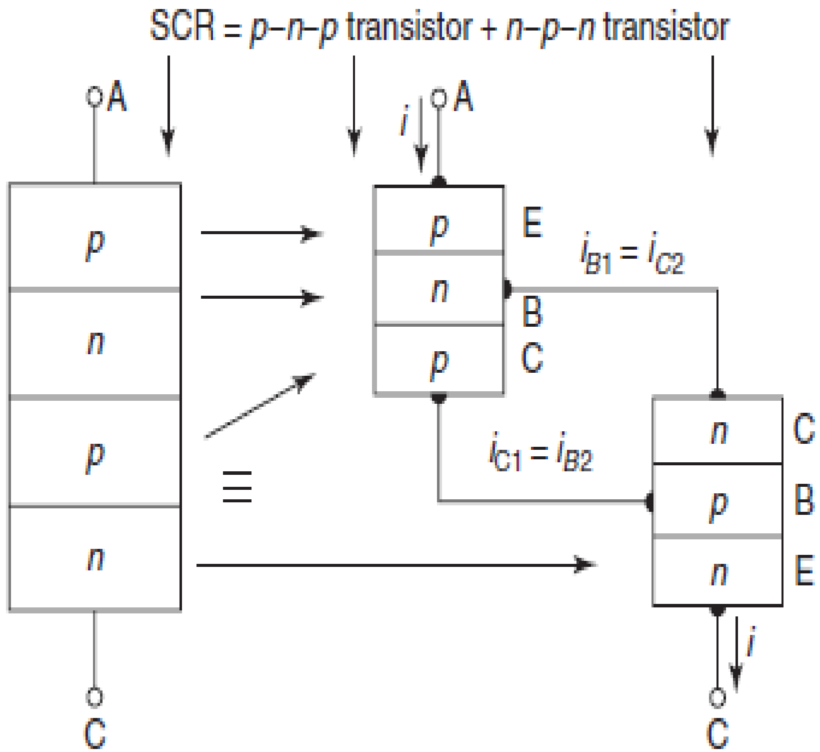


Figure 8-3 An SCR *p–n–p–n*: a combination of one *p–n–p* transistor and one *n–p–n* transistor

SCR in Reverse Bias:

- The total current through the SCR is the sum of *iC1 and iC2:*
- $I_{C1} + I_{=} i$ ....(8-3)
- Substituting the values of collector current from Eqs. (8-1) and (8-2) in Eq. (8-3) we get:
- $i(\alpha 1 + \alpha 2) + I_{CO1} + I_{CO2} = i$
- $i = (I_{CO1} + I_{CO2})/(1 - \alpha 1 + \alpha 2)$ ....(8-4)
- **<u>Case I:</u> When** *(α1 + α2)* **→ *1, then the SCR current i* → *infinite.***
- As the sum of the values of alphas tends to unity, the SCR current *i increases rapidly. The derivation is no*
- longer valid as *(α1 + α2) equals unity.*
- **<u>Case II:</u> When** *(α1 + α2* **→ *0, i.e., when the summation value of alphas goes to zero, the SCR resultant current*** can be expressed as:
- $i = I_{CO1} + I_{CO2}$ ....(8-5)
- The current, *i, passing through the SCR is very small. It is the combined collector-saturation currents of the* two equivalent transistors as long as the sum *(α1 + α2) is very small or almost near zero.*

I–V Characteristics of the SCR:

- **Forward-Blocking State:**
- When the device is biased in the forward-blocking state, as shown in Fig. 8-4(a), the applied voltage appears primarily across the reverse-biased junction *j2. Al though the junctions j1 and j3 are forward-biased, the current* is small.

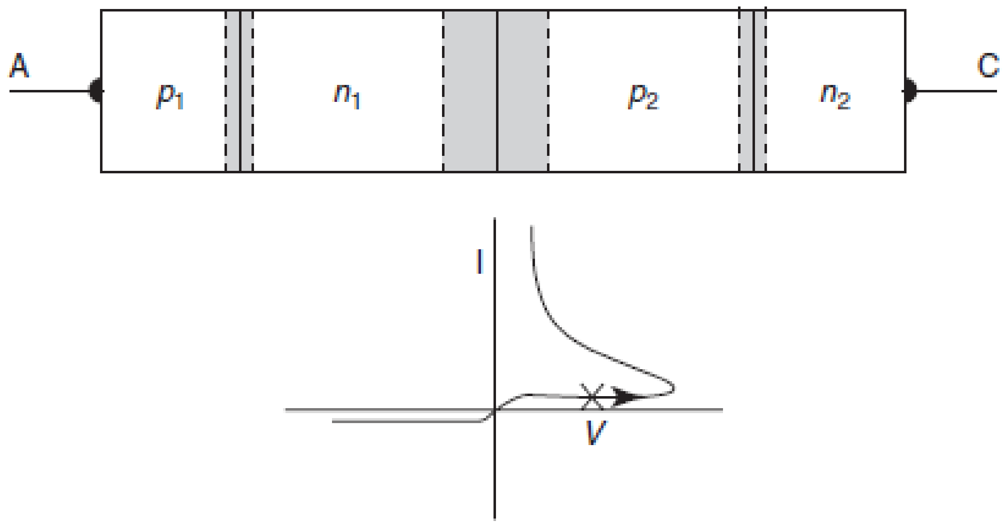


Figure 8-4 (a) The forward-blocking state of the SCR

I–V Characteristics of the SCR:

- **<u>Forward-Conducting State of the SCR</u>:**

  As the value of ($\alpha 1 + \alpha 2$) *approaches unity through one of the mechanisms ,many holes* injected at *j1 survive to be swept across j2 into p2.*

- *This process helps feed the recombination in p2 and support* the injection of holes into *n2. In a similar manner, the transistor action of electrons injected at j3 and collected* at *j2 supplies electrons for n1.*
- *The current through the device can be much* ***larger.***

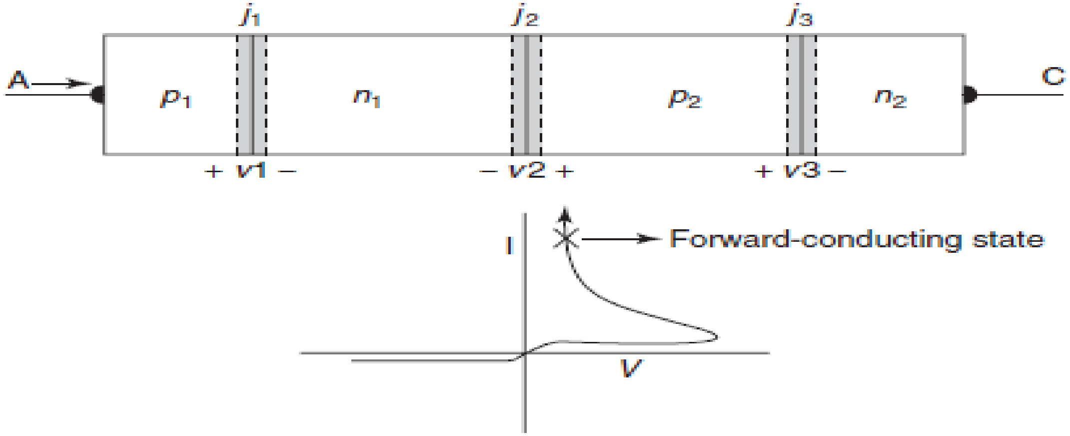


Figure 8-4 (b) Forward-conducting state of the SCR

Series operation of SCRs

If the input voltage is higher than the voltage rating of the available SCR, two or more SCRs must be connected in series.

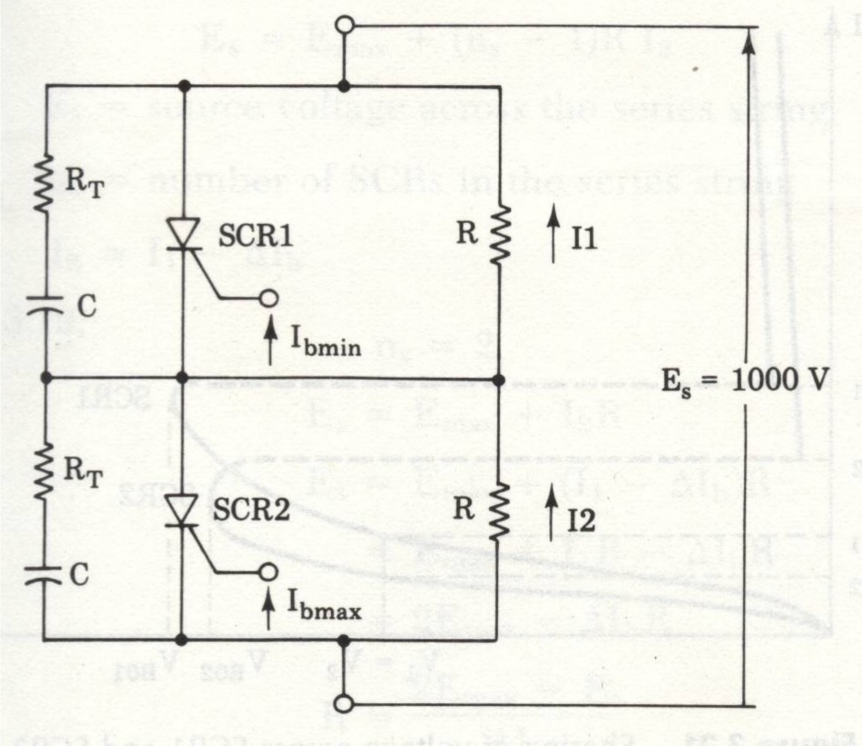


Figure 3.19. Two SCRs in series.

Series operation of SCRs

Under steady state condition ,external resistor (R) have to be connected across each SCR. And here the SCR currents will differs and hence the new characteristics will appears.

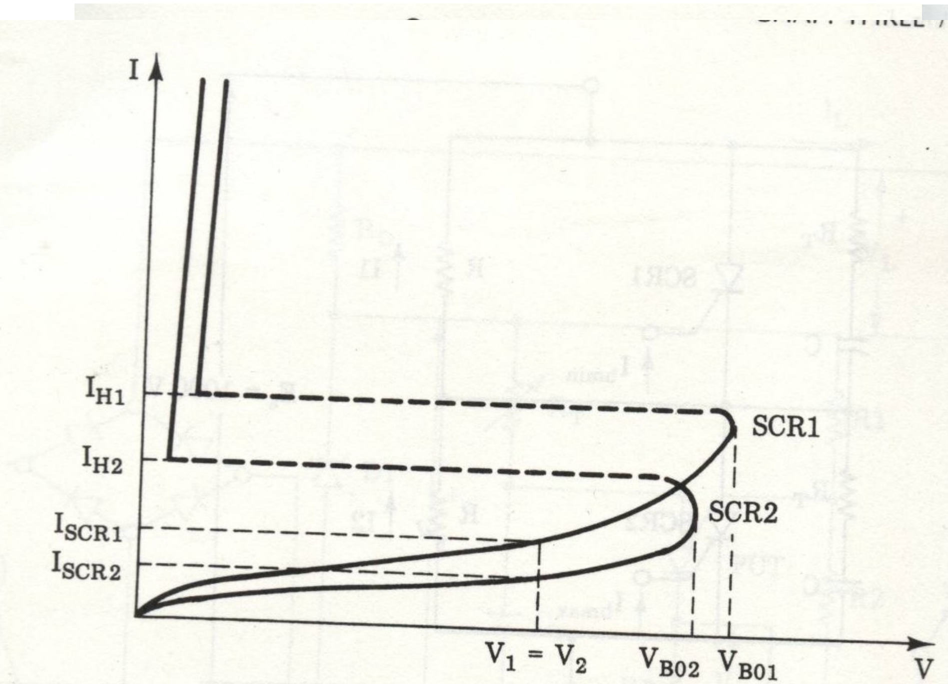


Figure 3.21. Sharing of voltage across SCR1 and SCR2.

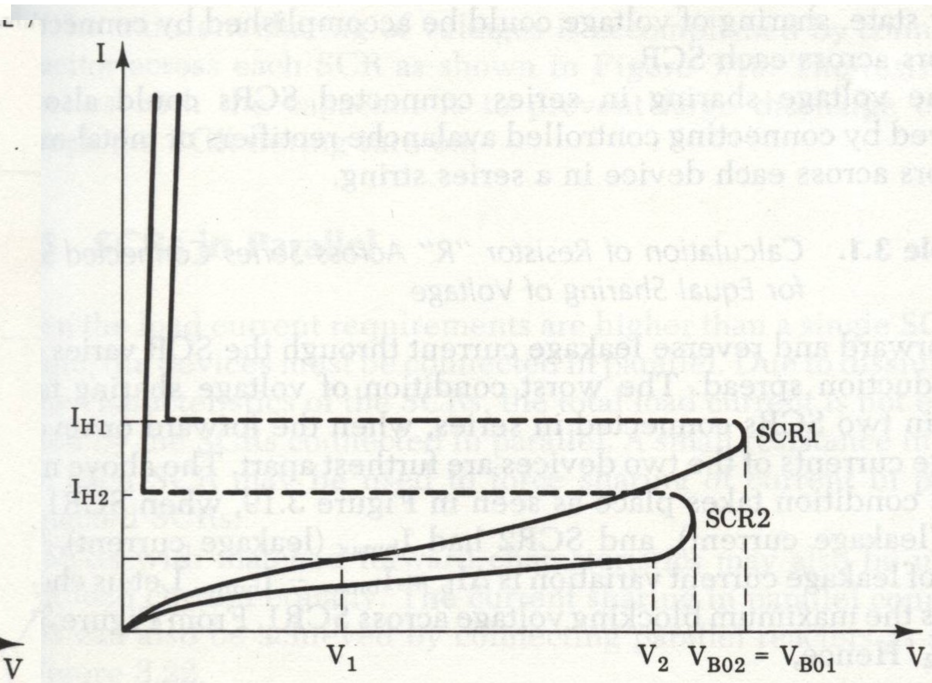


Figure 3.20. SCR V-I characteristics.

Series operation of SCRs

The transient sharing of voltages is accomplished by connecting capacitor across each SCR.

The resistor RT in series with the capacitor is to prevent large discharge current through Scr during turn on.

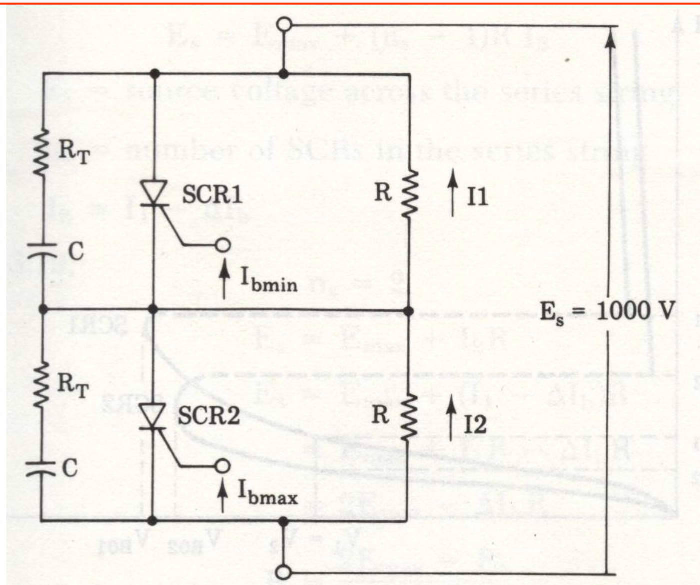


Figure 3.19. Two SCRs in series.

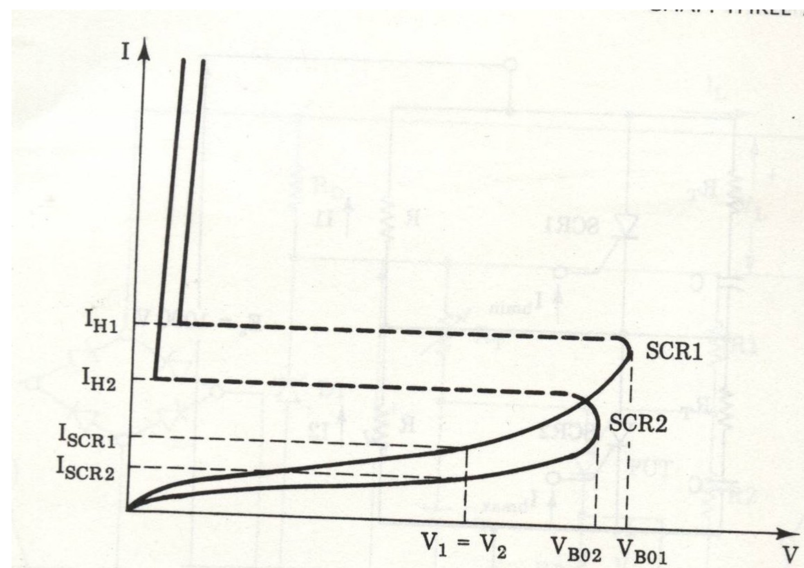


Figure 3.21. Sharing of voltage across SCR1 and SCR2.

Parallel operation of SCRs

When the current through Scr1 increase over that Scr2, an opposing voltage is induced proportional to the difference in current through Scr1. then boosting voltage is induced in series with scr2 increasing the current flow through the device.

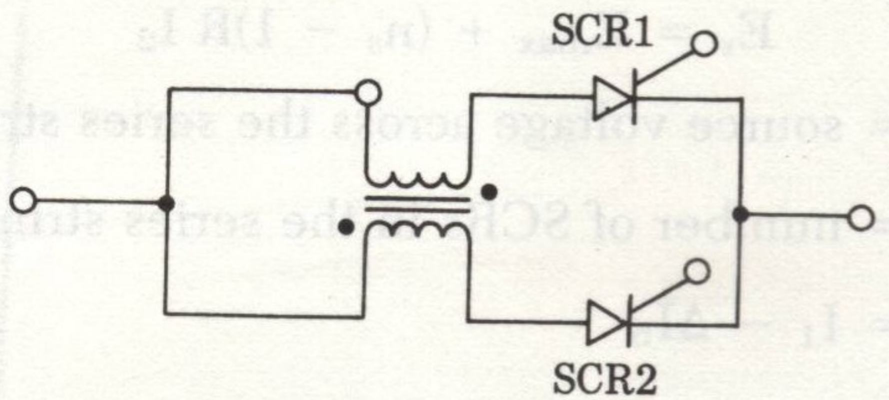


Figure 3.22. Current sharing in SCRs with parallel reactors.

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