

# 20

# Silicon Controlled Rectifiers

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## INTRODUCTION

**T**he silicon controlled rectifier (abbreviated as *SCR*) is a three-terminal semiconductor switching device which is probably the most important circuit element after the diode and the transistor. Invented in 1957, an *SCR* can be used as a controlled switch to perform various functions such as rectification, inversion and regulation of power flow. The *SCR* has assumed paramount importance in electronics because it can be produced in versions to handle currents upto several thousand amperes and voltages upto more than 1 kV.

The *SCR* has appeared in the market under different names such as thyristor, thyrode transistor. It is a unidirectional power switch and is being extensively used in switching d.c. and a.c., rectifying a.c. to give controlled d.c. output, converting d.c. into a.c. etc. In this chapter, we shall examine the various characteristics of silicon controlled rectifiers and their increasing applications in power electronics.

## 20.1 Silicon Controlled Rectifier (SCR)

A silicon \*controlled rectifier is a semiconductor \*\*device that acts as a true electronic switch. It can

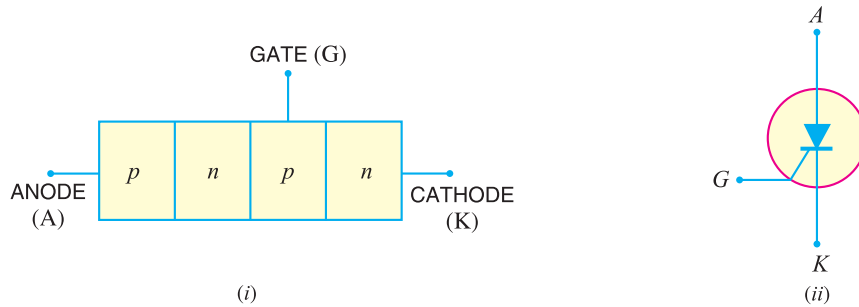
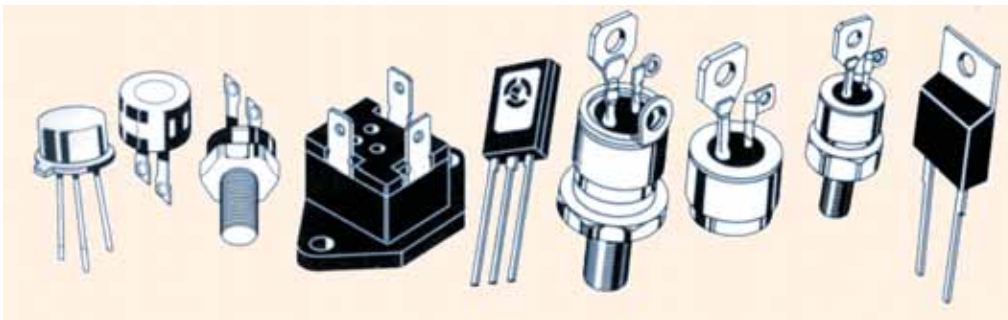


Fig. 20.1

change alternating current into direct current and at the same time can control the amount of power fed to the load. Thus SCR combines the features of a rectifier and a transistor.

**Constructional details.** When a  $pn$  junction is added to a junction transistor, the resulting three  $pn$  junction device is called a silicon controlled rectifier. Fig. 20.1 (i) shows its construction. It is clear that it is essentially an ordinary rectifier ( $pn$ ) and a junction transistor ( $nnp$ ) combined in one unit to form  $pnpn$  device. Three terminals are taken; one from the outer  $p$ -type material called *anode*  $A$ , second from the outer  $n$ -type material called *cathode*  $K$  and the third from the base of transistor section and is called *gate*  $G$ . In the normal operating conditions of SCR, anode is held at high positive potential *w.r.t.* cathode and gate at small positive potential *w.r.t.* cathode. Fig. 20.1 (ii) shows the symbol of SCR.

The silicon controlled rectifier is a solid state equivalent of thyatron. The gate, anode and cathode of SCR correspond to the grid, plate and cathode of thyatron. For this reason, SCR is sometimes called *thyristor*.



Typical SCR Packages

## 20.2 Working of SCR

In a silicon controlled rectifier, load is connected in series with anode. The anode is always kept at positive potential *w.r.t.* cathode. The working of SCR can be studied under the following two heads:

- \* **Why not germanium controlled rectifier ?** The device is made of silicon because leakage current in silicon is very small as compared to germanium. Since the device is used as a switch, it will carry leakage current in the off condition which should be as small as possible.
- \*\* It got this name because it is a silicon device and is used as a rectifier and that rectification can be controlled.

(i) **When gate is open.** Fig. 20.2 shows the SCR circuit with gate open *i.e.* no voltage applied to the gate. Under this condition, junction  $J_2$  is reverse biased while junctions  $J_1$  and  $J_3$  are forward biased. Hence, the situation in the junctions  $J_1$  and  $J_3$  is just as in a *npn* transistor with base open. Consequently, no current flows through the load  $R_L$  and the SCR is *cut off*. However, if the applied voltage is gradually increased, a stage is reached when \* reverse biased junction  $J_2$  breaks down. The SCR now conducts \*\* heavily and is said to be in the *ON* state. The applied voltage at which SCR conducts heavily without gate voltage is called *Breakover voltage*.

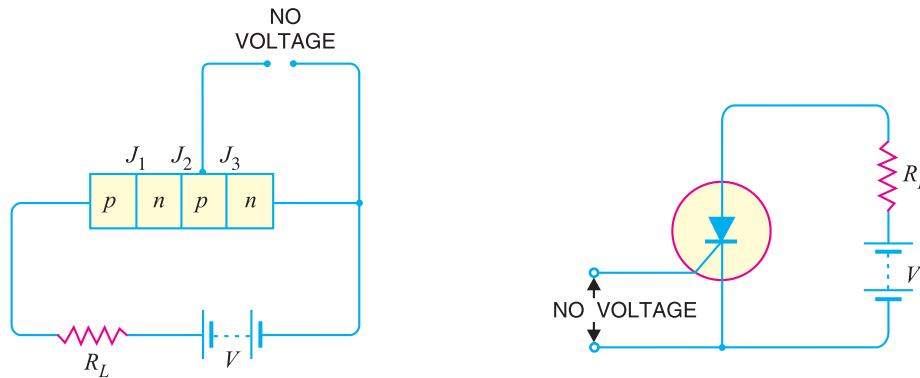


Fig. 20.2

(ii) **When gate is positive w.r.t. cathode.** The SCR can be made to conduct heavily at smaller applied voltage by applying a small positive potential to the gate as shown in Fig. 20.3. Now junction  $J_3$  is forward biased and junction  $J_2$  is reverse biased. The electrons from *n*-type material start moving across junction  $J_3$  towards left whereas holes from *p*-type towards the right. Consequently, the electrons from junction  $J_3$  are attracted across junction  $J_2$  and gate current starts flowing. As soon as the gate current flows, anode current increases. The increased anode current in turn makes more electrons available at junction  $J_2$ . This process continues and in an extremely small time, junction  $J_2$  breaks down and the SCR starts conducting heavily. *Once SCR starts conducting, the gate* (the reason for this name is obvious) *loses all control*. Even if gate voltage is removed, the anode current does not decrease at all. The only way to stop conduction (*i.e.* bring SCR in off condition) is to reduce the applied voltage to zero.

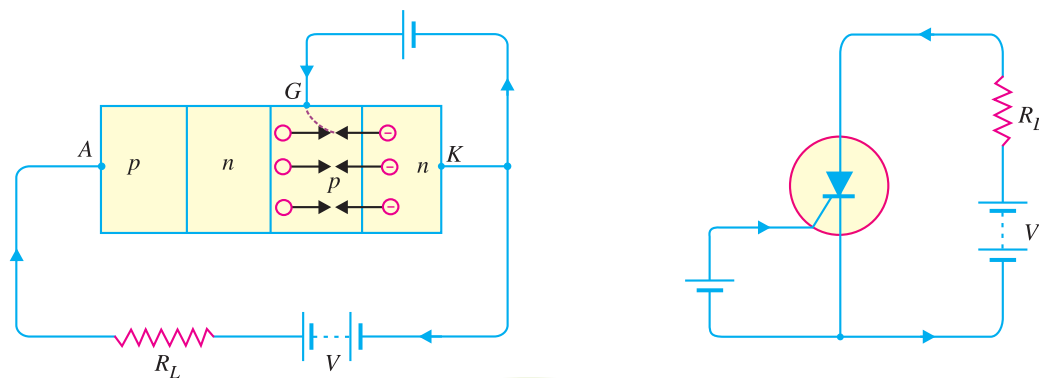


Fig. 20.3

\* The whole applied voltage  $V$  appears as reverse bias across junction  $J_2$  as junctions  $J_1$  and  $J_3$  are forward biased.  
 \*\* Because  $J_1$  and  $J_3$  are forward biased and  $J_2$  has broken down.

**Conclusion.** The following conclusions are drawn from the working of SCR :

(i) An SCR has two states *i.e.* either it does not conduct or it conducts heavily. There is no state inbetween. Therefore, SCR behaves like a switch.

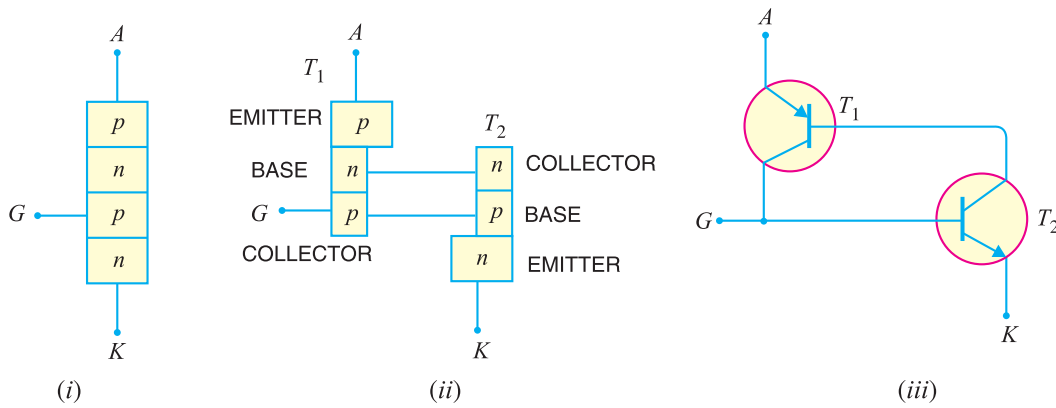
(ii) There are two ways to turn on the SCR. The first method is to keep the gate open and make the supply voltage equal to the breakover voltage. The second method is to operate SCR with supply voltage less than breakover voltage and then turn it on by means of a small voltage ( typically 1.5 V, 30 mA) applied to the gate.

(iii) Applying small positive voltage to the gate is the normal way to close an SCR because the breakover voltage is usually much greater than supply voltage.

(iv) To open the SCR (*i.e.* to make it non-conducting ), reduce the supply voltage to zero.

### 20.3 Equivalent Circuit of SCR

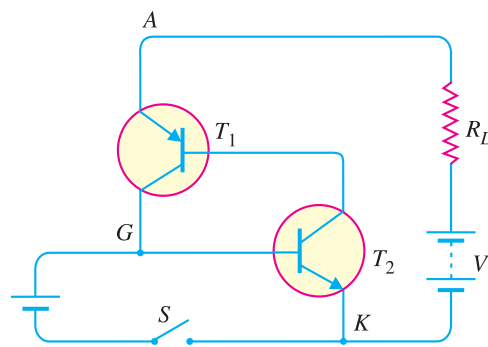
The SCR shown in Fig. 20.4 (i) can be visualised as separated into two transistors as shown in



**Fig. 20.4**

Fig. 20.4 (ii). Thus, the equivalent circuit of SCR is composed of *pnp* transistor and *npn* transistor connected as shown in Fig. 20.4. (iii). It is clear that collector of each transistor is coupled to the base of the other, thereby making a positive feedback loop.

The working of SCR can be easily explained from its equivalent circuit. Fig. 20.5. shows the equivalent circuit of SCR with supply voltage  $V$  and load resistance  $R_L$ . Assume the supply voltage  $V$  is less than breakover voltage as is usually the case. With gate open (*i.e.* switch  $S$  open), there is no base current in transistor  $T_2$ . Therefore, no current flows in the collector of  $T_2$  and hence that of  $T_1$ . Under such conditions, the SCR is open. However, if switch  $S$  is closed, a small gate current will flow through the base of  $T_2$  which means its collector current will increase. The collector current of  $T_2$  is the base current of  $T_1$ . Therefore, collector current of  $T_1$  increases. But collector current of  $T_1$  is the base current of  $T_2$ . This action is accumulative since an increase of current in one transistor causes an increase of current in the other transistor. As a result of this action, both



**Fig. 20.5**

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transistors are driven to saturation, and heavy current flows through the load  $R_L$ . Under such conditions, the SCR closes.

### 20.4 Important Terms

The following terms are much used in the study of SCR :

- (i) Breakover voltage
- (ii) Peak reverse voltage
- (iii) Holding current
- (iv) Forward current rating
- (v) Circuit fusing rating

(i) **Breakover voltage.** *It is the minimum forward voltage, gate being open, at which SCR starts conducting heavily i.e. turned on.*

Thus, if the breakover voltage of an SCR is 200 V, it means that it can block a forward voltage (i.e. SCR remains open) as long as the supply voltage is less than 200 V. If the supply voltage is more than this value, then SCR will be turned on. In practice, the SCR is operated with supply voltage less than breakover voltage and it is then turned on by means of a small voltage applied to the gate. Commercially available SCRs have breakover voltages from about 50 V to 500 V.

(ii) **Peak reverse voltage (PRV).** *It is the maximum reverse voltage (cathode positive w.r.t. anode) that can be applied to an SCR without conducting in the reverse direction.*

Peak reverse voltage (PRV) is an important consideration while connecting an SCR in an a.c. circuit. During the negative half of a.c. supply, reverse voltage is applied across SCR. If PRV is exceeded, there may be avalanche breakdown and the SCR will be damaged if the external circuit does not limit the current. Commercially available SCRs have PRV ratings upto 2.5 kV.

(iii) **Holding current.** *It is the maximum anode current, gate being open, at which SCR is turned off from ON conditions.*

As discussed earlier, when SCR is in the conducting state, it cannot be turned OFF even if gate voltage is removed. The only way to turn off or open the SCR is to reduce the supply voltage to almost zero at which point the internal transistor comes out of saturation and opens the SCR. The anode current under this condition is very small (a few mA) and is called *holding current*. Thus, if an SCR has a holding current of 5mA, it means that if anode current is made less than 5mA, then SCR will be turned off.

(iv) **Forward current rating.** *It is the maximum anode current that an SCR is capable of passing without destruction.*

Every SCR has a safe value of forward current which it can conduct. If the value of current exceeds this value, the SCR may be destroyed due to intensive heating at the junctions. For example, if an SCR has a forward current rating of 40A, it means that the SCR can safely carry only 40 A. Any attempt to exceed this value will result in the destruction of the SCR. Commercially available SCRs have forward current ratings from about 30A to 100A.

(v) **Circuit fusing ( $I^2t$ ) rating.** *It is the product of square of forward surge current and the time of duration of the surge i.e.,*

$$\text{Circuit fusing rating} = I^2t$$

The circuit fusing rating indicates the maximum forward surge current capability of SCR. For example, consider an SCR having circuit fusing rating of  $90 A^2s$ . If this rating is exceeded in the SCR circuit, the device will be destroyed by excessive power dissipation.

**Example 20.1.** *An SCR has a breakover voltage of 400 V, a trigger current of 10 mA and holding current of 10 mA. What do you infer from it ? What will happen if gate current is made 15 mA ?*

**Solution.** (i) **Breakover voltage of 400 V.** It means that if gate is open and the supply voltage is

400 V, then SCR will start conducting heavily. However, as long as the supply voltage is less than 400 V, the SCR stays open *i.e.* it does not conduct.

(ii) **Trigger current of 10 mA.** It means that if the supply voltage is less than breakover voltage (*i.e.* 400 V) and a minimum gate current of 10 mA is passed, the SCR will close *i.e.* starts conducting heavily. The SCR will not conduct if the gate current is less than 10 mA. It may be emphasised that triggering is the normal way to close an SCR as the supply voltage is normally much less than the breakover voltage.

(iii) **Holding current of 10 mA.** When the SCR is conducting, it will not open (*i.e.* stop conducting) even if triggering current is removed. However, if supply voltage is reduced, the anode current also decreases. When the anode current drops to 10 mA, the holding current, the SCR is turned off.

(iv) If gate current is increased to 15 mA, the SCR will be turned on lower supply voltage.

**Example 20.2.** An SCR in a circuit is subjected to a 50 A surge that lasts for 12 ms. Determine whether or not this surge will destroy the device. Given that circuit fusing rating is 90 A<sup>2</sup>s.

**Solution.** Circuit fusing rating =  $I^2t = (50)^2 \times (12 \times 10^{-3}) = 30 \text{ A}^2\text{s}$

Since this value is well below the maximum rating of 90 A<sup>2</sup>s, the device will not be destroyed.

**Example 20.3.** An SCR has a circuit fusing rating of 50 A<sup>2</sup>s. The device is being used in a circuit where it could be subjected to a 100 A surge. Determine the maximum allowable duration of such a surge.

**Solution.**  $t_{max} = \frac{I^2t \text{ (rating)}}{I_s^2}$  where  $I_s =$  known value of surge current

$$\therefore t_{max} = \frac{50}{(100)^2} = 5 \times 10^{-3} \text{ s} = 5 \text{ ms}$$

**Example 20.4.** A 220Ω resistor is connected in series with the gate of an SCR as shown in Fig. 20.6. The gate current required to fire the SCR is 7mA. What is the input voltage ( $V_{in}$ ) required to fire the SCR ?

**Solution.** The input voltage must overcome the junction voltage between the gate and cathode (0.7V) and also cause 7mA to flow through the 220Ω resistor. According to Kirchhoff's voltage law,  $V_{in}$  is given by;

$$\begin{aligned} V_{in} &= V_{GK} + I_G R \\ &= 0.7\text{V} + (7\text{mA})(220\Omega) = 2.24\text{V} \end{aligned}$$

### 20.5 V-I Characteristics of SCR

It is the curve between anode-cathode voltage (V) and anode current (I) of an SCR at constant gate current. Fig. 20.7 shows the V-I characteristics of a typical SCR.

(i) **Forward characteristics.** When anode is positive *w.r.t.* cathode, the curve between V and I is called the forward characteristic. In Fig. 20.7, OABC is the forward characteristic of SCR at  $I_G = 0$ . If the supply voltage is increased from zero, a point is reached (point A) when the SCR starts conducting. Under this condition, the voltage across SCR suddenly drops as shown by dotted curve AB and most of supply voltage appears across the load resistance  $R_L$ . If proper gate current is made to flow, SCR can close at much smaller supply voltage.

(ii) **Reverse characteristics.** When anode is negative *w.r.t.* cathode, the curve between V and I is known as *reverse characteristic*. The reverse voltage does come across SCR when it is operated with a.c. supply. If the reverse voltage is gradually increased, at first the anode current remains small (*i.e.* leakage current) and at some reverse voltage, avalanche breakdown occurs and the SCR starts conducting heavily in the reverse direction as shown by the curve DE. This maximum reverse voltage at which SCR starts conducting heavily is known as *reverse breakdown voltage*.

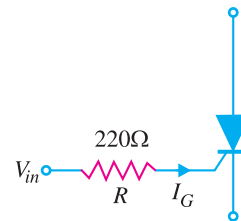


Fig. 20.6

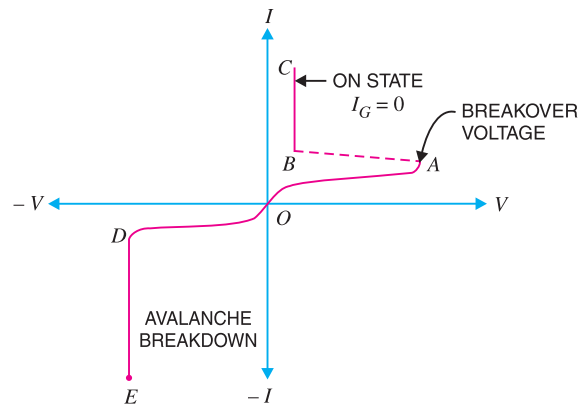


Fig. 20.7

## 20.6 SCR in Normal Operation

In order to operate the *SCR* in normal operation, the following points are kept in view :

- (i) The supply voltage is generally much less than breakover voltage.
- (ii) The *SCR* is turned on by passing an appropriate amount of gate current (a few mA) and not by breakover voltage.
- (iii) When *SCR* is operated from a.c. supply, the peak reverse voltage which comes during negative half-cycle should not exceed the reverse breakdown voltage.
- (iv) When *SCR* is to be turned *OFF* from the *ON* state, anode current should be reduced to holding current.
- (v) If gate current is increased above the required value, the *SCR* will close at much reduced supply voltage.

## 20.7 SCR as a Switch

The *SCR* has only two states, namely; *ON* state and *OFF* state and no state inbetween. When appropriate gate current is passed, the *SCR* starts conducting heavily and remains in this position indefinitely even if gate voltage is removed. This corresponds to the *ON* condition. However, when the anode current is reduced to the holding current, the *SCR* is turned *OFF*. It is clear that behaviour of *SCR* is similar to a mechanical switch. As *SCR* is an electronic device, therefore, it is more appropriate to call it an *electronic switch*.

**Advantages of SCR as a switch.** An *SCR* has the following advantages over a mechanical or electromechanical switch (relay) :

- (i) It has no moving parts. Consequently, it gives noiseless operation at high efficiency.
- (ii) The switching speed is very high upto  $10^9$  operations per second.
- (iii) It permits control over large current (30–100 A) in the load by means of a small gate current (a few mA).
- (iv) It has small size and gives trouble free service.

## 20.8 SCR Switching

We have seen that *SCR* behaves as a switch *i.e.* it has only two states *viz.* *ON* state and *OFF* state. It is profitable to discuss the methods employed to turn-on or turn-off an *SCR*.

**1. SCR turn-on methods.** In order to turn on the SCR, the gate voltage  $V_G$  is increased upto a minimum value to initiate triggering. This minimum value of gate voltage at which SCR is turned ON is called *gate triggering voltage*  $V_{GT}$ . The resulting gate current is called gate *triggering current*  $I_{GT}$ . Thus to turn on an SCR all that we have to do is to apply positive gate voltage equal to  $V_{GT}$  or pass a gate current equal to  $I_{GT}$ . For most of the SCRs,  $V_{GT} = 2$  to  $10$  V and  $I_{GT} = 100 \mu\text{A}$  to  $1500$  mA. We shall discuss two methods to turn on an SCR.

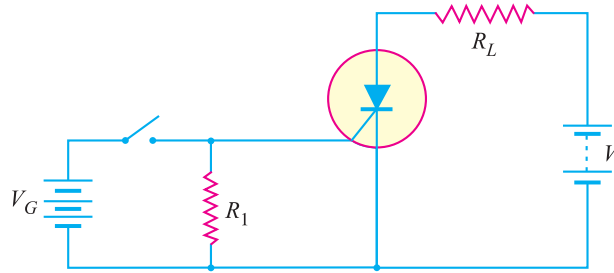


Fig. 20.8

(i) *D.C. gate trigger circuit.* Fig. 20.8 shows a typical circuit used for triggering an SCR with a d.c. gate bias. When the switch is closed, the gate receives sufficient positive voltage ( $= V_{GT}$ ) to turn the SCR on. The resistance  $R_1$  connected in the circuit provides noise suppression and improves the turn-on time. The turn-on time primarily depends upon the magnitude of the gate current. The higher the gate-triggered current, the shorter the turn-on time.

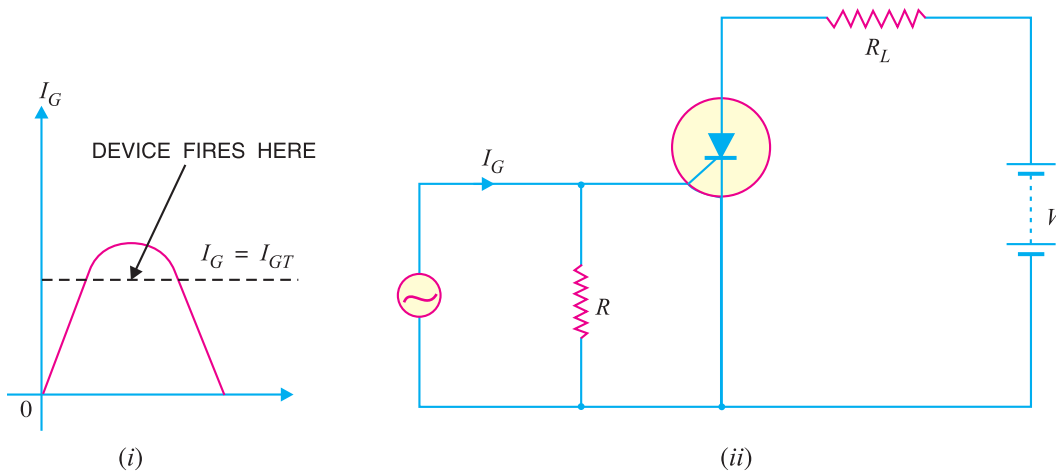


Fig. 20.9

(ii) *A.C. trigger circuit.* An SCR can also be turned on with positive cycle of a.c. gate current. Fig. 20.9 (ii) shows such a circuit. During the positive half-cycle of the gate current, at some point  $I_G = I_{GT}$ , the device is turned on as shown in Fig. 20.9 (i).

**2. SCR turn-off methods.** The SCR turn-off poses more problems than SCR turn-on. It is because once the device is ON, the gate loses all control. There are many methods of SCR turn-off but only two will be discussed.



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(i) **Anode current interruption.** When the anode current is reduced below a minimum value called holding current, the SCR turns off. The simple way to turn off the SCR is to open the line switch  $S$  as shown in Fig. 20.10.

(ii) **Forced commutation.** The method of discharging a capacitor in parallel with an SCR to turn off the SCR is called forced commutation. Fig. 20.11 shows the forced commutation of SCR where capacitor  $C$  performs the commutation. Assuming the SCRs are switches with SCR1 ON and SCR2 OFF, current flows through the load and  $C$  as shown in Fig. 20.11. When SCR2 is triggered on,  $C$  is effectively paralleled across SCR1. The charge on  $C$  is then opposite to SCR1's forward voltage, SCR1 is thus turned off and the current is transferred to  $R$ -SCR2 path.

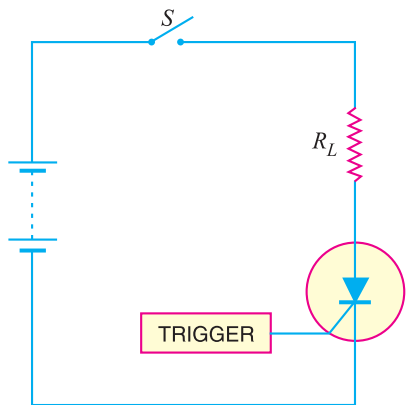


Fig. 20.10

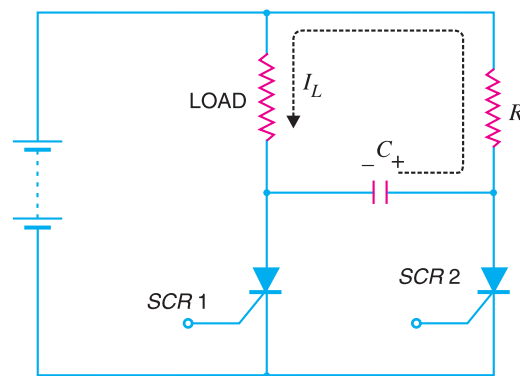


Fig. 20.11

### 20.9 SCR Half-Wave Rectifier

One important application of an SCR is the controlled half-wave rectification. Fig. 20.12 (i) shows the circuit of an SCR half-wave rectifier. The a.c. supply to be rectified is supplied through the transformer. The load resistance  $R_L$  is connected in series with the anode. A variable resistance  $r$  is inserted in the gate circuit to control the gate current.

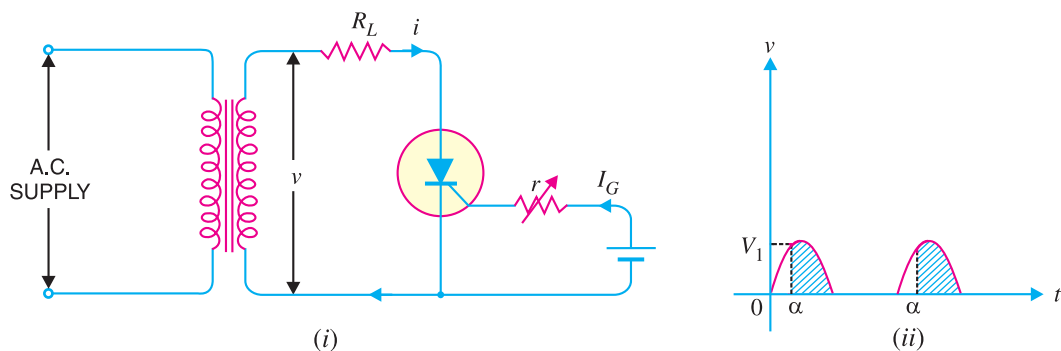


Fig. 20.12

**Operation.** The a.c. supply to be converted into d.c. supply is applied to the primary of the transformer. Suppose the peak reverse voltage appearing across secondary is less than the reverse

breakdown voltage of the SCR. This condition ensures that SCR will not break down during negative half-cycles of a.c. supply. The circuit action is as follows :

(i) During the negative half-cycles of a.c. voltage appearing across secondary, the SCR does not conduct regardless of the gate voltage. It is because in this condition, anode is negative *w.r.t.* cathode and also *PRV* is less than the reverse breakdown voltage.

(ii) The SCR will conduct during the positive half-cycles provided proper gate current is made to flow. The greater the gate current, the lesser the supply voltage at which SCR is turned ON. The gate current can be changed by the variable resistance *r* as shown in Fig. 20.12 (i).

(iii) Suppose that gate current is adjusted to such a value that SCR closes at a positive voltage  $V_1$  which is less than the peak voltage  $V_m$ . Referring to Fig. 20.12 (ii), it is clear that SCR will start conducting when secondary a.c. voltage becomes  $V_1$  in the positive half-cycle. Beyond this, the SCR will continue to conduct till voltage becomes zero at which point it is turned OFF. Again at the start of the next positive half-cycle, SCR will start conducting when secondary voltage becomes  $V_1$ .

(iv) Referring to Fig. 20.12 (ii), it is clear that firing angle is  $\alpha$  *i.e.* at this angle in the positive half-cycle, SCR starts conduction. The conduction angle is  $\phi (= 180^\circ - \alpha)$ .

It is worthwhile to distinguish between an ordinary half-wave rectifier and SCR half-wave rectifier. Whereas an ordinary half-wave rectifier will conduct full positive half-cycle, an SCR half-wave rectifier can be made to conduct full or part of a positive half-cycle by proper adjustment of gate current. Therefore, an SCR can control power fed to the load and hence the name *controlled rectifier*.

**Mathematical treatment.** Referring to Fig. 20.12 (i), let  $v = V_m \sin \theta$  be the alternating voltage that appears across the secondary. Let  $\alpha$  be the firing angle. It means that rectifier will conduct from  $\alpha$  to  $180^\circ$  during the positive half-cycles.

$$\begin{aligned} \therefore \text{Average output, } V_{av} &= \frac{1}{2\pi} \int_{\alpha}^{180^\circ} V_m \sin \theta d\theta = \frac{V_m}{2\pi} \int_{\alpha}^{180^\circ} \sin \theta d\theta \\ &= \frac{V_m}{2\pi} [-\cos \theta]_{\alpha}^{180^\circ} \\ &= \frac{V_m}{2\pi} (\cos \alpha - \cos 180^\circ) \\ \therefore V_{av} &= \frac{V_m}{2\pi} (1 + \cos \alpha) \\ \text{Average current, } I_{av} &= \frac{V_{av}}{R_L} = \frac{V_m}{2\pi R_L} (1 + \cos \alpha) \end{aligned}$$

The following points may be noted :

(i) If the firing angle  $\alpha = 0^\circ$ , then full positive half-cycle will appear across the load  $R_L$  and the output current becomes :

$$I_{av} = \frac{V_m}{2\pi R_L} (1 + \cos 0^\circ) = \frac{V_m}{\pi R_L}$$

This is the value of average current for ordinary half-wave rectifier. This is expected since the full positive half-cycle is being conducted.

(ii) If  $\alpha = 90^\circ$ , then average current is given by :

$$I_{av} = \frac{V_m}{2\pi R_L} (1 + \cos 90^\circ) = \frac{V_m}{2\pi R_L}$$

This shows that greater the firing angle  $\alpha$ , the smaller is the average current and *vice-versa*.

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**Example 20.5.** A half-wave rectifier circuit employing an SCR is adjusted to have a gate current of 1 mA. The forward breakdown voltage of SCR is 100 V for  $I_g = 1 \text{ mA}$ . If a sinusoidal voltage of 200 V peak is applied, find :

- (i) firing angle                      (ii) conduction angle              (iii) average current.

Assume load resistance =  $100 \Omega$  and the holding current to be zero.

**Solution.**

$$v = V_m \sin \theta$$

Here,  $v = 100 \text{ V}$ ,  $V_m = 200 \text{ V}$

(i)  $\therefore 100 = 200 \sin \theta$

or  $\sin \theta = \frac{100}{200} = 0.5$

$\therefore \theta = \sin^{-1}(0.5) = 30^\circ$  i.e. Firing angle,  $\alpha = \theta = 30^\circ$

(ii) Conduction angle,  $\phi = 180^\circ - \alpha = 180^\circ - 30^\circ = 150^\circ$

(iii) Average voltage =  $\frac{V_m}{2\pi} (1 + \cos \alpha) = \frac{200}{2\pi} (1 + \cos 30^\circ) = 59.25 \text{ V}$

$\therefore$  Average current =  $\frac{\text{Average voltage}}{R_L} = \frac{59.25}{100} = 0.5925 \text{ A}$

**Example 20.6.** An SCR half-wave rectifier has a forward breakdown voltage of 150 V when a gate current of 1 mA flows in the gate circuit. If a sinusoidal voltage of 400 V peak is applied, find:

- (i) firing angle                      (ii) average output voltage  
(iii) average current for a load resistance of  $200 \Omega$               (iv) power output

Assume that the gate current is 1 mA throughout and the forward breakdown voltage is more than 400 V when  $I_g = 1 \text{ mA}$ .

**Solution.**

$$V_m = 400 \text{ V}, \quad v = 150 \text{ V}, \quad R_L = 200 \Omega$$

(i) Now  $v = V_m \sin \theta$

or  $\sin \theta = \frac{v}{V_m} = \frac{150}{400} = 0.375$

i.e. firing angle,  $\alpha (= \theta) = \sin^{-1} 0.375 = 22^\circ$

(ii) Average output voltage is

$$V_{av} = \frac{V_m}{2\pi} (1 + \cos 22^\circ) = \frac{400}{2\pi} (1 + \cos 22^\circ) = 122.6 \text{ V}$$

(iii) Average current,  $I_{av} = \frac{\text{average output voltage}}{R_L} = \frac{122.6}{200} = 0.613 \text{ A}$

(iv) Output power =  $V_{av} \times I_{av} = 122.6 \times 0.613 = 75.15 \text{ W}$

**Example 20.7.** An a.c. voltage  $v = 240 \sin 314 t$  is applied to an SCR half-wave rectifier. If the SCR has a forward breakdown voltage of 180 V, find the time during which SCR remains off.

**Solution.** The SCR will remain off till the voltage across it reaches 180 V. This is shown in Fig. 20.13. Clearly, SCR will remain off for  $t$  second.

Now  $v = V_m \sin 314 t$

Here  $v = 180 \text{ V}$ ;  $V_m = 240 \text{ V}$

$\therefore 180 = 240 \sin (314 t)$

$$\begin{aligned} \text{or } \sin 314 t &= \frac{180}{240} = 0.75 \\ \text{or } 314 t &= \sin^{-1}(0.75) \\ &= 48.6^\circ = 0.848 \text{ radian} \\ \therefore t &= \frac{0.848}{314} = 0.0027 \text{ sec} \\ &= \mathbf{2.7 \text{ millisecond}} \end{aligned}$$

**Example 20.8.** In an SCR half-wave rectifier circuit, what peak-load current will occur if we measure an average (d.c.) load current of 1A at a firing angle of 30° ?

**Solution.** Let  $I_m$  be the peak load current.

$$\begin{aligned} \text{Now, } I_{av} &= \frac{V_m}{2\pi R_L} (1 + \cos \alpha) \\ &= \frac{I_m}{2\pi} (1 + \cos \alpha) \quad (\text{Q } I_m = \frac{V_m}{R_L}) \\ \therefore I_m &= \frac{2\pi I_{av}}{1 + \cos \alpha} \\ \text{Here } I_{av} &= I_{dc} = 1 \text{ A ; } \alpha = 30^\circ \\ \therefore I_m &= \frac{2\pi \times 1}{1 + \cos 30^\circ} = \mathbf{3.36 \text{ A}} \end{aligned}$$

**Example 20.9.** Power (brightness) of a 100W, 110 V tungsten lamp is to be varied by controlling the firing angle of an SCR in a half-wave rectifier circuit supplied with 110 V a.c. What r.m.s. voltage and current are developed in the lamp at firing angle  $\alpha = 60^\circ$  ?

**Solution.** The a.c. voltage is given by;

$$v = V_m \sin \theta$$

Let  $\alpha$  be the firing angle as shown in Fig. 20.14. This means that the SCR will fire (i.e. start conducting) at  $\theta = \alpha$ . Clearly, SCR will conduct from  $\alpha$  to  $180^\circ$ .

$$\begin{aligned} E_{r.m.s.}^2 &= \frac{1}{2\pi} \int_{\alpha}^{\pi} V_m^2 \sin^2 \theta d\theta \\ &= V_m^2 \frac{2(\pi - \alpha) + \sin 2\alpha}{8\pi} \\ \therefore E_{r.m.s.} &= V_m \sqrt{\frac{2(\pi - \alpha) + \sin 2\alpha}{8\pi}} \end{aligned}$$

$$\text{Here, } V_m = \sqrt{2} \times 110 = 156 \text{ V ; } \alpha = 60^\circ = \pi/3$$

$$\therefore E_{r.m.s.} = 156 \sqrt{\frac{2(\pi - \pi/3) + \sin 120^\circ}{8\pi}} = \mathbf{70 \text{ V}}$$

$$\text{Lamp resistance, } R_L = \frac{V^2}{P} = \frac{(110)^2}{100} = 121 \Omega$$

$$\therefore I_{r.m.s.} = \frac{E_{r.m.s.}}{R_L} = \frac{70}{121} = \mathbf{0.58 \text{ A}}$$

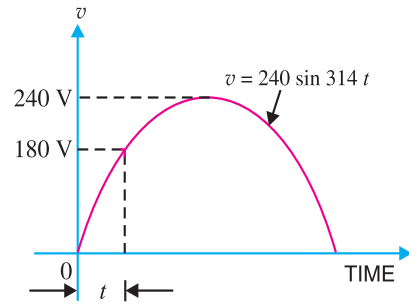


Fig. 20.13

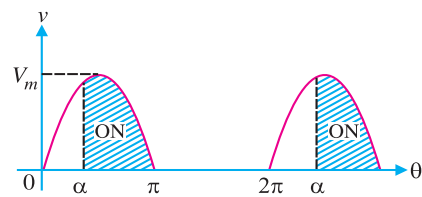


Fig. 20.14

\* On carrying out the integration.

**Comments.** The load current can be decreased by increasing the firing angle. The larger the value of  $\alpha$ , the smaller is the load current and vice-versa. This method of controlling power is very efficient because other methods, such as added series resistance, waste much power in the added control element.

### 20.10 SCR Full-Wave Rectifier

Fig. 20.15 (i) shows the circuit of SCR full-wave rectifier. It is exactly like an ordinary centre-tap circuit except that the two diodes have been replaced by two SCRs. The gates of both SCRs get their

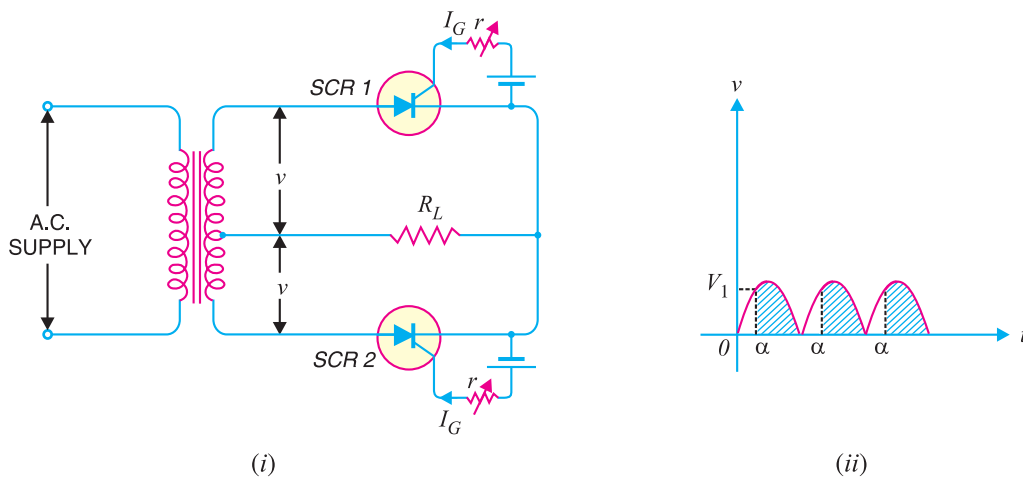


Fig. 20.15

supply from two gate controls. One SCR conducts during the positive half-cycle and the other during the negative half-cycle. Consequently, full-wave rectified output is obtained across the load.

**Operation.** The angle of conduction can be changed by adjusting the gate currents. Suppose the gate currents are so adjusted that SCRs conduct as the secondary voltage (across half winding) becomes  $V_1$ . During the positive half-cycle of a.c. across secondary, the upper end of secondary is positive and the lower end negative. This will cause SCR1 to conduct. However, the conduction will start only when the voltage across the upper half of secondary becomes  $V_1$  as shown in Fig. 20.15 (ii). In this way, only shaded portion of positive half-cycle will pass through the load.

During the negative half-cycle of a.c. input, the upper end of secondary becomes negative and the lower end positive. This will cause SCR2 to conduct when the voltage across the lower half of secondary becomes  $V_1$ . It may be seen that current through the load is in the same direction (d.c.) on both half-cycles of input a.c. The obvious advantage of this circuit over ordinary full-wave rectifier circuit is that by adjusting the gate currents, we can change the conduction angle and hence the output voltage.

**Mathematical treatment.** Referring to Fig. 20.15 (i), let  $v = V_m \sin \theta$  be the alternating voltage that appears between centre tap and either end of secondary. Let  $\alpha$  be the firing angle.

$$\begin{aligned} \text{Average output, } V_{av} &= \frac{1}{\pi} \int_{\alpha}^{180^{\circ}} V_m \sin \theta \, d\theta = \frac{V_m}{\pi} \int_{\alpha}^{180^{\circ}} \sin \theta \, d\theta \\ &= \frac{V_m}{\pi} [-\cos \theta]_{\alpha}^{180^{\circ}} = \frac{V_m}{\pi} (\cos \alpha - \cos 180^{\circ}) \end{aligned}$$

$$\therefore V_{av} = \frac{V_m}{\pi} (1 + \cos \alpha)$$

This value is double that of a half-wave rectifier. It is expected since now negative half-cycle is also rectified.

$$\text{Average current, } I_{av} = \frac{V_{av}}{R_L} = \frac{V_m}{\pi R_L} (1 + \cos \alpha)$$

**Example 20.10.** An SCR full-wave rectifier supplies to a load of 100 Ω. If the peak a.c. voltage between centre tap and one end of secondary is 200V, find (i) d.c. output voltage and (ii) load current for a firing angle of 60°.

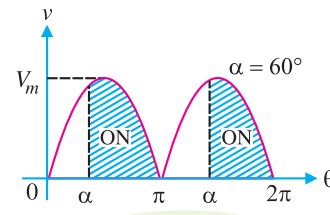
**Solution.**  $V_m = 200 \text{ V}; \alpha = 60^\circ; R_L = 100 \Omega$

(i) D.C. output voltage,  $V_{av} = \frac{V_m}{\pi} (1 + \cos \alpha) = \frac{200}{\pi} (1 + \cos 60^\circ) = \mathbf{95.5 \text{ V}}$

(ii) Load current,  $I_{av} = \frac{V_{av}}{R_L} = \frac{95.5}{100} = \mathbf{0.955 \text{ A}}$

**Example 20.11.** Power (brightness) of a 100 W, 110 V lamp is to be varied by controlling firing angle of SCR full-wave circuit; the r.m.s. value of a.c. voltage appearing across each SCR being 110 V. Find the r.m.s. voltage and current in the lamp at firing angle of 60°.

**Solution.** Let  $v = v_m \sin \theta$  be the alternating voltage that appears between centre tap and either end of the secondary. Let  $\alpha$  be the firing angle as shown in Fig. 20.16. This means that SCR will conduct at  $\theta = \alpha$ . Clearly, SCR circuit will conduct from  $\alpha$  to 180°.



$$E_{r.m.s.}^2 = \frac{1}{\pi} \int_{\alpha}^{\pi} V_m^2 \sin^2 \theta d\theta$$

$$= V_m^2 \frac{2(\pi - \alpha) + \sin 2\alpha}{4\pi}$$

$$\therefore E_{r.m.s.} = V_m \sqrt{\frac{2(\pi - \alpha) + \sin 2\alpha}{4\pi}}$$

Here  $V_m = 110 \times \sqrt{2} = 156 \text{ V}; \alpha = 60^\circ$

$$\therefore E_{r.m.s.} = 156 \sqrt{\frac{2(\pi - \pi/3) + \sin 120^\circ}{4\pi}} = \mathbf{98.9 \text{ V}}$$

$$\text{Lamp resistance, } R_L = \frac{V^2}{P} = \frac{(110)^2}{100} = 121 \Omega$$

$$\therefore I_{r.m.s.} = \frac{E_{r.m.s.}}{R_L} = \frac{98.9}{121} = \mathbf{0.82 \text{ A}}$$

### 20.11 Single-Phase SCR Inverter Circuit

SCR inverter provides an efficient and economical way of converting direct current or voltage into alternating current or voltage. In this application, SCR acts as a controlled switch, alternately opening and closing a d.c. circuit. Fig. 20.17 shows the basic inverter circuit. Here, a.c. voltage is generated by alternately closing and opening switches  $S_1$  and  $S_2$ . Replacing, the mechanical switches

\* On carrying out the integration.

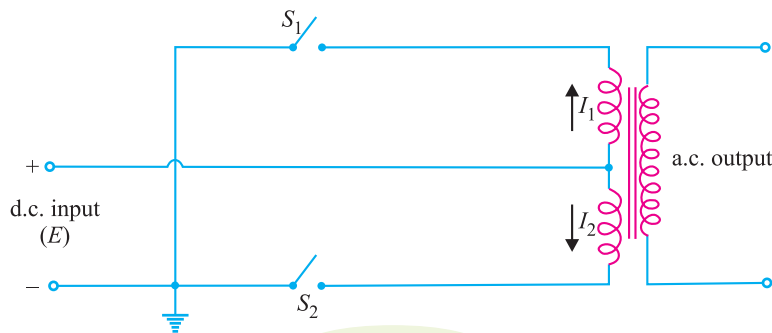


Fig. 20.17

with SCRs, whose gates are triggered by an external pulse generator, we get the practical SCR inverter as shown in Fig. 20.18.

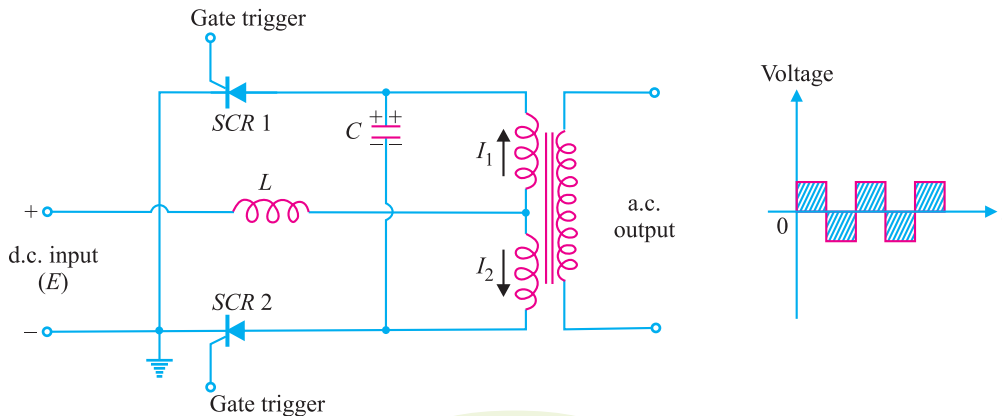


Fig. 20.18

**Circuit Action**

The circuit action is as under :

(i) When conduction is initiated by applying a positive trigger pulse to SCR 1 (SCR 2 is assumed OFF), the voltage across SCR decreases rapidly as the current through it increases. At the same time, the capacitor C charges through SCR 1 in the polarity shown. The load current flows through inductor L, upper half of the transformer primary winding and SCR1.

(ii) When a firing pulse is applied to the gate of SCR 2, this SCR turns on and conducts current. At this instant, capacitor C begins to discharge through SCR 1 and SCR 2. This discharge current flows through SCR 1 in a reverse direction. This reverse current turns off SCR1. At this time, with SCR 1 turned off, the capacitor voltage (approximately  $-2E$ ) appears across SCR 1 as a reverse voltage, long enough for this SCR to recover for forward blocking.

Simultaneously, during this interval, conducting SCR 2 allows the capacitor to discharge through the transformer primary winding and inductor L. The function of L is to control the discharge rate of C to allow sufficient time for SCR 1 to turn OFF. Capacitor C discharges rapidly from  $-2E$  to zero and then charges up in the opposite direction to  $+2E$ . The load current is now carried through the second half of the transformer primary winding and SCR 2.

(iii) When trigger pulse is applied to the gate of SCR 1, this device will conduct and SCR 2 will turn off by the process just described. In this way, SCR 1 and SCR 2 alternately turn ON and OFF. Consequently, a.c. output is obtained as shown in Fig. 20.18.

\* The capacitor voltage will charge to double the supply voltage (E) as a result of transformer action between the two primary windings.

The a.c. waveform produced by a single-phase inverter is a poor version of sine wave and would not be suitable for most industrial, commercial and domestic loads. More complex inverters using multiple *SCRs* and sophisticated triggering circuits are capable of generating a.c. voltages that are extremely close to a pure sine wave.

### 20.12 Applications of SCR

The ability of an *SCR* to control large currents in a load by means of small gate current makes this device useful in switching and control applications. Some of the important applications of *SCR* are discussed below :

(i) **SCR as static contactor.** An important application of *SCR* is for switching operations. As *SCR* has no moving parts, therefore, when it is used as a switch, it is often called a *static contactor*.

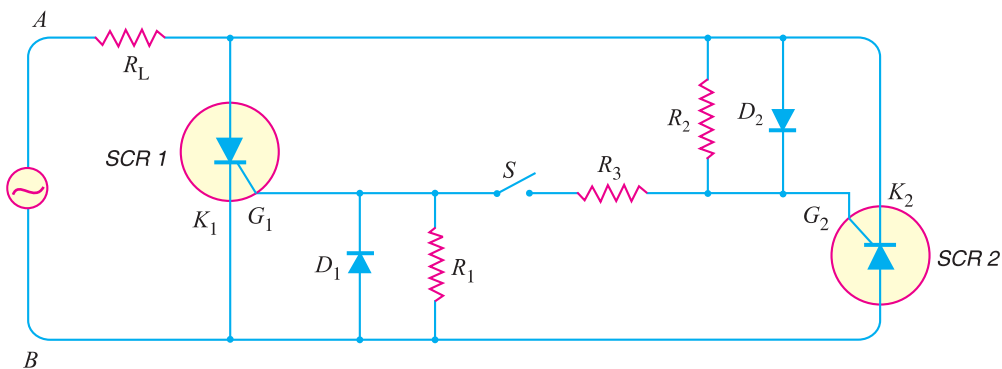


Fig. 20.19

Fig. 20.19 shows the use of *SCR* to switch *ON* or *OFF* a.c. power to a load  $R_L$ . Resistances  $R_1$  and  $R_2$  are for the protection of diodes  $D_1$  and  $D_2$  respectively. Resistance  $R_3$  is the gate current limiting resistor. To start the circuit, switch is closed. During the positive half-cycle of a.c. supply, end *A* is positive and end *B* is negative. Then diode  $D_2$  sends gate current through *SCR1*. Therefore *SCR1* is turned *ON* while *SCR2* remains *OFF* as its anode is negative *w.r.t.* cathode. The current conduction by *SCR1* follows the path  $A R_L K_1 B A$ . Similarly, in the next half-cycle, *SCR2* is turned *ON* and conducts current through the load. It may be seen that switch *S* handles only a few mA of gate current to switch *ON* several hundred amperes in the load  $R_L$ . This is a distinct advantage over a mechanical switch.

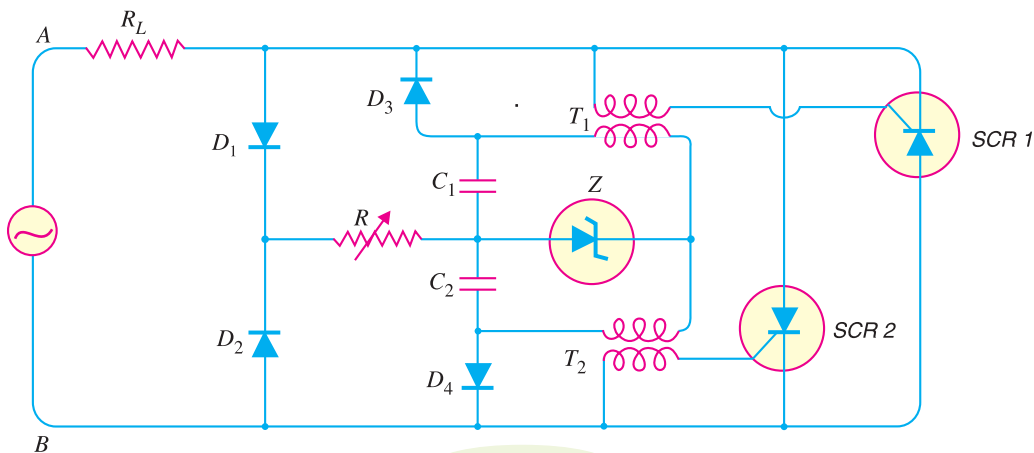


Fig. 20.20



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(ii) **SCR for power control.** It is often necessary to control power delivered to some load such as the heating element of a furnace. Series resistances or potentiometers cannot be used because they waste power in high power circuits. Under such conditions, silicon controlled rectifiers are used which are capable of adjusting the transmitted power with little waste. Fig. 20.20 shows a common circuit for controlling power in the load  $R_L$ . During the positive half-cycle of a.c. supply, end  $A$  is positive and end  $B$  is negative. Therefore, capacitor  $C_2$  is charged through  $AD_1RC_2D_4B$ . The charge on the capacitor  $C_2$  depends upon the value of potentiometer  $R$ . When the capacitor  $C_2$  is charged through a sufficient voltage, it discharges through the zener  $Z$ . This gives a pulse to the primary and hence secondary of transformer  $T_2$ . This turns on  $SCR2$  which conducts currents through the load  $R_L$ . During negative half-cycle of supply, the capacitor  $C_1$  is charged. It discharges through the zener and fires  $SCR1$  which conducts current through the load.

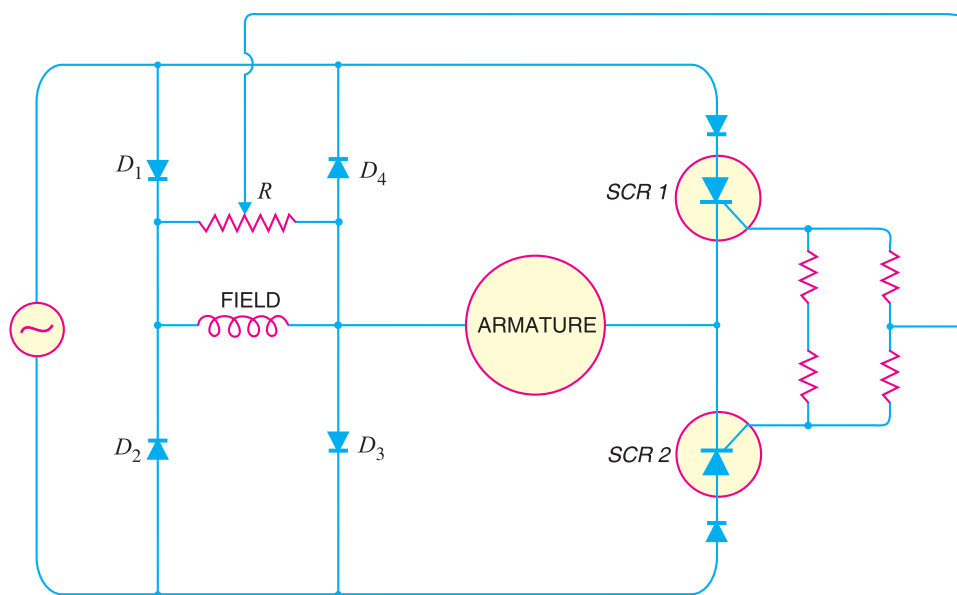


Fig. 20.21

The angle of conduction can be controlled by the potentiometer  $R$ . The greater the resistance of  $R$ , lesser is the voltage across  $C_1$  or  $C_2$  and hence smaller will be the time during which  $SCR1$  and  $SCR2$  will conduct in a full cycle. In this way, we can control a large power of several kW in the load  $R_L$  with the help of a small potentiometer  $R$ .

(iii) **SCRs for speed control of d.c. shunt motor.** The conventional method of speed control of d.c. shunt motor is to change the field excitation. But change in field excitation changes the motor torque also. This drawback is overcome in  $SCR$  control as shown in Fig. 20.21. Diodes  $D_1, D_2, D_3$  and  $D_4$  form the bridge. This bridge circuit converts a.c. into d.c. and supplies it to the field winding of the motor. During the positive half-cycle of a.c. supply,  $SCR1$  conducts because it gets gate current from bridge circuit as well as its anode is positive w.r.t. cathode. The armature winding of the motor gets current. The angle of conduction can be changed by varying the gate



SCR Power Control

current. During the negative half-cycle of a.c. supply, *SCR*2 provides current to the armature winding. In this way, the voltage fed to the motor armature and hence the speed can be controlled.

(iv) **Overlight detector.** Fig. 20.22 shows the use of *SCR* for overlight detection. The resistor *R* is a photo-resistor, a device whose resistance decreases with the increase in light intensity. When the light falling on *R* has normal intensity, the value of *R* is high enough and the voltage across *R*<sub>1</sub> is insufficient to trigger the *SCR*. However, when *R* is in strong light, its resistance decreases and the voltage drop across *R*<sub>1</sub> becomes high enough to trigger the *SCR*. Consequently, the buzzer sounds the alarm. It may be noted that even if the strong light disappears, the buzzer continues to sound the alarm. It is because once the *SCR* is fired, the gate loses all control.

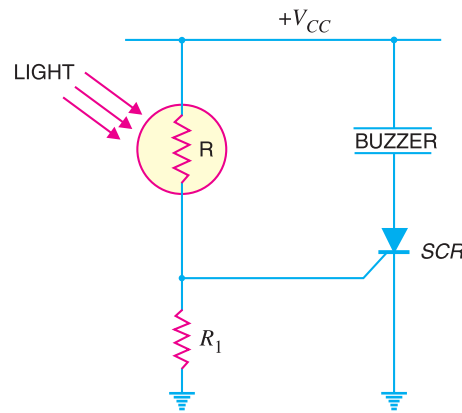


Fig. 20.22

(v) **SCR Crowbar.** A crowbar is a circuit that is used to protect a voltage-sensitive load from excessive d.c. power supply output voltages. Fig. 20.23 shows the *SCR* crowbar circuit. It consists of a zener diode, a gate resistor *R*<sub>G</sub> and an *SCR*. It also contains a \*snubber to prevent false triggering.

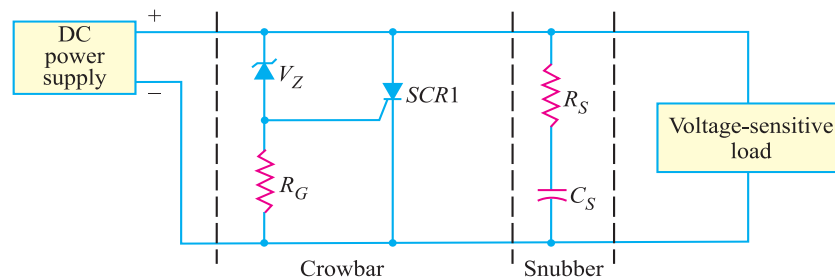


Fig. 20.23

**Operation.** The circuit action is as under:

(a) Under normal conditions, the zener diode and the *SCR* are *OFF*. With zener diode being in cutoff, there is no current through *R*<sub>G</sub> and no voltage drop occurs across this resistor. This means that the gate of *SCR* is at 0V so that the *SCR* is in the off state. Therefore, as long as zener diode is off, the *SCR* behaves as an open and will not affect either the d.c. power supply or the load.

(b) Suppose the output voltage from the d.c. power supply suddenly *increases*. This causes the zener diode to break down and conduct current. As the current flows through the zener diode, voltage is developed across resistor *R*<sub>G</sub> which causes the *SCR* to conduct current. When the *SCR* conducts, the voltage source is shorted by the *SCR*. The supply voltage fuse blows out and the load is protected from overvoltage.

### 20.13 Light-Activated SCR

The light-activated *SCR* (*LASCR*) is the light sensitive equivalent of the normal *SCR* and is shown in Fig. 20.24. As the name suggests, its state is controlled by the light falling on depletion layers. In a normal *SCR*, gate current

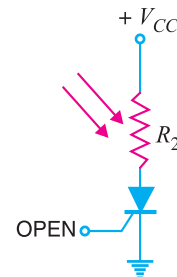


Fig. 20.24

\* It is an *RC* circuit connected between the *SCR* anode and cathode to eliminate false triggering.

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turns on the device. In the \*LASCR, instead of having the external gate current applied, light shining on the device turns it ON. Just as a normal SCR, the LASCR will continue to conduct even if the light source is removed. The LASCRs find many applications including optical light controls, relays, phase control, motor control and a large number of computer applications. The maximum current (r.m.s.) and power (gate) ratings for LASCRs commercially available today are about 3A and 0.1W. It may be noted that LASCR is most sensitive to light when the gate terminal is open. Its sensitivity can be reduced and controlled by the insertion of a gate resistor.

**Example 20.12.** The SCR of Fig. 20.25 has gate trigger voltage  $V_T = 0.7\text{V}$ , gate trigger current  $I_T = 7\text{ mA}$  and holding current  $I_H = 6\text{ mA}$ .

- What is the output voltage when the SCR is off?
- What is the input voltage that triggers the SCR?
- If  $V_{CC}$  is decreased until the SCR opens, what is the value of  $V_{CC}$ ?

**Solution.**

(i) When the SCR is off (i.e. it is not conducting), there is no current through the  $100\Omega$  resistor.

$$\therefore V_{out} = \text{Supply voltage } V_{CC} = 15\text{V}$$

(ii) The input voltage  $V_{in}$  must overcome  $V_T (=0.7\text{V})$  and also cause  $7\text{ mA}$  to flow through  $1\text{ k}\Omega$  resistor.

$$\therefore V_{in} = V_T + I_T R = 0.7 + (7\text{ mA})(1\text{ k}\Omega) = 7.7\text{V}$$

(iii) In order to open the SCR, the  $V_{CC}$  must be reduced so that anode current is equal to  $I_H$ .

$$\therefore I_H = \frac{V_{CC} - V_T}{100\Omega}$$

$$\text{or } V_{CC} = (100\Omega)(I_H) + V_T = (100\Omega)(6\text{ mA}) + 0.7 = 1.3\text{V}$$

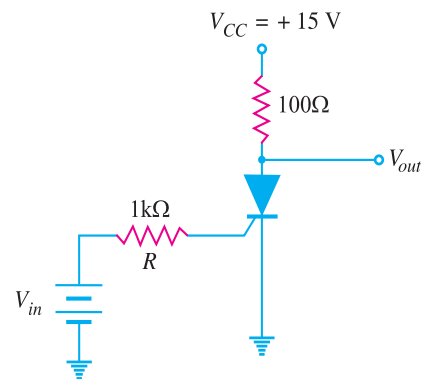


Fig. 20.25

**Example 20.13.** In Fig. 20.26, the SCR has a trigger voltage of  $0.7\text{ V}$ . Calculate the supply voltage that turns on the crowbar. Ignore zener diode resistance.

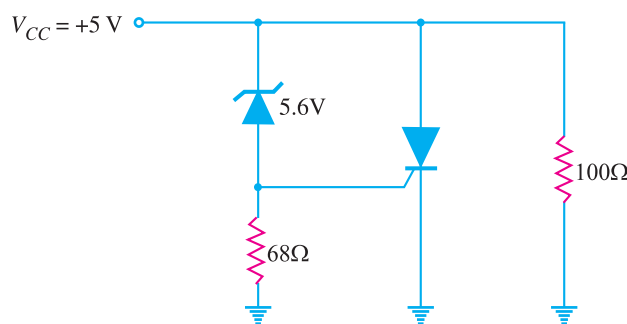


Fig. 20.26

**Solution.** The breakdown voltage of the zener is  $5.6\text{V}$ . To turn on the SCR, the voltage across  $68\Omega$  has to be equal to  $V_T (=0.7\text{V})$ .

$$\therefore V_{CC} = V_Z + V_T = 5.6 + 0.7 = 6.3\text{V}$$

\* For maximum sensitivity to light, the gate is left open.

When the supply voltage becomes 6.3 V, the zener breaks down and starts conducting. The voltage  $V_T (= 0.7V)$  across  $68\Omega$  forces the SCR into conduction. When the SCR conducts, the supply voltage is shorted by the SCR and the fuse in the supply voltage burns out. Thus the load ( $100\Omega$ ) is protected from overvoltage.

**Example. 20.14.** The zener diode of Fig. 20.27 has a tolerance of  $\pm 10\%$  and the trigger voltage can be as high as 1.5V. What is the maximum supply voltage where crowbaring takes place?

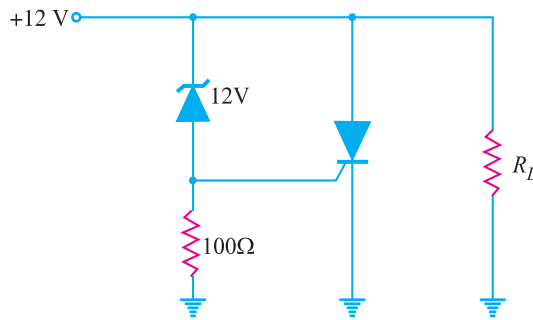


Fig. 20.27

**Solution.** The breakdown voltage of the zener diode is 12V and it has a tolerance of  $\pm 10\%$ . It means that breakdown voltage of zener can vary from 10.8V to 13.2V. Since the trigger voltage of SCR has a maximum value of 1.5 V,

$$\begin{aligned} \therefore \text{Maximum value of supply voltage for crowbaring} \\ = 13.2V + 1.5V = \mathbf{14.7V} \end{aligned}$$

**Example. 20.15.** The circuit of Fig. 20.28 is in a dark room. When a bright light is turned on, the LASCR fires. What is the approximate output voltage? If the bright light is turned off, what is the output voltage?

**Solution.** Fig. 20.28 shows a light-activated SCR, also known as a photo-SCR. When light falls on the device, it starts conducting and the output voltage is ideally,

$$V_{out} = \mathbf{0V}$$

However, if we take into account anode-cathode drop,  $V_{out} = 0.7V$ .

When light is turned off, the LASCR stops conducting and the output voltage is equal to the supply voltage  $V_{CC}$  i.e.

$$V_{out} = V_{CC} = \mathbf{+25V}$$

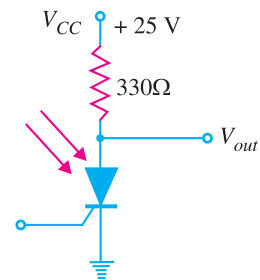


Fig. 20.28

**Example 20.16.** Give a simple method for testing an SCR.

**Solution.** Fig. 20.29 shows a simple circuit for testing an SCR. The test lamp serves two purposes. First, it is a visual indicator of current conduction. Secondly, it limits current through the SCR.

(i) When switch  $S$  is closed, the lamp should not light for the SCR to be good. It is because voltage is \*applied only between anode and cathode but there is no trigger voltage. If the lamp lights, the SCR is *shorted*.

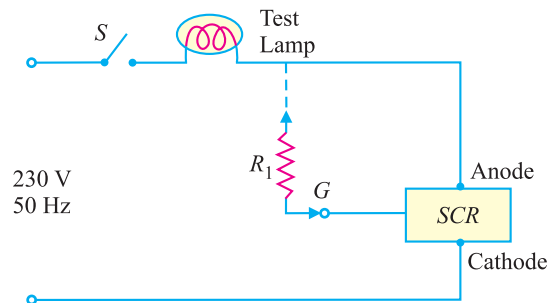


Fig. 20.29

\* It is understood that the applied voltage is less than the breakover voltage of the SCR.

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(ii) Now touch  $R_1$  momentarily between gate and anode terminals. For the SCR to be good, the lamp should light and \*continue to light. If it does not, the SCR is *open*.

Note that the lamp will be on at half brilliance because the SCR conducts only every other half-cycle.

### MULTIPLE-CHOICE QUESTIONS

1. An SCR has ..... *pn* junctions.
  - (i) two
  - (ii) three
  - (iii) four
  - (iv) none of the above
2. An SCR is a solid state equivalent of .....
  - (i) triode
  - (ii) pentode
  - (iii) gas-filled triode
  - (iv) tetrode
3. An SCR has ..... semiconductor layers.
  - (i) two
  - (ii) three
  - (iii) four
  - (iv) none of the above
4. An SCR has three terminals viz. ....
  - (i) cathode, anode, gate
  - (ii) anode, cathode, grid
  - (iii) anode, cathode, drain
  - (iv) none of the above
5. An SCR behaves as a ..... switch.
  - (i) unidirectional
  - (ii) bidirectional
  - (iii) mechanical
  - (iv) none of the above
6. An SCR is sometimes called .....
  - (i) triac
  - (ii) diac
  - (iii) unijunction transistor
  - (iv) thyristor
7. An SCR is made of .....
  - (i) germanium
  - (ii) silicon
  - (iii) carbon
  - (iv) none of the above
8. In the normal operation of an SCR, anode is ..... w.r.t. cathode.
  - (i) at zero potential
  - (ii) negative
  - (iii) positive
  - (iv) none of the above
9. In normal operation of an SCR, gate is ..... w.r.t. cathode.
  - (i) positive
  - (ii) negative
  - (iii) at zero potential
  - (iv) none of the above
10. An SCR combines the features of .....
  - (i) a rectifier and resistance
  - (ii) a rectifier and transistor
  - (iii) a rectifier and capacitor
  - (iv) none of the above
11. The control element in an SCR is .....
  - (i) cathode
  - (ii) anode
  - (iii) anode supply
  - (iv) gate
12. The normal way to turn on an SCR is by .....
  - (i) breakover voltage
  - (ii) appropriate anode current
  - (iii) appropriate gate current
  - (iv) none of the above
13. An SCR is turned off by .....
  - (i) reducing anode voltage to zero
  - (ii) reducing gate voltage to zero
  - (iii) reverse biasing the gate
  - (iv) none of the above
14. An SCR is a ..... triggered device.
  - (i) voltage
  - (ii) current
  - (iii) voltage as well as current
  - (iv) none of the above
15. In an SCR circuit, the supply voltage is generally ..... that of breakover voltage.
  - (i) equal to
  - (ii) less than
  - (iii) greater than
  - (iv) none of the above
16. When an SCR is turned on, the voltage across it is about .....
  - (i) zero
  - (ii) 10 V
  - (iii) 0.1 V
  - (iv) 1 V
17. An SCR is made of silicon and not germanium because silicon .....
  - (i) is inexpensive
  - (ii) is mechanically strong
  - (iii) has small leakage current
  - (iv) is tetravalent
18. An SCR is turned off when .....
  - (i) anode current is reduced to zero
  - (ii) gate voltage is reduced to zero
  - (iii) gate is reverse biased
  - (iv) none of the above

\* Recall that once the SCR is fired by the gate voltage, it continues to conduct current even if the gate voltage is removed.

19. In an SCR circuit, the angle of conduction can be changed by .....  
 (i) changing anode voltage  
 (ii) changing gate voltage  
 (iii) reverse biasing the gate  
 (iv) none of the above
20. If firing angle in an SCR circuit is increased, the output .....  
 (i) remains the same  
 (ii) is increased  
 (iii) is decreased  
 (iv) none of the above
21. If gate current is increased, then anode-cathode voltage at which SCR closes .....  
 (i) is decreased  
 (ii) is increased  
 (iii) remains the same  
 (iv) none of the above
22. When SCR is OFF, the current in the circuit is .....  
 (i) exactly zero  
 (ii) small leakage current  
 (iii) large leakage current  
 (iv) none of the above
23. An SCR can exercise control over ..... of a.c. supply.  
 (i) positive half-cycles only  
 (ii) negative half-cycles only  
 (iii) both positive and negative half-cycles  
 (iv) positive or negative half-cycles
24. We can control a.c. power in a load by connecting .....  
 (i) two SCRs in series  
 (ii) two SCRs in parallel  
 (iii) two SCRs in parallel opposition  
 (iv) none of the above
25. When SCR starts conducting, then ..... loses all control.  
 (i) gate (ii) cathode  
 (iii) anode (iv) none of the above

**Answers to Multiple-Choice Questions**

- |          |           |          |           |           |
|----------|-----------|----------|-----------|-----------|
| 1. (ii)  | 2. (iii)  | 3. (iii) | 4. (i)    | 5. (i)    |
| 6. (iv)  | 7. (ii)   | 8. (iii) | 9. (i)    | 10. (ii)  |
| 11. (iv) | 12. (iii) | 13. (i)  | 14. (ii)  | 15. (ii)  |
| 16. (iv) | 17. (iii) | 18. (i)  | 19. (ii)  | 20. (iii) |
| 21. (i)  | 22. (ii)  | 23. (iv) | 24. (iii) | 25. (i)   |

**Chapter Review Topics**

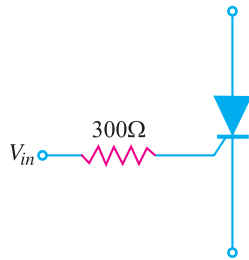
1. Explain the construction and working of an SCR.
2. Draw the equivalent circuit of an SCR and explain its working from this equivalent circuit.
3. Explain the terms breakover voltage, holding current and forward current rating as used in connection with SCR analysis.
4. Draw the V-I characteristics of an SCR. What do you infer from them ?
5. Explain the action of an SCR as a switch. What are the advantages of SCR switch over a mechanical or electro-mechanical switch ?
6. Discuss some important applications of SCR.

**Problems**

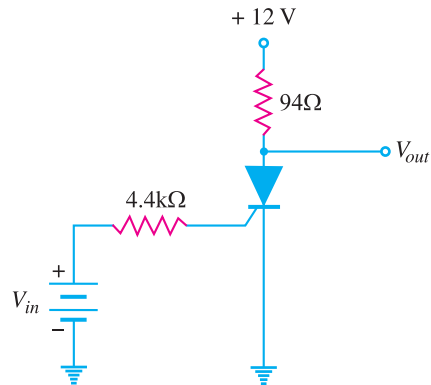
1. An SCR has a breakover voltage of 450 V, a trigger current of 15 mA and holding current of 10 mA. What do you infer from it?
2. An SCR in a circuit is subjected to a 50 A current surge that lasts for 10 ms. Determine whether or not this surge will destroy the device. Given that circuit fusing rating of SCR is  $90 A^2s$ .  
[will not be destroyed]
3. An SCR has a circuit fusing rating of  $70 A^2s$ . The device is being used in a circuit where it could be subjected to a 100 A surge. Determine the limit on the duration of such a surge. [7ms]
4. An SCR has a circuit fusing rating of  $60 A^2s$ . Determine the highest surge current value that SCR can withstand for a period of 20 ms. [54.77A]

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5. In Fig. 20.30, what value of input voltage would be required to cause the SCR to break down if the gate current required for firing is 10 mA ? [3.7V]



**Fig. 20.30**



**Fig. 20.31**

6. In Fig. 20.31, if the trigger current of the SCR is 1.5 mA, what is the input voltage that triggers the SCR? Given  $V_T = 0.7\text{V}$ . [7.3V]
7. A 24V r.m.s. supply is connected to a half-wave SCR circuit that is triggered at  $50^\circ$ . What is the d.c. voltage delivered to the load ? [8.88V]

### Discussion Questions

1. How does SCR differ from an ordinary rectifier ?
2. Why is SCR always turned on by gate current ?
3. Why SCR cannot be used as a bidirectional switch ?
4. How does SCR control the power fed to the load ?
5. Why are SCRs usually used in a.c. circuits?
6. Name three thyristor devices.
7. Why is SCR turned on by high-frequency radiation ?