Silicon Controlled Rectifier (SCR)

Topics Covered from Module 2: *Silicon Controlled Rectifier (SCR) – Two-transistor model, Switching action, Characteristics, Phase control application.*

Introduction

A silicon controlled rectifier (SCR) is a switching device widely used in power control applications. It is a four-layer device with three terminals – anode (A), cathode (K) and gate (G). SCR has a wide range of applications including rectifiers, regulated power supplies, dc to ac conversion (inverters), relay control, time-delay circuits and many more.

Basic Operation and Symbols

SCR is made of silicon because of high temperature requirement of handling large current and power. Its four layers are *PNPN* as shown in Fig. 1 (a). The outer p-layer is connected to anode terminal and outer n-layer is connected to cathode terminal. The p-layer closer to the cathode is connected to the gate terminal. The symbol of an SCR is as shown in Fig. 1 (b).

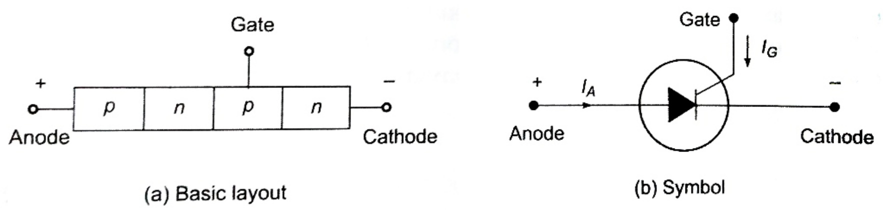


Fig. 1 Silicon controlled rectifier (SCR)

When a forward voltage is applied across the anode and cathode, no conduction takes place as the middle pn-junction is reverse biased. If a positive pulse is applied at the gate, such that a current of magnitude equal to or more than $I_{G(turn-on)}$ flows into the gate, the SCR turns on and conducts. However, because of regenerative action, removing the gate current does not cause the device to turn off.

Two-Transistor Model

The basic operation of an SCR can be best explained by splitting the four-layer *PNPN* structure into two three-layer structures as shown in Fig. 2 (a). The resultant two-transistor circuit model is shown in Fig. 2 (b).

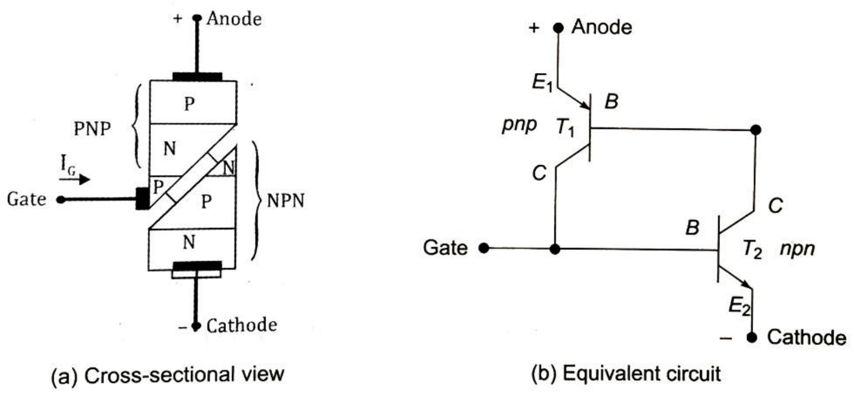


Fig. 2 Two-transistor model of SCR

According to this model, the SCR comprises of two transistors – one *PNP* transistor and one *NPN* transistor. The base of *PNP* is connected to the collector of *NPN* and the collector of *PNP* is connected to the base of *NPN*. The gate is connected to the base of *NPN*.

Switching Action (Operation)

Let a positive voltage V be applied to the anode (E_1) and let the cathode (E_2) and gate (G) be both grounded as shown in Fig. 3 (a).

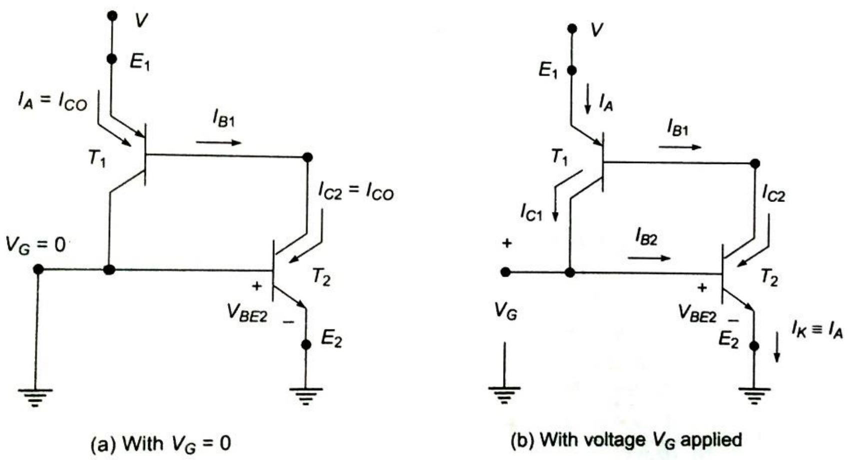


Fig. 3 Switching action of SCR

As $V_G = V_{BE_2} = 0$, the transistor T_2 is in OFF state. It means that the collector-base junction of T_2, through emitter-base junction of T_1, is reverse biased. Therefore $I_{B_1} = I_{CO}$ (leakage current due to minority charge carriers) is too small to turn-on T_1. Thus both T_1 and T_2 are OFF and hence the anode current $I_A = I_{B_1} = I_{CO}$ is of negligible order. This means that SCR is in OFF state, that is, the switch between anode (E_1) and cathode (E_2) is *open*.

Now, let a voltage $V_G > 0$ be applied at the gate as shown in Fig. 3 (b). As $V_{BE_2} = V_G$, when V_G is sufficiently large, I_{B_2} will cause T_2 to turn on and the collector current I_{C_2} becomes large. As $I_{B_1} = I_{C_2}$, T_1 turns on causing a large collector current I_{C_1} $(I_A = I_{C_1})$ to flow. This is turn, increases I_{B_2} causing a regenerative action to set in. As a result, the SCR is turned ON, that is, the switch between anode (E_1) and cathode (E_2) is *closed*.

The turn-on time of an SCR is typically 0.1 to 1 µs. However, for high-power devices, the turn-on time may be 10 to 25 µs.

Turn-OFF (Commutation)

Once the SCR is turned ON, it cannot be turned OFF by simply removing the gate signal. The mechanism of turning OFF an SCR is called *commutation*. There are two types of commutation – natural commutation and forced commutation.

Natural Commutation

When the source that feeds the current to anode of SCR is such that it passes through zero, the SCR turns off at the current zero. This is the case when the SCR is fed from an ac source. This is known as natural commutation or line commutation.

Forced Commutation

In this method, the current through the SCR is forced to become zero by passing a current through it in opposite direction from an independent circuit. A variety of circuits are available for forced commutation. Fig. 4 shows a basic turn-off circuit.

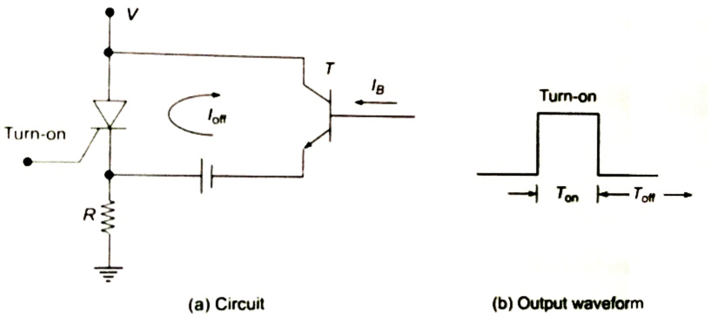


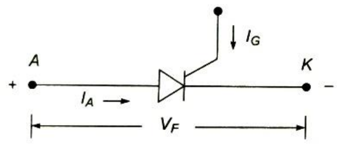
Fig. 4 SCR turn-off (commutation) circuit

A transistor and a dc battery source in series are connected to the SCR. When the SCR is in conduction mode (ON) and $I_B = 0$, the transistor is off and it is almost an open circuit. To turn off the SCR, a positive pulse (I_B) of magnitude large enough to drive the transistor into saturation is applied at the transistor base. The transistor acts almost like a short circuit. This causes flow of very large current I_{off} through the SCR in the direction opposite to its conduction current. The total SCR current reduces to zero in a very short time causing it to turn OFF.

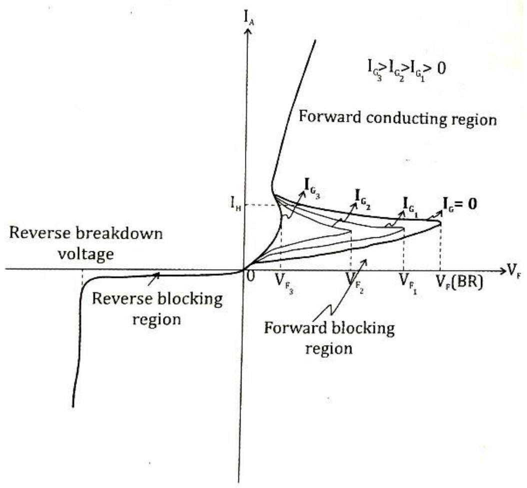
The turn-off time of an SCR is typically 5 to 30 μs.

SCR Characteristics

The symbol and V-I characteristics of SCR for different values of gate current are shown in Fig. 5.



(a) Symbol



(b) V-I characteristics

Fig. 5 SCR characteristics

Various parameters of importance are described below:

i) Forward Breakover Voltage $V_{F(BR)}$: It is the voltage at which, for a given I_G, the SCR enters into conduction mode. This voltage reduces as I_G increases.

ii) Holding Current (I_H): It is the value of the anode current below which SCR switches from conduction state to forward blocking region.

iii) Latching Current (I_L): It is the minimum value of the anode current required to keep the SCR turned ON after removing the gate signal. Latching current is larger than holding current.

iv) Forward Conduction Region: It is the region in which SCR is ON (short circuited) and is in conduction mode. In this region, the SCR conducts forward current from anode to cathode.

v) Forward and Reverse Blocking Region: These are the regions in which the SCR is OFF (open circuited) and no current flows from anode to cathode.

vi) Reverse Breakdown Voltage: It is the reverse anode to cathode voltage at which Zener or avalanche breakdown of the device takes place and the current rises abruptly.

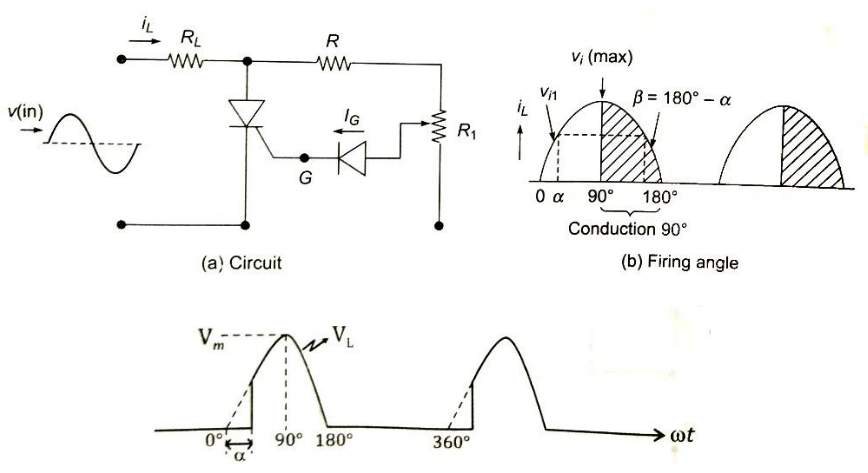
Applications of SCR

SCR is widely used in power control applications. It has a wide range of applications including rectifiers, regulated power supplies, dc to ac conversion (inverters), relay control, time-delay circuits and many more.

Variable Resistance Phase Control

An SCR can be used to control the phase of an ac signal by using a variable resistance. It is an effective method of controlling the rms value of the current and thereby power delivered to the load.

On triggering, an SCR permits flow of only forward current, but blocks the current in reverse direction. This action is similar to that of a diode, but an SCR needs to be triggered for each positive half cycle. It then produces a constant dc (average) current through load and dc voltage across load. By adjusting the triggering time on positive half cycle of ac voltage, we can get variable dc output. This method is known as phase control.



(c) Firing angle $\alpha < 90°$

Fig. 6 Variable resistance phase control using SCR

A variable resistance phase control circuit is shown in Fig. 6. The triggering circuit consists of a diode D, a fixed resistor R and a variable resistor R_1. The combination of R and R_1 limits the gate current during positive half cycle of the input. The diode D prevents the flow of reverse gate current during negative cycle of the input.

Let R_1 be adjusted to high value, so that even at the peak value v_i, $I_G < I_{G(turn-on)}$ and no conduction takes place. As R_1 is reduced, I_G rises to turn-on value at a particular angle of v_i. The conduction then begins and continues till v_i reaches zero (180°). The firing angle of SCR can be adjusted by varying R_1.

At R_1 corresponding to the firing angle of 90°, $v_i = v_{i(\max)}$. If R_1 is adjusted for firing at α, the firing will take place at angle $\alpha < 90°$, but not at $\beta = (180° - \alpha) > 90°$ as the angle α is reached earlier in time on the v_i wave. So, the operation of this circuit is known as *half-wave variable resistance phase control*.

Questions

1. What is SCR? Explain the working of SCR using two-transistor model. ***(Sep '20 – 8M, Jan '20 – 6M, Jul '19 – 6M, MQP '18 – 6M)***
2. Draw and explain the operation of SCR using two-transistor equivalent circuit. ***(MQP '18 – 8M)***
3. Using the two-transistor model, explain the switching action of SCR.
4. What is commutation in SCR? Explain two types of commutation. ***(Jul '19 – 5M)***
5. Explain natural and forced commutation turn off methods of SCR. ***(Sep '20 – 6M)***
6. Draw and explain the V-I characteristics of SCR. ***(Jan '19 – 6M, MQP '18 – 6M)***
7. Explain phase control application of SCR. ***(MQP '18 – 6M)***

References

1. D.P. Kothari, I. J. Nagrath, ***"Basic Electronics"***, McGraw Hill Education (India) Private Limited, Second Edition, 2014.
2. Thomas L. Floyd, ***"Electronic Devices"***, Pearson Education, Ninth Edition, 2012.