Thyristors

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Introduction

Bell Laboratories were the first to fabricate a silicon-based semiconductor device called thyristor. Later on, many other devices having characteristics similar to that of a thyristor were developed.

The Thyristor Family. These semiconductor devices, with their characteristics identical with that of a thyristor, are triac, diac, silicon-controlled switch(SCS), programmable unijunction transistor (PUT), GTO, RCT etc. This whole family of semiconductor devices is given the name thyristor. Thus the term thyristor denotes *"a family of semiconductor devices used for power control in dc and ac systems"*. One oldest member of this thyristor family, called silicon-controlled rectifier (SCR), is the most widely used device. At present, the use of SCR is so vast that over the years, the word thyristor has become synonymous with SCR. It appears that the term thyristor is now becoming more common than the actual term SCR.

*The name 'THYRISTOR'.*A thyristor has characteristics similar to a *thyratron tube*. But from the construction view point, a thyristor (a pnpn device) belongs to *transistor* (pnp or npn device) family. The present-day reader may not be familiar with thyratron tube as this is not being taught these days. The name `thyristor', is derived by a combination of the capital letters from THYRatron and transISTOR. This means that thyristor is a solid state device like a transistor and has characteristics similar to that of a thyratron tube.

Construction

Thyristor is a four layer, three-junction, p-n-p-n semiconductor switching device. It has three terminals ; anode, cathode and gate. Fig. 4.1 gives constructional details of a typical thyristor. Schematic diagram and *circuit symbol* for a thyristor are shown respectively in Figs. 4.1 (b) and (c). Basically, a thyristor consists of four layers of alternate p-type and n-type silicon semiconductors forming three junctions J1, J2 and J3 as shown in Fig. 4.1 (b). Gate terminal is usually kept near the cathode terminal Fig. 4.1 (b). The terminal connected to outer p region is called anode (A), the terminal connected to outer n region is called cathode and that connected to inner p region is called the gate (G).

SCR rating has improved considerably since its introduction in 1957. Now SCRs of voltage rating 10 kV and an rms current rating of 3000 A with corresponding power-handling capacity of 30 MW are available. Such a high power thyristor can be switched on by a low voltage supply of about 1 A and 10 W and this gives us an idea of the immense power amplification capability (= 3×10^6) of this device. As SCRs are solid state devices, they are compact, possess high reliability and have low loss. Because of these useful features, SCR is almost universally employed these days for all high power-controlled devices.

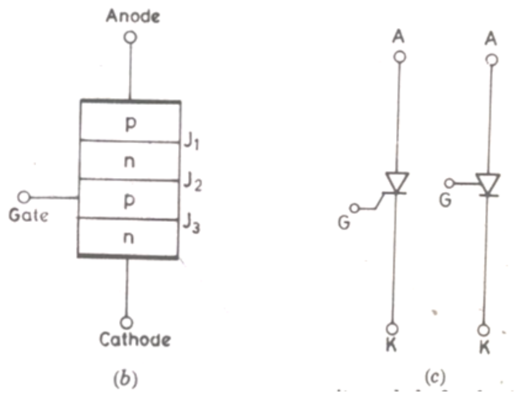


Fig. 4.1. (b) Schematic diagram and (c) circuit symbol of a thyristor

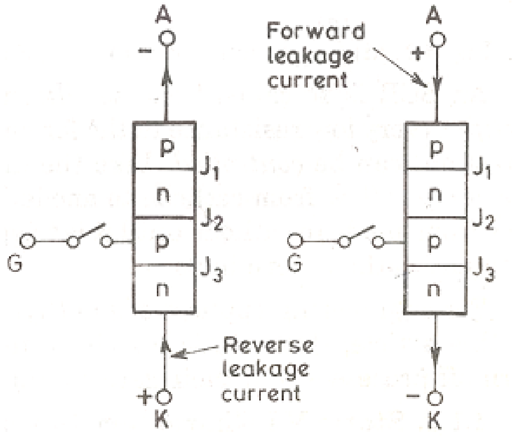
An SCR is so called because silicon is used for its construction and its operation as a rectifier (very low resistance in the forward conduction and very high resistance in the reverse direction) can be controlled. Like the diode, an SCR is an *unidirectional device* that blocks the current flow from cathode to anode. Unlike the diode, a thyristor also blocks the current flow from anode to cathode until it is triggered into conduction by a proper gate signal between gate and cathode terminals.

For engineering applications of thyristors, their terminal characteristics must be known. In this article, their static V-I characteristics, dynamic characteristics during turn-on and turn-off processes and their gate characteristics are discussed turn-off processes and their gate characteristics are discussed.

4.1.1. Static V-I Characteristics of a Thyristor

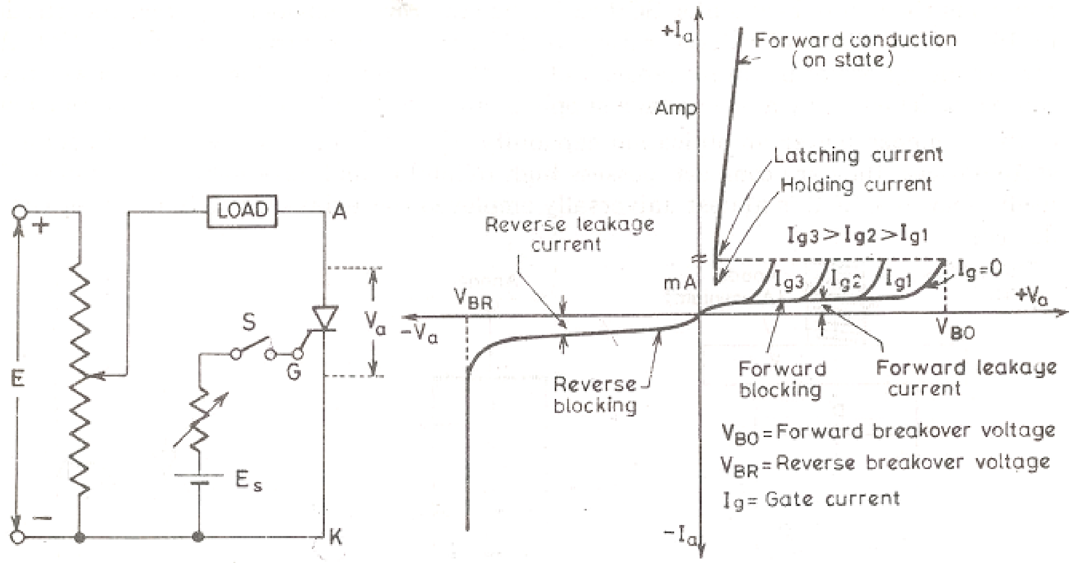
An elementary circuit diagram for obtaining static V-I characteristics of a thyristor is shown in Fig. 4.2 (a). The anode and cathode are connected to main source through the load. The gate and cathode are fed from a source E_S which provides positive gate current from gate to cathode. Fig. 4.2 (b) shows static V-I characteristics of a thyristor. Here Va is the anode voltage across thyristor terminals A, K and Ia is the anode current. Typical SCR V-I characteristic shown in Fig. 4.2 (b) reveals that a thyristor has three basic modes of operation namely,

- forward blocking (off-state) mode
- forward conduction (on-state) mode and
- reverse blocking mode



(a) (b)
Fig. 4.3. (a) J_2 forward biased and J_1, J_3 reverse biased (b) J_2 reverse biased and J_1, J_3 forward biased.

These three modes of operation are now discussed below:



(a) (b)
Fig. 4.2. (a) Elementary circuit for obtaining thyristor V-I characteristics (b) Static V-I characteristics of a thyristor.

Forward Blocking Mode: When anode is positive with respect to the cathode, with gate circuit open, thyristor is said to be forward biased as shown in Fig. 4.3 (b). It is seen from this figure that junctions J1, J3 are forward biased but junction J2 is reverse biased. In this mode, a small current, called *forward leakage current*, flows as shown in Figs. 4.2 (b) and 4.3 (b). In case the forward voltage is increased, then the reverse biased junction J2 will have an *avalanche breakdown* at a voltage called *forward breakover voltage* V_{BO}. When forward voltage is less than V_{BO}, SCR offers a *high impedance*. Therefore, a thyristor can be treated as an *open switch* in the forward blocking mode.

Forward Conduction Mode: In this mode, thyristor conducts currents from anode to cathode with a very small voltage drop across it. A thyristor is brought from forward blocking mode to forward conduction mode by turning it on by

- exceeding the forward breakover voltage or by
- applying a gate pulse between gate and cathode.

In this mode, thyristor is in on-state and behaves like a *closed switch*. Voltage drop across thyristor in the on state is of the order of 1 to 2 V depending on the rating of SCR. It may be seen from Fig. 4.2 (b) that this voltage drop increases slightly with an increase in anode current. In conduction mode, anode current is limited by load impedance alone as voltage drop across SCR is quite small. This small voltage drop vT across the device is due to ohmic drop in the four layers.

Reverse Blocking Mode. When cathode is made positive with respect to anode with switch S open, Fig. 4.2 (a), thyristor is reverse biased as shown in Fig. 4.3 (a). Junctions J1, J3 are seen to be reverse biased whereas junction J2 is forward biased. The device behaves as if two diodes are connected in series with reverse voltage applied across them. A small leakage current of the order of a few milli amperes (or a few microamperes depending upon the SCR rating) flows. This is reverse blocking mode, called the *off-state*, of the thyristor. If the reverse voltage is increased, then at a critical breakdown level, called *reverse breakdown voltage* V_{BR}, an avalanche occurs at J1 and J3 and the reverse current increases rapidly. A large current associated with V_{BR} gives rise to more losses in the SCR. This may lead to *thyristor damage* as the junction temperature may exceed its permissible temperature rise. It should, therefore, be ensured that maximum working reverse voltage across a thyristor does not exceed V_{BR}. When reverse voltage applied across a thyristor is less than V_{BR}, the device offers a *high impedance* in the reverse direction. The SCR in the reverse blocking mode may therefore be treated as an *open switch*.

Note that V-I characteristic after avalanche J1, J3 forward biased. Breakdown during reverse blocking mode is applicable only when load resistance is zero, Fig. 4.2 (b). In case load resistance is present, a large anode current associated with avalanche breakdown at VBR would cause substantial voltage drop across load and as a result, V-I characteristic in third quadrant would bend to the right of vertical line drawn at V_{BR}.

4.3 Latching & Holding Current

Once the SCR is conducting a forward current, reverse biased junction J2 no longer exists. As such, no gate current is required for the device to remain in on-state. Therefore, if the gate current is removed, the conduction of current from anode to cathode remains unaffected. However, if gate current is reduced to zero before the rising anode current attains a value, called the *latching current*, the thyristor will tum-off again. The gate pulse width should therefore be judiciously chosen to ensure that anode current rises above the latching current.

Thus latching current may be defined as " *the minimum value of anode current which it must attain during turn-on process to maintain conduction when gate signal is removed*."

Once the thyristor is conducting, gate loses control. The thyristor can be turned-off (or the thyristor can be returned to forward blocking state) only if the forward current falls below a low-level current called the *holding current*.

Thus holding current may be defined as *"the minimum value of anode current below which it must fall for turning-off the thyristor".* The latching current is higher than the holding current. Note that latching current is associated with turn-on process and holding current with turn-off process. It is usual to take latching current as two to three times the holding current [1]. In industrial applications, holding current (typically 10 mA) is almost taken as zero.

4.5 Two Transistor Model of a Thyristor

The principle of operation of a thyristor can be explained using a two transistor model. Figure 4.15(a) shows the schematic diagram of a thyristor. From this figure the two transistor model is obtained by bisecting along the dotted lines as shown in Figure 4.15(b). The circuit diagram of the two transistor model is shown in Figure 4.15(c).

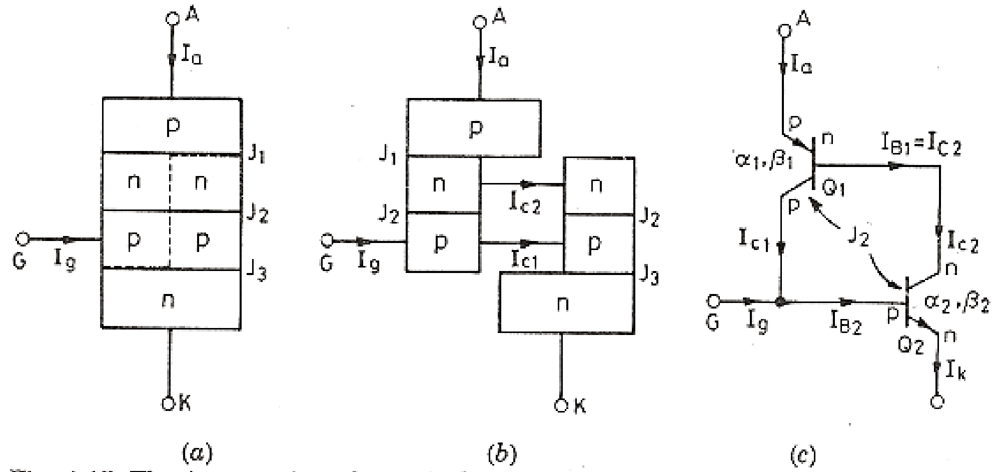


Fig. 4.15. Thyristor (*a*) its schematic diagram, (*b*) and (*c*) its two-transistor model.