1.5 Thyristor (SCR)

A thyristor is a four-layer semiconductor device of pnpn structure with three pn junction. Figure (1.13) shows the thyristor symbol and the sectional view of the three pn-junctions. A typical v-i characteristic of a thyristor is shown in figure (1.14).

1) When the anode voltage is made positive with respect to the cathode, the junctions J_1 and J_3 are forward biased. The junction J_2 is reversed biased and only a small leakage current flows from anode to cathode. The thyristor is then said to be in the forward blocking or off-state condition.

2) If a thyristor is forward biased, the injection of gate current by applying positive gate voltage between the gate and cathode terminals would turn on the thyristor. The anode current must be more than a value known as latching current I_L, otherwise the device reverts to the blocking condition. Once the thyristor conducts, it behaves like a conducting diode.

** Latching current I_L: is the minimum anode current required to maintain the thyristor on immediately after a thyristor has been turned on and the gate signal has been removed.

** Holding current I_H: is the minimum anode current to maintain the thyristor in the on-state.

3) In the absence of gate current, if the anode to cathode voltage V_{AK} is increased to a sufficiently large value, known as forward breakover (V_{BO}) voltage, the reverse-biased junction J_2 will break. The device will then be in a conducting state (or on-state). This mode of turn-on may be destructive and should be avoided with SCRs, but it is normal operation of devices such as pnpn switch and diac.

4) The reverse characteristic (i.e. the thyristor is reverse biased) is similar to reversed biased diode.

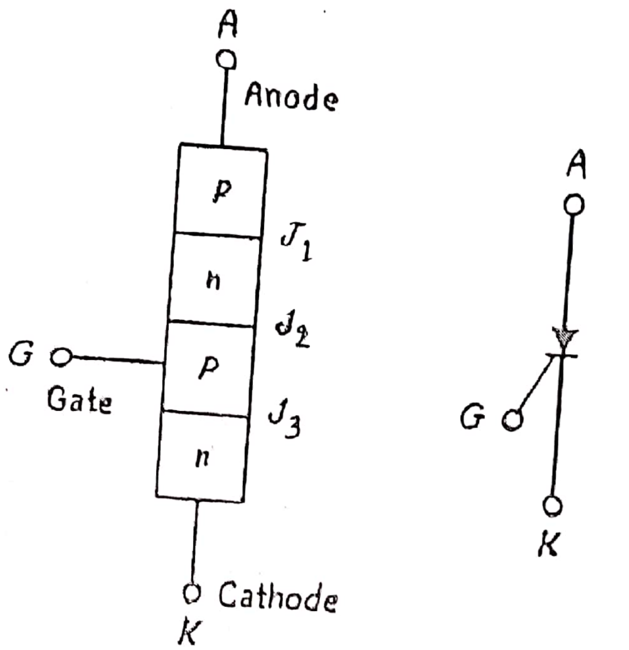

Figure (1.13)

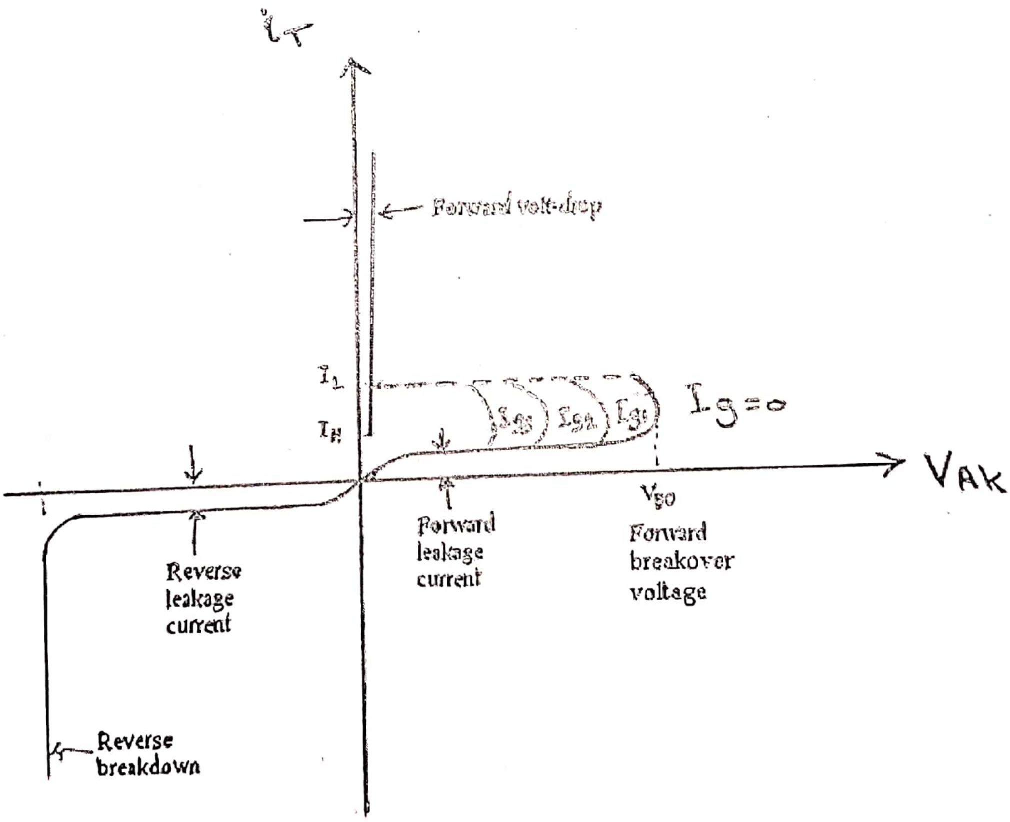

Figure (1.14)

1.5.1 SCR dynamic properties at switching on

If a thyristor is forward biased, the injection of gate current by applying positive gate voltage between the gate and cathode terminals would turn on the thyristor as shown in figure (1.15).

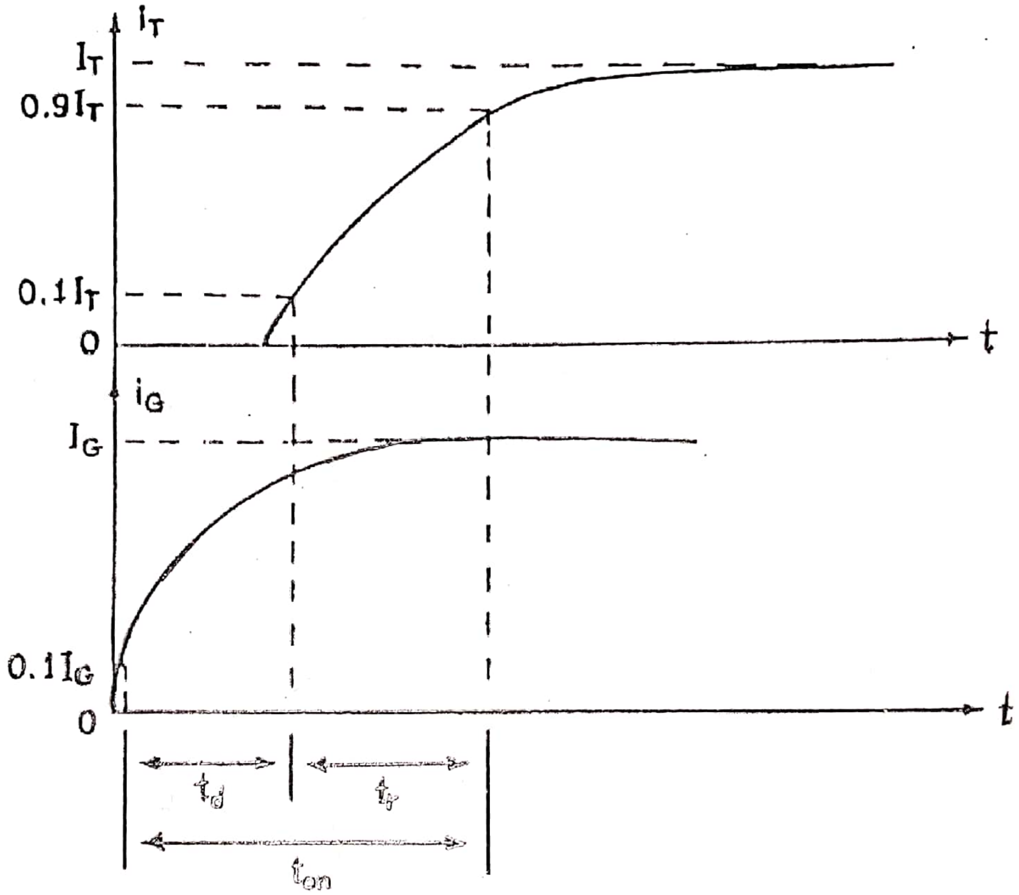

Figure (1.15)

- Turn-on time t_{on} is a time delay between the application of gate signal and the conduction of a thyristor, and it is defined as the time interval between 10% of steady-state gate current I_G and 90% of the steady state thyristor on-state current I_T.
- Delay time (t_d) is defined as the time period between 10% of gate current and 10% of thyristor current I_T.
- Rising time (t_r) is the required time for the thyristor anode current I_T to rise from 10% to 90%.

1.5.2 SCR dynamic properties at turning-off and methods of turning- off

Once a thyristor is turned on, it remains latched-on provided that:

i) The holding current is exceeded.

ii) It is forward biased.

Methods of turning-off:

1- Natural Commutation: If the supply voltage is AC, a thyristor will turn-off after the supply voltage has reversed and the anode current attempts to reverse.

2- Load commutation: If the supply voltage is DC, but the load is a series L-C resonant circuit, the anode current falls to zero when the capacitor is fully charged. The load current falls to below the holding current level and turn-off is occurred.

3- Forced Commutation: In thyristor application involving DC supplies and resistive/inductive loads, a thyristor once on will remain on. Neither the supply nor the load is capable of reducing the anode current below the holding current level, or producing reverse bias across the thyristor. Such a thyristor can be turned-off only if the anode current is interrupted or forced below the holding current. External circuitry called a commutation circuit is employed to accomplish turn-off by reverse-biasing the thyristor and reducing the anode current to near zero.

Dynamic properties at turn-off:

The turn-off interval thyristor anode waveforms are shown in figure (1.16) for forced commutated SCR device.

Given forward thyristor current I_T which is turned-off at a given di_{RR}/dt rate, the current will go into reverse until the carrier storage charge Q_R is recovered. The actual thyristor turn-off time is t_q which is longer than the current reverse recovery period t_{rr}.

** i_{RR} is reverse recovery current.

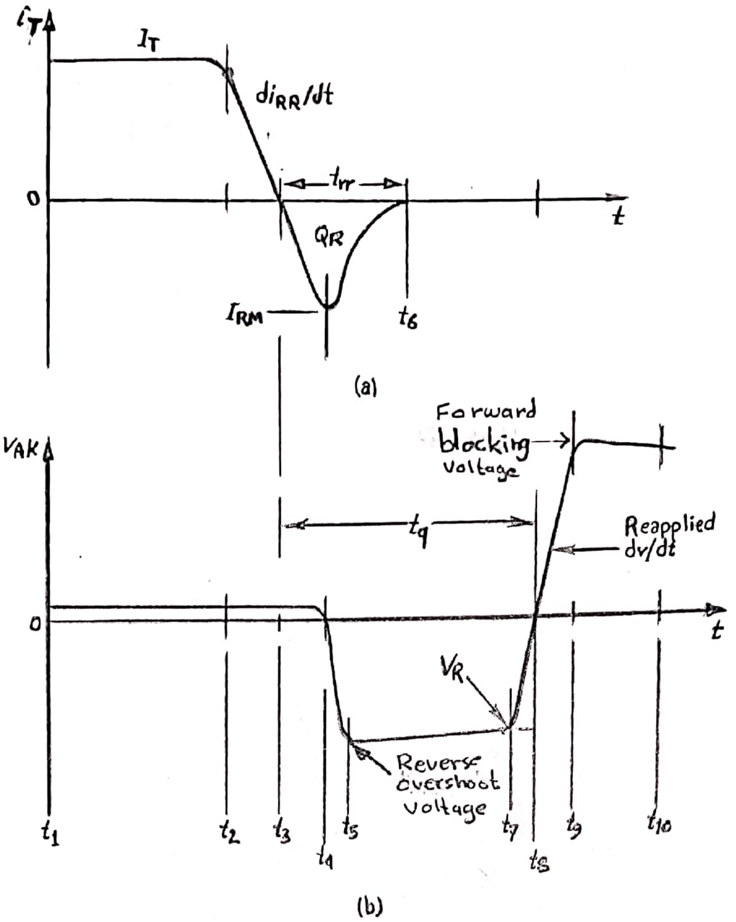

Figure (1.16) Thyristor anode waveforms for turn-off time measurement with forced commutation: (a) anode current; (b) anode-cathode voltage.

The turn-off time t_q is the period from t_3 to t_8 and this period will increase with increased:

1) Junction temperature.
2) Forward current magnitude.
3) Rate of decay of forward current.
4) Rate of application of forward blocking voltage; reapplied dv/dt during t_8-t_9.
5) Forward blocking voltage during t_9-t_{10}.
6) External gate impedance.
7) Positive gate bias but less than the gate non-trigger voltage V_{GD} [at which the manufacturer guarantees that no device will trigger].

And decreased

1) Peak reverse current.
2) Reverse voltage during t_5-t_7.