G H RAISONI INSTITUTE OF ENGINEERING AND TECHNOLOGY, NAGPUR

(Approved by AICTE, New Delhi and Recognized by DTE, Maharashtra)

An Autonomous Institute, Accredited by NBA & NAAC with A+ Grade

RAISONI GROUP
a vision beyond

V-semester

POWER ELECTRONICS

CHAPTER NO. - 1

THYRISTOR CHARACTERISTICS AND APPLICATIONS

CHAPTER 1:- SYLLABUS

1. SCR – Construction & Operation
2. V-I characteristics & Gate characteristics of SCR
3. Dynamic Turn-on &Turn-off Characteristics
4. Series & parallel Connection of SCRs
5. Ratings and protection of SCR
6. Commutation methods

The student will be able to:

1. Understand different solid state power electronic devices.

SCR – Construction & Operation

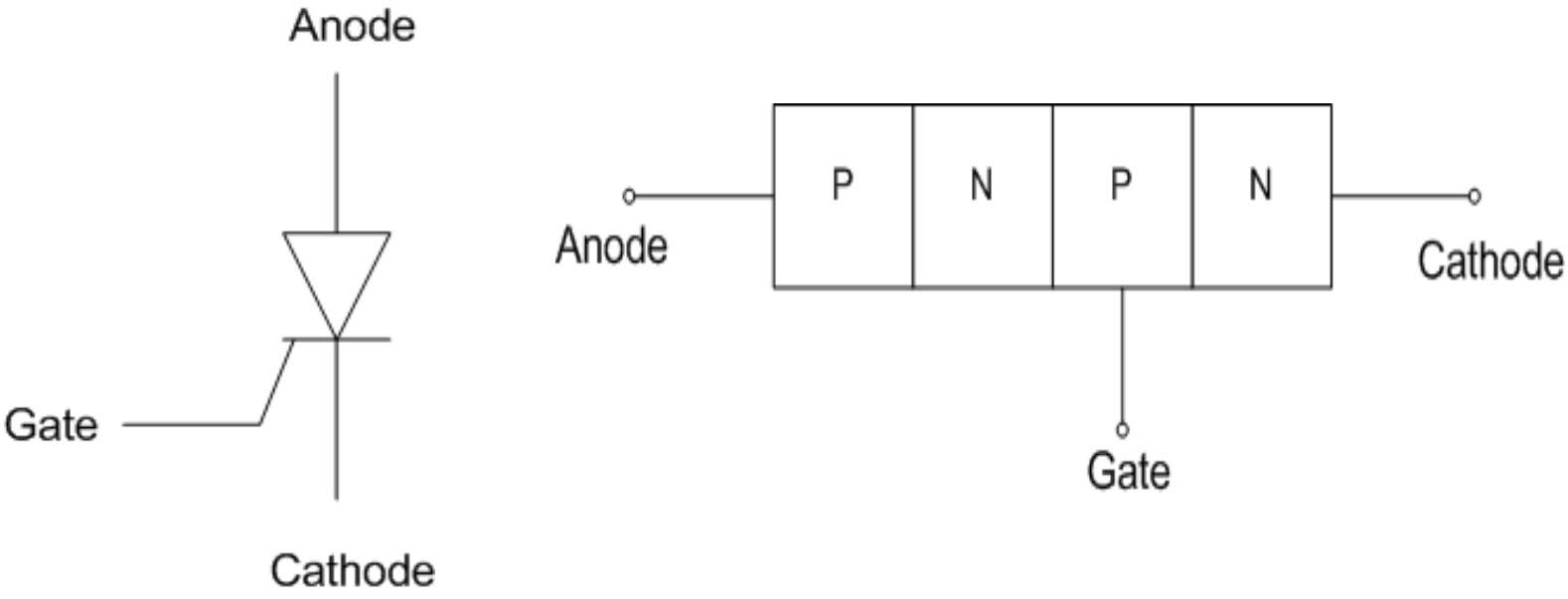


Fig.1.1 (a) Symbol & Structure of SCR

Silicon Controlled Rectifier

- Is a three terminal four layered pnpn device.
- Its three terminals are anode, cathode and gate.
- It is a unidirectional device.
- It is most widely used device of the thyristor family and hence it is universally referred as thyristor.
- It is made up of silicon and its working as a rectifier can be controlled hence, it is called as ‘Silicon Controlled Rectifier’.

SCR – Construction & Operation

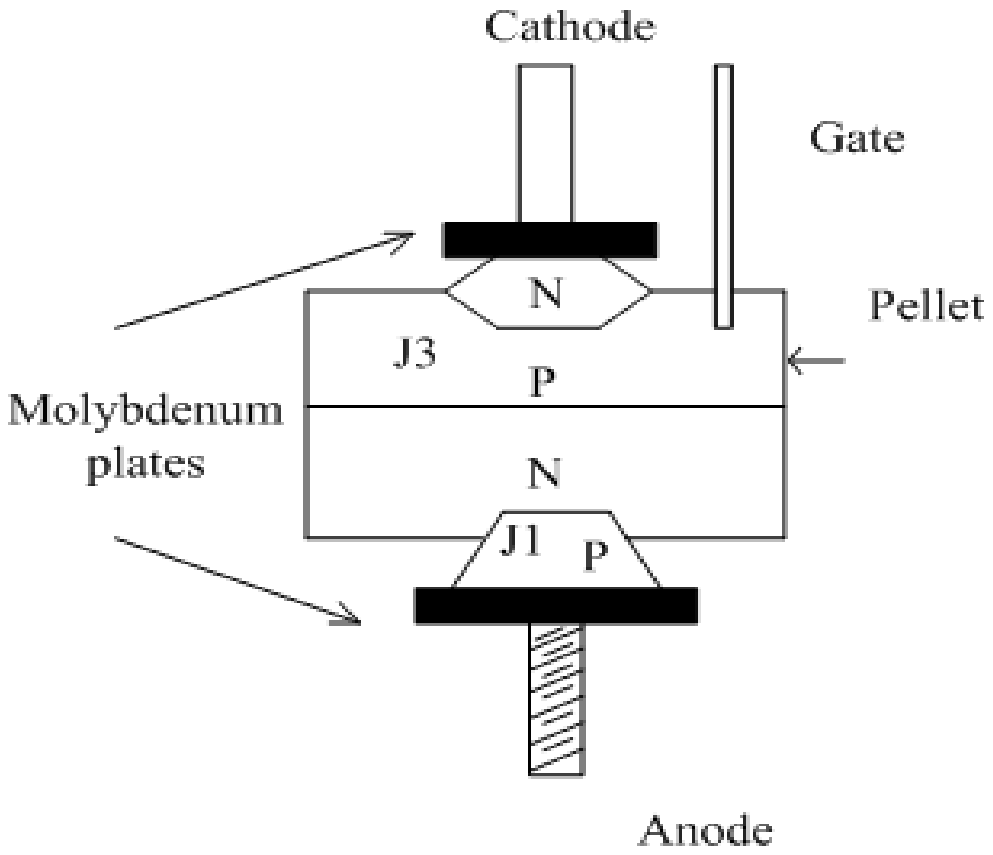
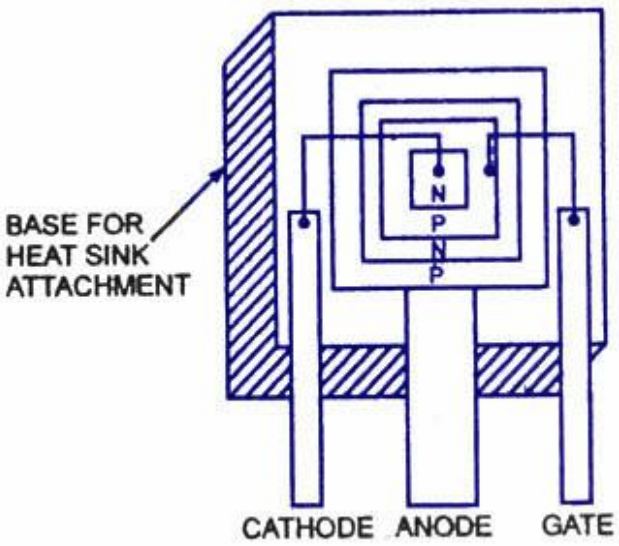
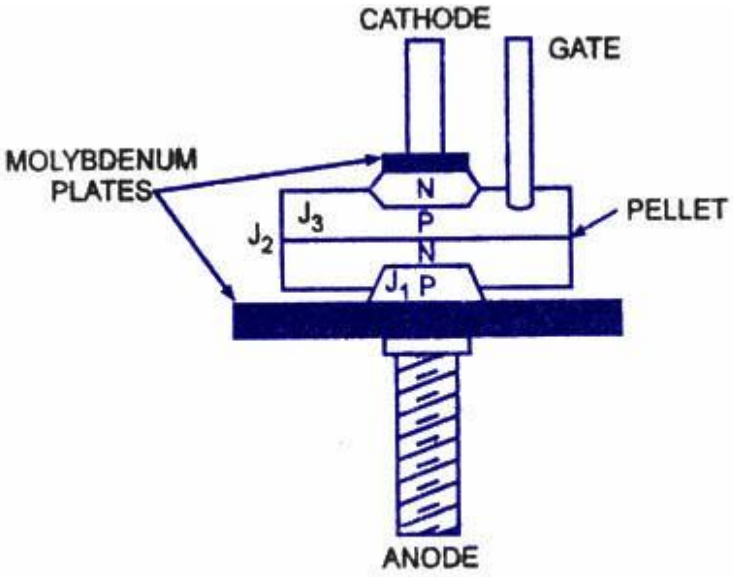


Fig.1.2 (a) Cross-sectional view of alloy-diffused SCR (Mesa type)

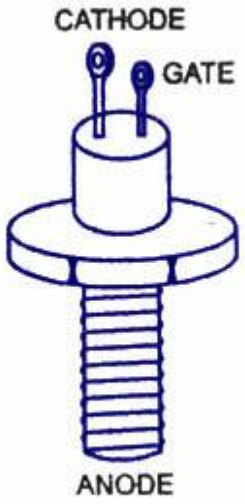
SCR – Construction & Operation



Planar Type Construction



Mesa Type Construction



External Construction

Fig.1.2 (b) Cross-sectional view of alloy-diffused SCR

SCR – Construction & Operation

- In Mesa type of SCR, inner junction J2 is obtained by diffusion and outer two layers are alloyed to it.
- The pnpn pellet is properly braced with molybdenum plates to provide mechanical strength.
- One of the plates is hard soldered to a copper or aluminium stud which is threaded for attachment to heat sink.
- Use of hard solder between pellet and backup plates minimizes thermal fatigue when SCR is subjected to temperature induced stresses.

Two Transistor Model of SCR

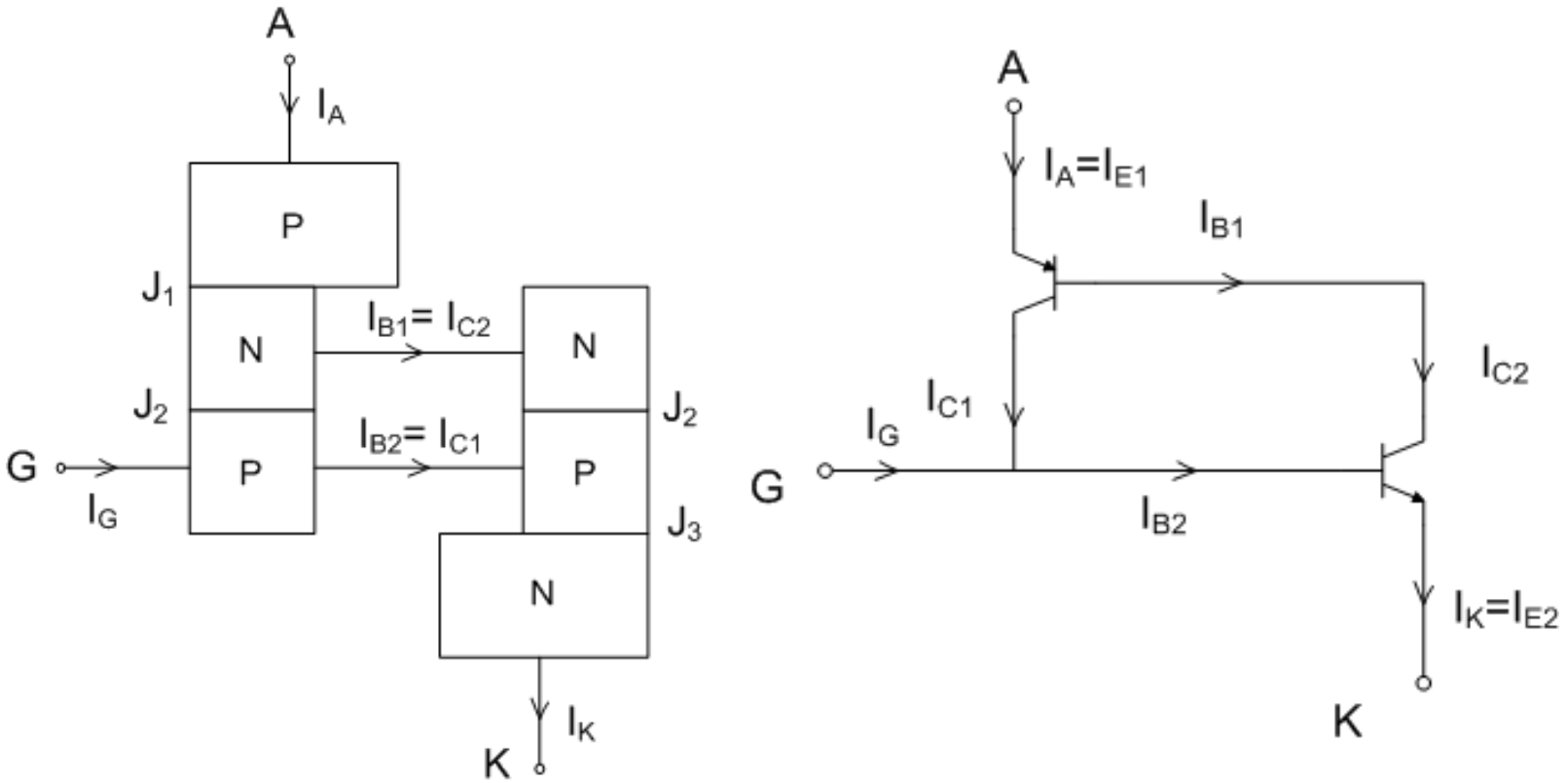


Fig. 1.3 Two transistor model of SCR

Two Transistor Model of SCR

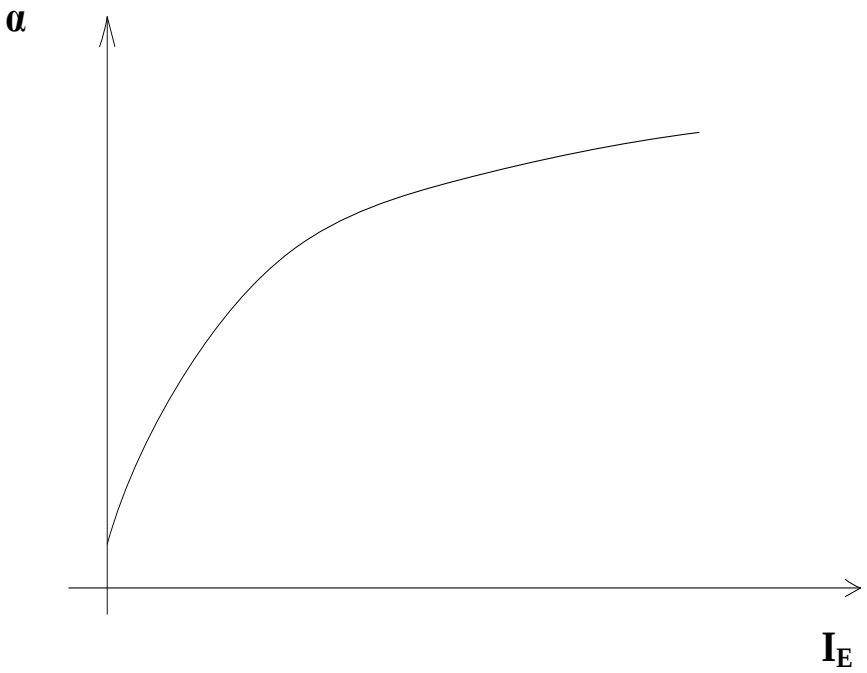


Fig. 1.4 Variation of current gain α with emitter current I_E

- The current gain α varies with emitter current I_E .
- In most SCRs current gain is low at low emitter currents but increases fairly rapidly as emitter current is increased.

Two Transistor Model of SCR

- Two transistor model is obtained by splitting middle two layers of SCR.
- So, SCR can be considered as a combination of a pnp and npn transistor.
- Anode current as a function of gate current is given by –

$$I_A = \frac{\alpha_2 I_G}{1 - (\alpha_1 + \alpha_2)}$$

- Thus from this analogy it is observed that anode current approaches infinity if $(\alpha_1 + \alpha_2)$ is equal to one.
- So, the device will suddenly switch into on state.
- So. Gate current should be such that $(\alpha_1 + \alpha_2)$ approaches unity.

Static Characteristics of SCR

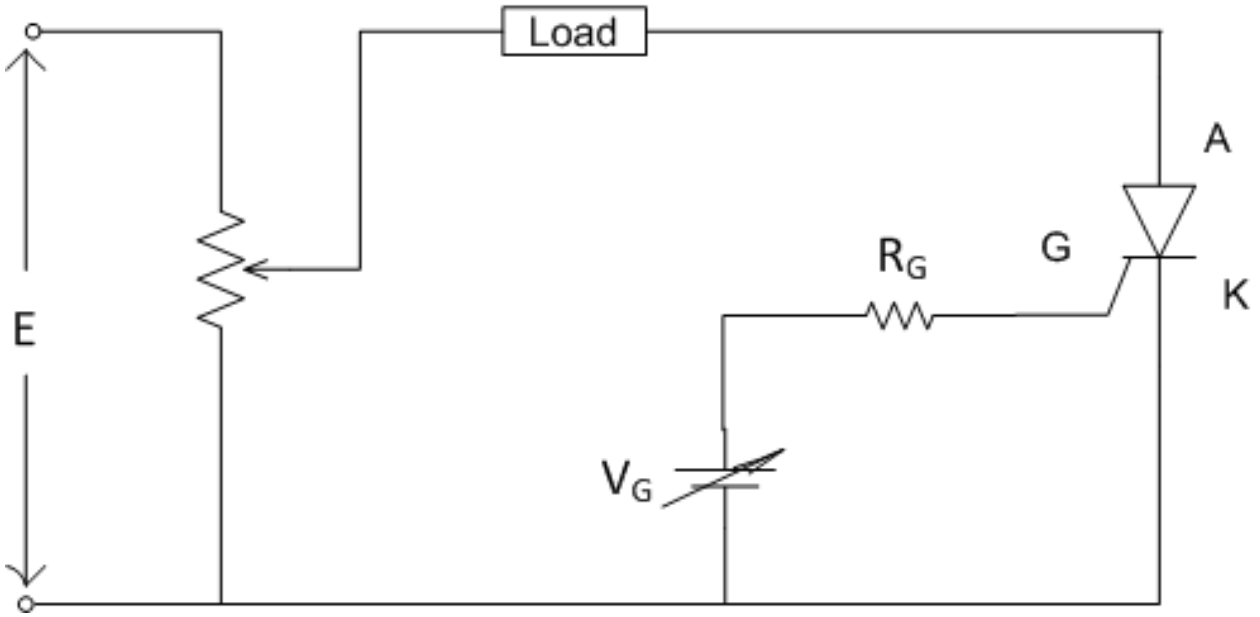
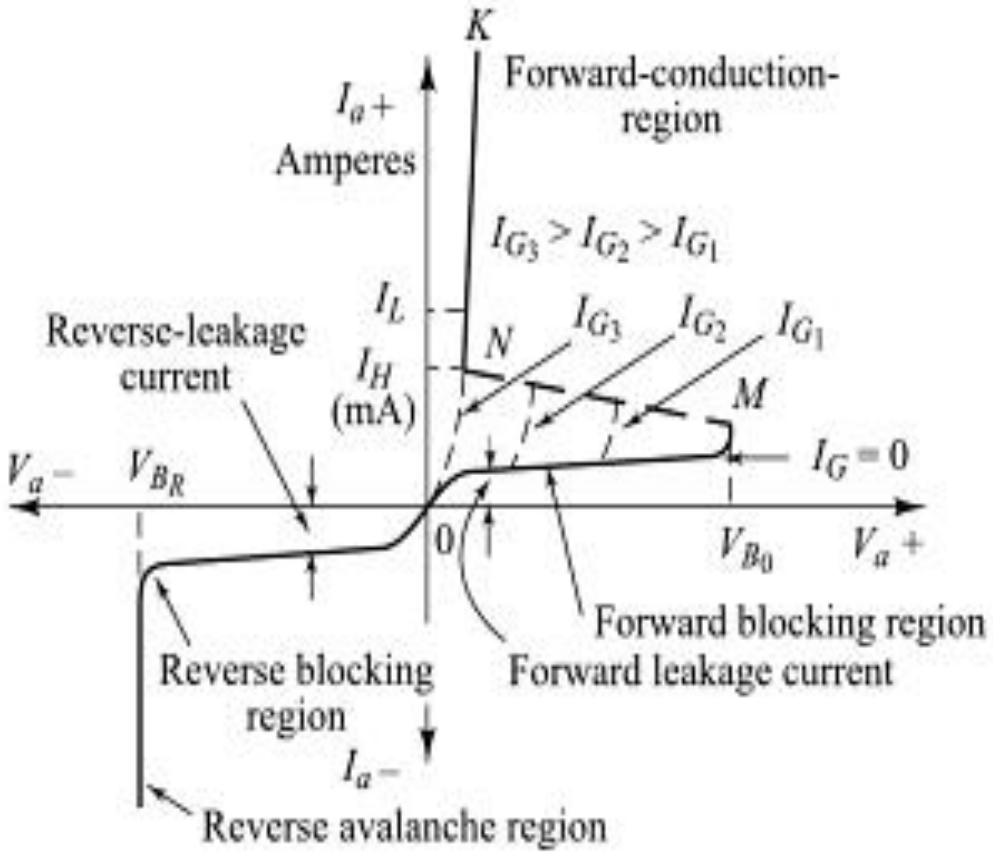


Fig. 1.4 Elementary Circuit for V-I characteristics of SCR

Static Characteristics of SCR



V_{B_0} = Forward breakover voltage; V_{B_R} = Reverse breakover voltage; I_G = Gate current; I_L = Latching current; and I_H = Holding current

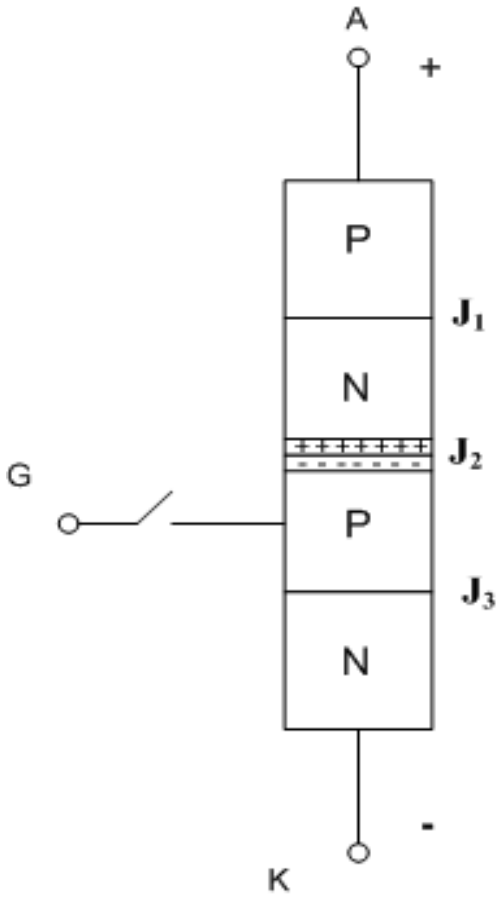
Fig.1.5 V-I characteristics of SCR

Ref – Power Electronics by M.D.Singh and Khanchandani

Static Characteristics of SCR

❑ Forward Blocking Mode:

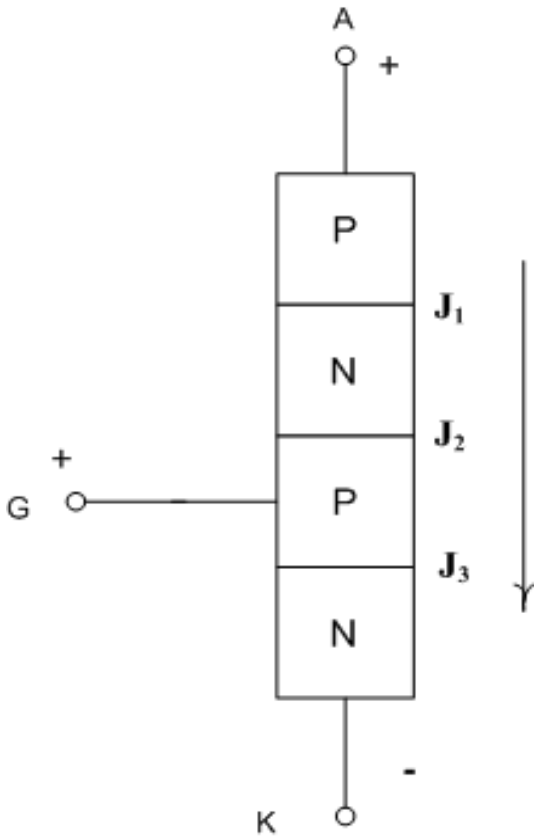
In this mode of operation anode is positive with respect to cathode. No supply is given to the gate. Hence, junctions J1 & J3 are forward-biased while junction J2 is reversed-biased. So, SCR is said to be in forward blocking state and a very small I current called as forward leakage current flows.



Static Characteristics of SCR

❑ Forward Conduction Mode :

In this mode of operation when anode is positive with respect to cathode and forward voltage is sufficiently increased up to breakover voltage $V_{BO,}$ reverse bias junction J2 breaks down .So, SCR starts conducting, its anode current starts increasing. When a gate signal is applied, SCR turns on before V_{BO} is reached.



Static Characteristics of SCR

- **Holding Current I_H:-**

  It is the minimum anode current required to turn on SCR. If anode current falls below holding current SCR will revert back to off state.

- **Latching Current I_L:-**

  It is the minimum anode current required to maintain SCR in on state after removal of gate supply. If anode current rises above latching current SCR will remain in on state.

Static Characteristics of SCR

Datasheet showing comparison between holding and latching current of SCR :-

VISHAY

www.vishay.com

VS-25TTS..PbF Series, VS-25TTS..-M3 Series

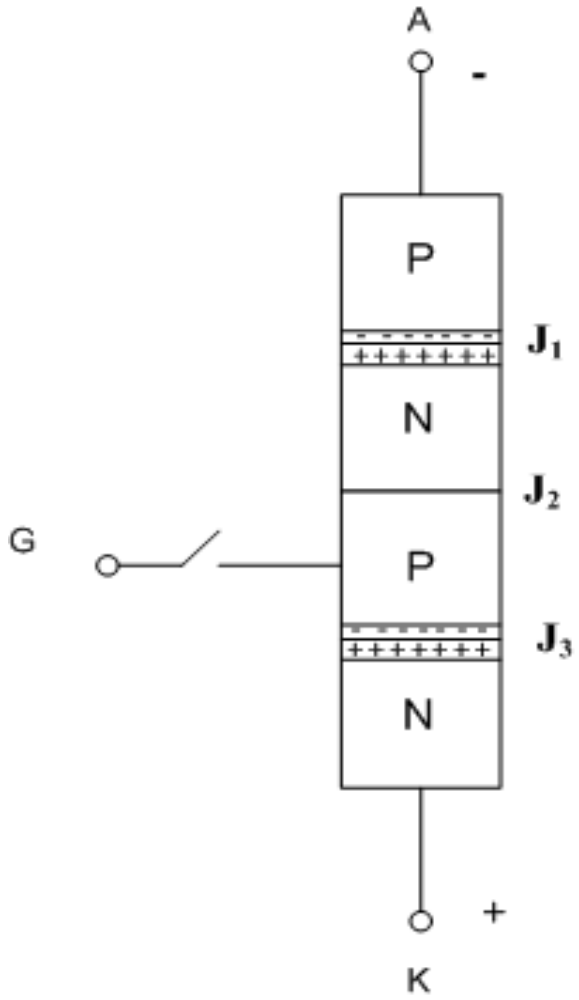
Vishay Semiconductors

ABSOLUTE MAXIMUM RATINGS

PARAMETER	SYMBOL	TEST CONDITIONS	VALUES TYP.	VALUES MAX.	UNITS
Maximum average on-state current	$I_{T(AV)}$	T_C = 93 °C, 180° conduction half sine wave	16		A
Maximum RMS on-state current	I_{RMS}		25		A
Maximum peak, one-cycle, non-repetitive surge current	I_{TSM}	10 ms sine pulse, rated V_{RRM} applied	270		A
		10 ms sine pulse, no voltage reapplied	320		A
Maximum I^2t for fusing	I^2t	10 ms sine pulse, rated V_{RRM} applied	365		A^2s
		10 ms sine pulse, no voltage reapplied	515		A^2s
Maximum $I^2\sqrt{t}$ for fusing	$I^2\sqrt{t}$	t = 0.1 to 10 ms, no voltage reapplied	5152		$A^2\sqrt{s}$
Maximum on-state voltage drop	V_{TM}	16 A, T_J = 25 °C	1.25		V
On-state slope resistance	r_t	T_J = 125 °C	12.0		mΩ
Threshold voltage	$V_{T(TO)}$	T_J = 125 °C	1.0		V
Maximum reverse and direct leakage current	I_{RM}/I_{DM}	T_J = 25 °C; V_R = Rated V_{RRM}/V_{DRM}	0.5		mA
		T_J = 125 °C; V_R = Rated V_{RRM}/V_{DRM}	10		mA
Holding current	I_H	Anode supply = 6 V, resistive load, initial I_T = 1 A, T_J = 25 °C	-	150	mA
Maximum latching current	I_L	Anode supply = 6 V, resistive load, T_J = 25 °C	200		mA

Static Characteristics of SCR

- **Reverse Blocking Mode :**
  In this mode of operation cathode is positive with respect to anode. Hence, junctions J1 & J3 are reversed- biased while junction J2 is forward-biased.
  So, SCR is said to be in reverse blocking state and a very small current called as reverse leakage current flows.



Gate Characteristics of SCR

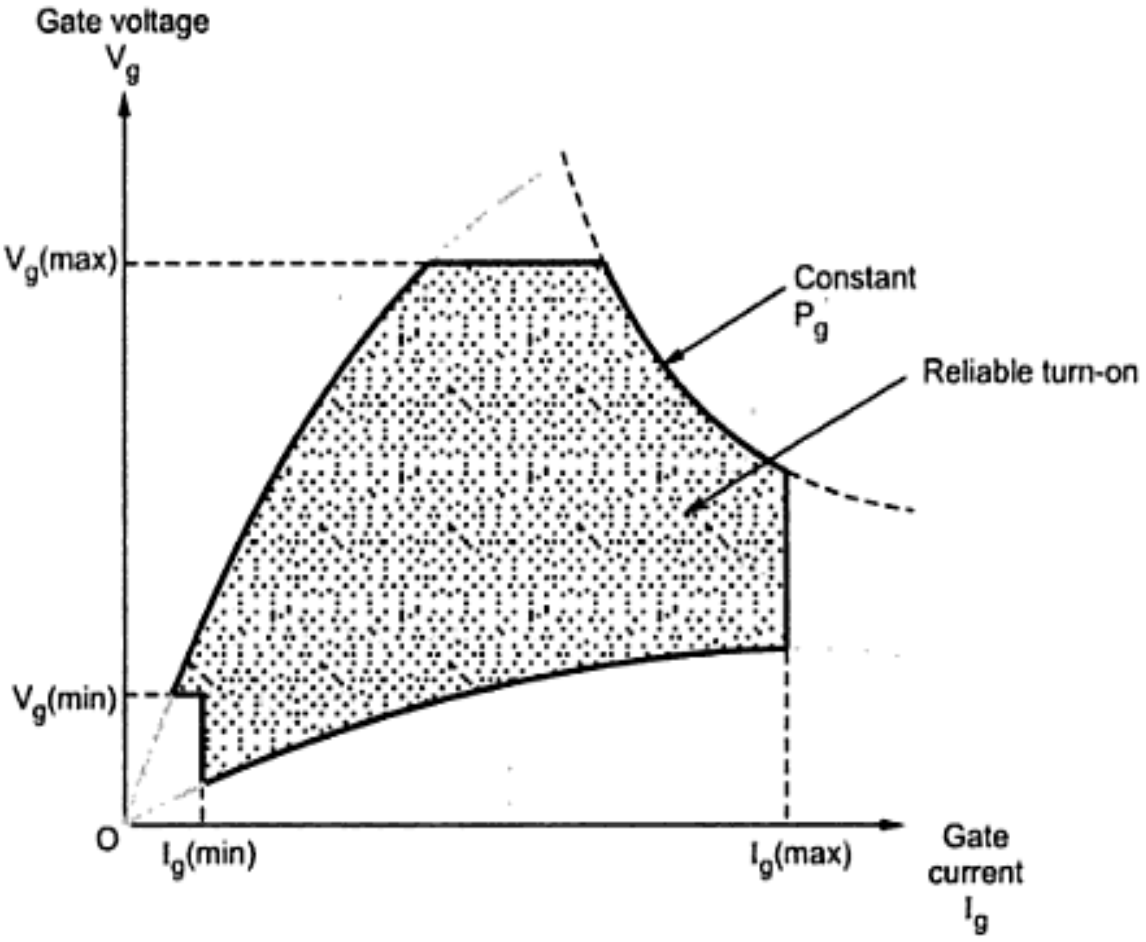


Fig.1.6 Gate characteristics of SCR

Static Characteristics of SCR

- Gate characteristics of SCR is the graph drawn between forward gate to cathode voltage V_G and gate current IG. Due to difference in doping levels of SCRs, the gate characteristics spreads between two different curves for a particular type of SCR.
- $I_{g(max)}$ is the maximum gate current that can flow through the thyristor without damaging it .Similarly Vg(max) is the maximum gate voltage to be applied.
- Similarly $V_{g\ (min)}$ and $I_{g(min)}$ are minimum gate voltage and current, below which thyristor will not be turned-on. Hence to turn-on the thyristor successfully the gate current and voltage should be

$$I_{g(min)} < I_g < I_{g(max)}$$
$$V_{g\ (min)} < V_g < V_{g(max)}$$

Static Characteristics of SCR

- The characteristic of Fig1.5 also shows the curve for constant gate power (P_g). Thus for reliable turn-on, the (V_g, I_g) point must lie in the shaded area in Fig. 1.6.
- It turns-on thyristor successfully. Any spurious voltage or current spikes at the gate must be less than $V_{g(min)}$ and $I_{g(min)}$ to avoid false triggering of the thyristor.
- The gate characteristics shown in Fig.1.6 are for DC values of gate voltage and current.

Triggering Methods of SCR

Following methods are generally employed for triggering SCR.

- Forward Voltage Triggering
- Thermal Triggering
- Light Triggering
- Gate Triggering
- dv/dt Triggering

Triggering Methods of SCR

- **Forward Voltage Triggering:**

  This is triggering without application of gate voltage with only application of a large voltage across the anode-cathode such that it is greater than the forward breakdown voltage V_{BO} . This type of turn on is destructive and should be avoided.

Triggering Methods of SCR

❑Thermal Triggering:

If the temperature of the thyristor is high, there will be an increase in charge carriers which would increase the leakage current. This would cause an increase in α_1 and α_2 and the thyristor may turn on. This type of turn on many cause thermal run away and is usually avoided.

Triggering Methods of SCR

- **Light Triggering :**

  If light be allowed to fall on the junctions of a thyristor, charge carrier concentration would increase which may turn on the SCR. Light activated SCRs are turned on by allowing light to strike the silicon wafer.

Triggering Methods of SCR

❑ Gate Triggering:

This triggering method is practically employed to turn-on the thyristor. In this method gate can be supplied with either ac ,dc source or pulse generator circuit.

Triggering Methods of SCR

❑ dv/dt triggering:

Under transient conditions, the capacitances of the p-n junction will influence the characteristics of a thyristor. If the thyristor is in the blocking state, a rapidly rising voltage applied across the device would cause a high current to flow through the device resulting in turn-on.

Dynamic Characteristics of SCR

Turn –on characteristics

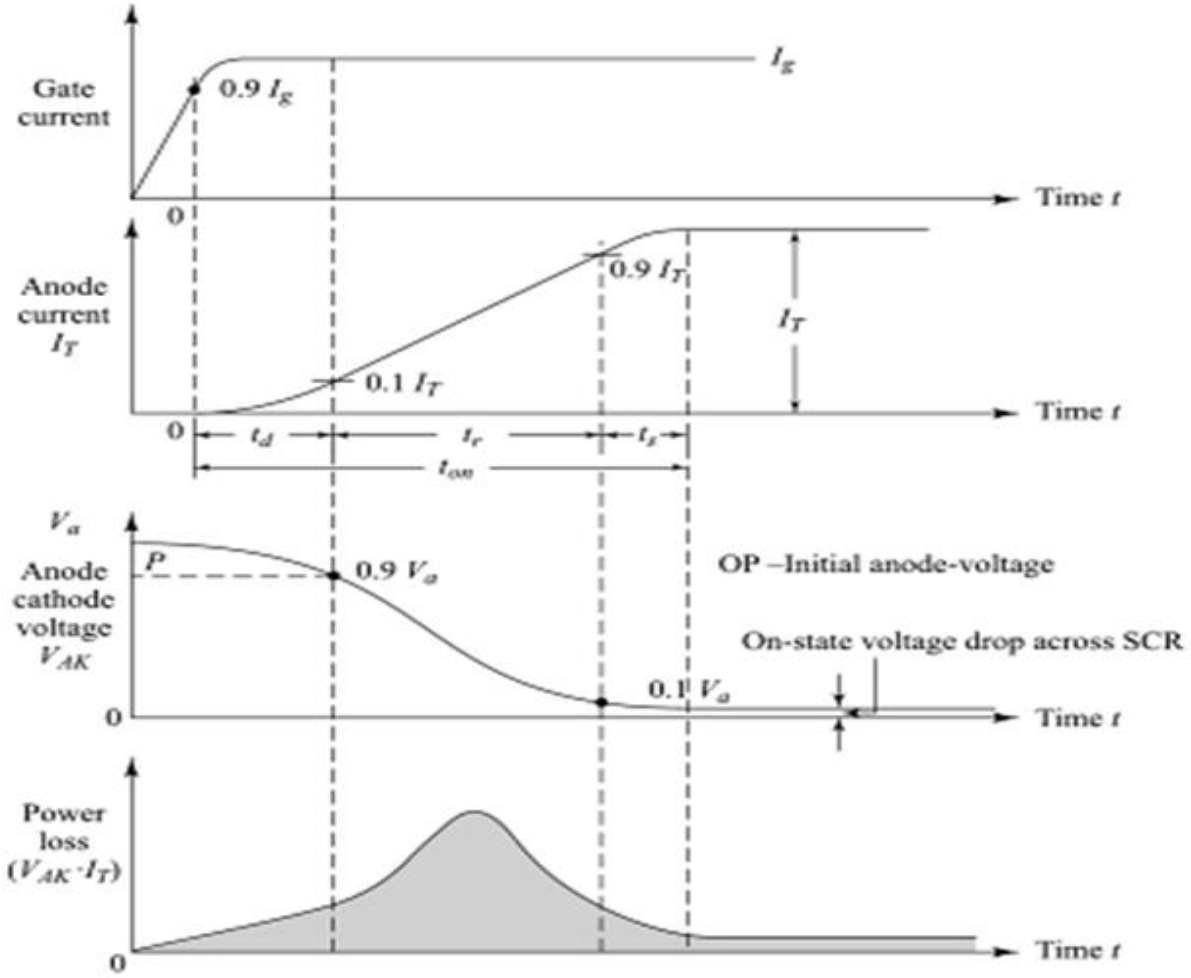
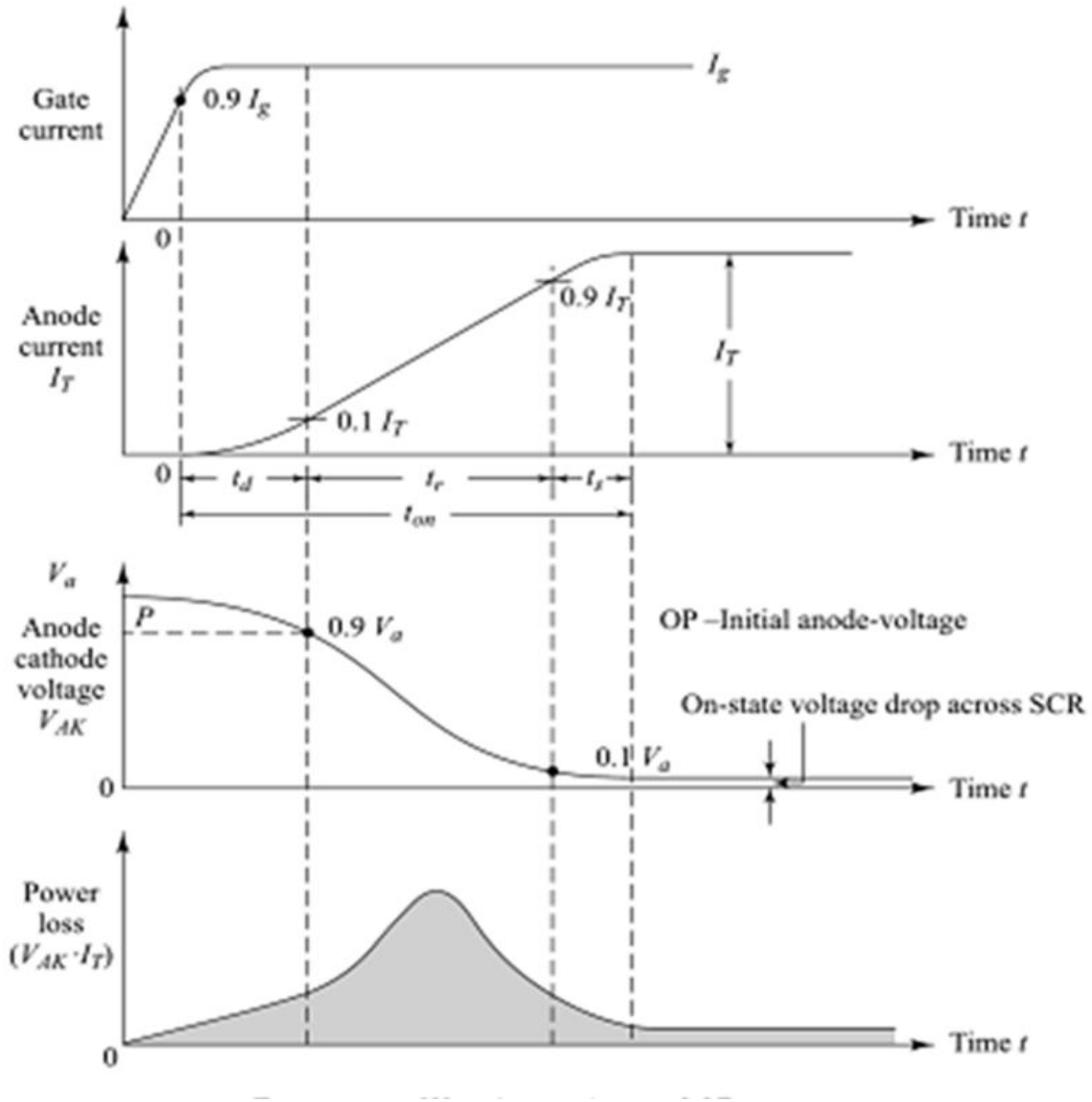


Fig.1.7 Turn –on characteristics of SCR.

Ref – Power Electronics by M.D.Singh and Khanchandani

Dynamic Characteristics of SCR



The transition from one state to another state requires a finite period of time. The turn on time t_{on} of SCR is sub-divided into three distinct periods called delay time, rise time and spread time.

Fig.1.7 (a) Turn –on characteristics of SCR.

Dynamic Characteristics of SCR

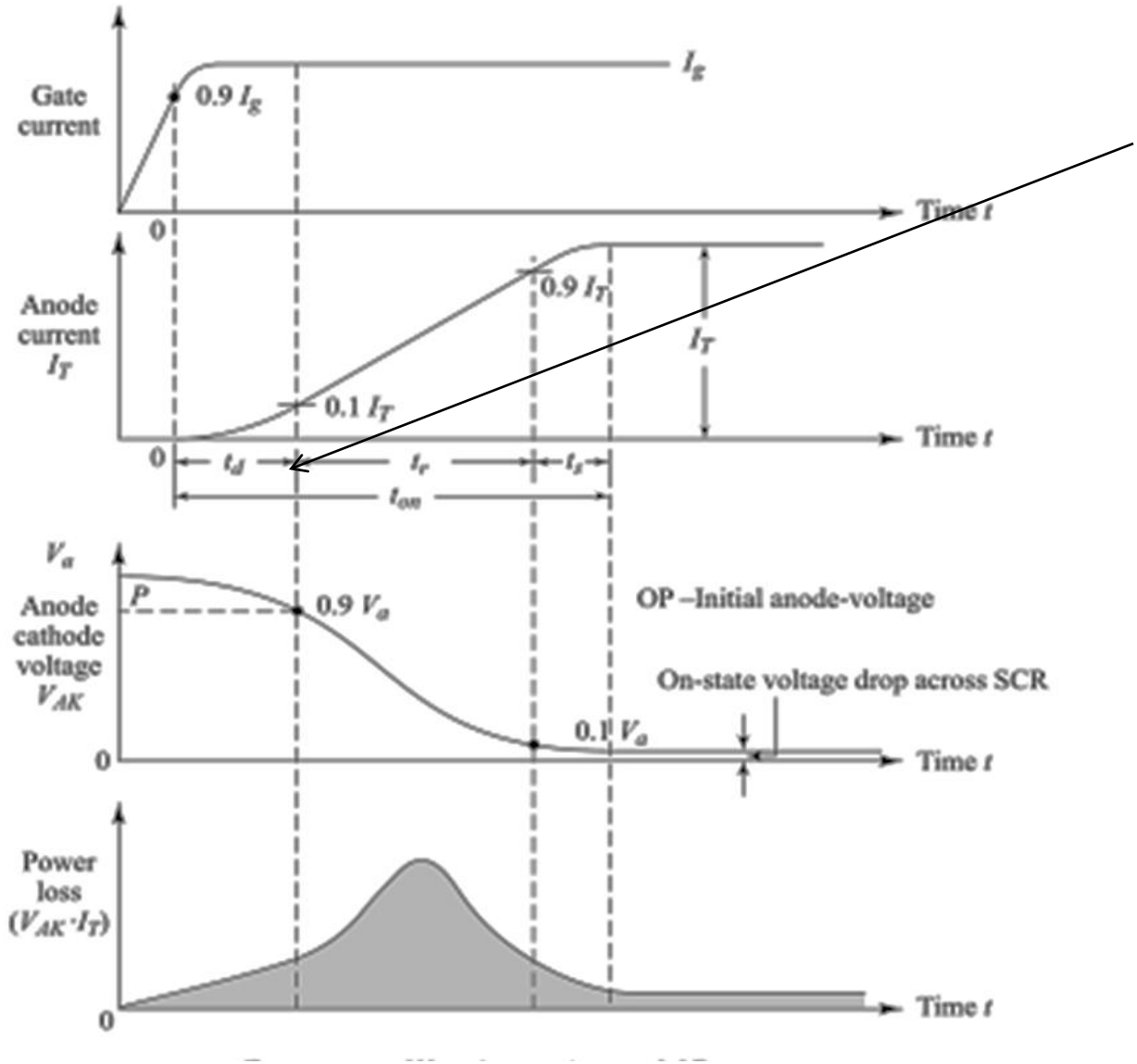
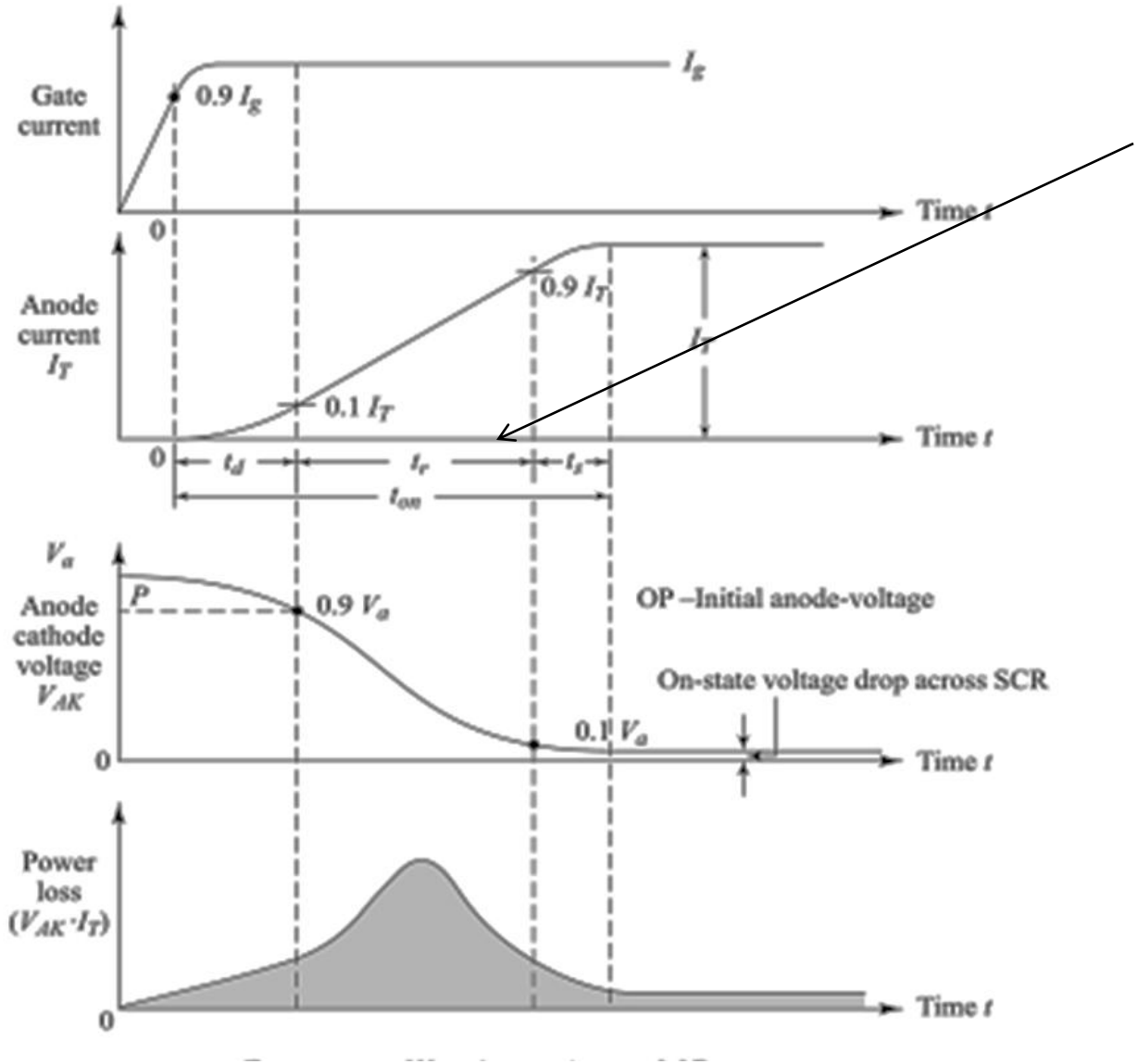


Fig.1.7 (b) Turn –on characteristics of SCR.

❑ **Delay time (t_d) :**

It is the time between the instant at which the gate current reaches 90 % of its final value and the instant at which anode current reaches 10 % of its final value.

Dynamic Characteristics of SCR



❑ **Rise time (t_r) :**

It is the time required for the anode current to rise from 10 to 90 % of its final value. It can also be defined as the time required for the forward blocking off state voltage to fall from 0.9 to 0.1 of its initial value – OP.

Fig.1.7 (c) Turn –on characteristics of SCR.

Dynamic Characteristics of SCR

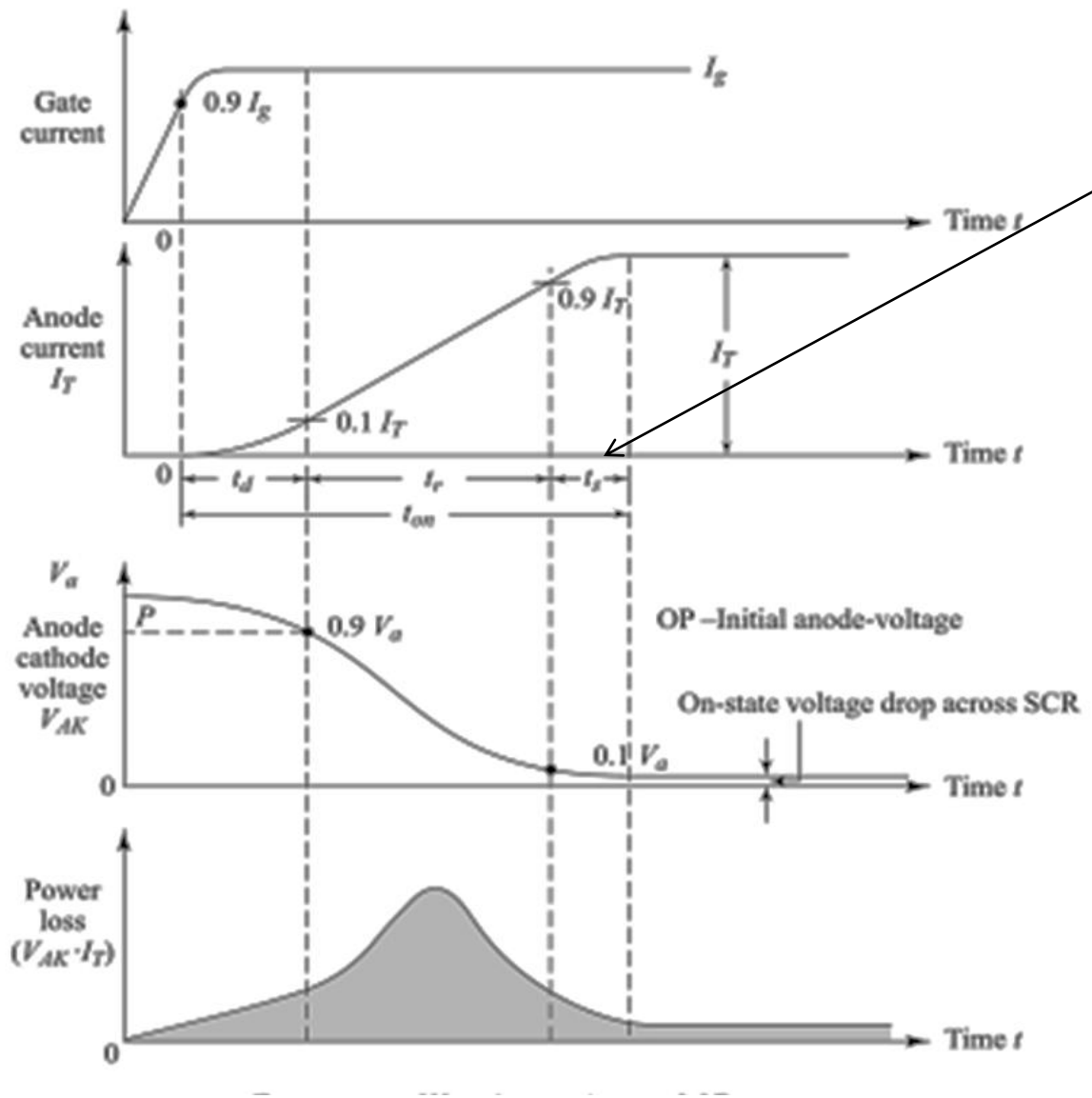


Fig.1.7 (d) Turn –on characteristics of SCR.

❑ **Spread time (t_s):**

It is the time required for the forward blocking voltage to fall from 0.1 to its value to the on-state voltage drop (1 to 1.5 V). After the spread time anode current attains steady-state values and the voltage drop across SCR is equal to the on-state voltage drop of the order of 1 to 1.5 V.

Dynamic Characteristics of SCR

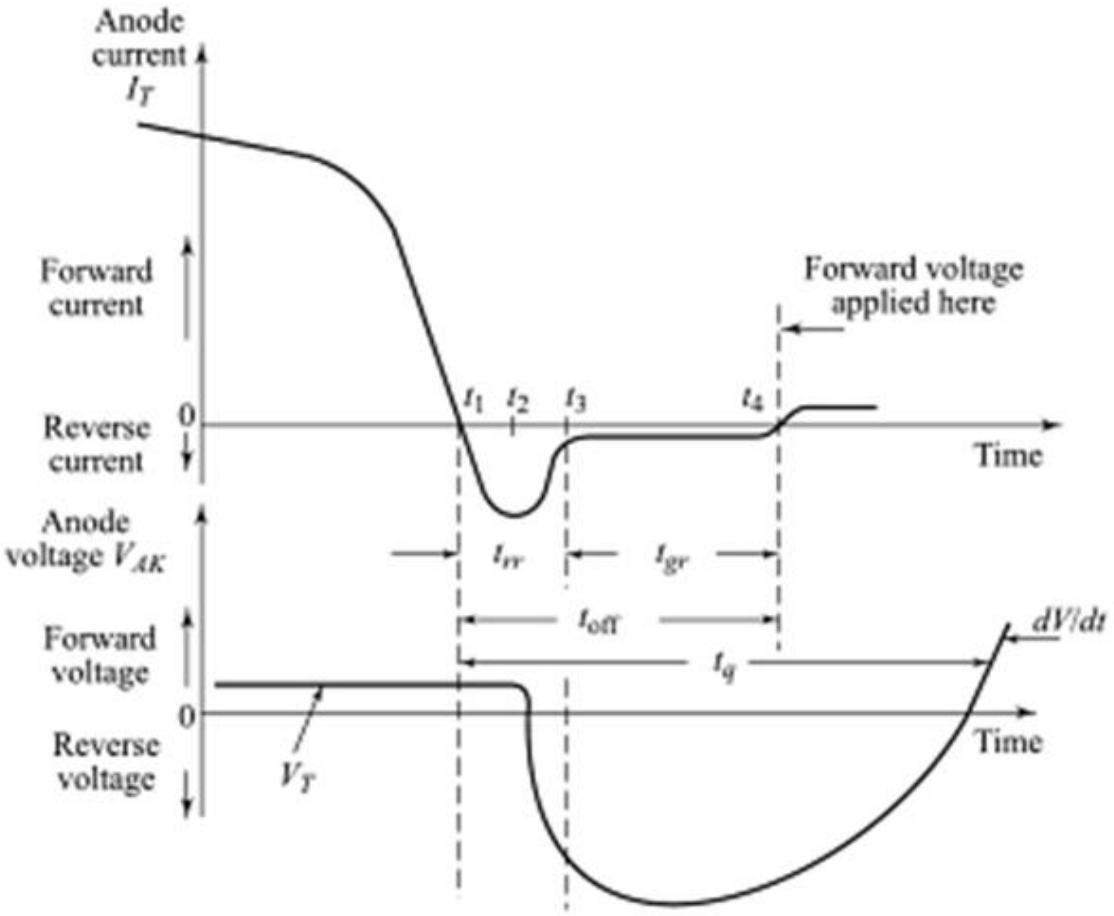


Fig.1.8 (a) Turn –off characteristics of SCR.

SCR can be turned off by reducing its anode current below holding current level. The process of turn off is termed as commutation. The total turn off time of SCR is divided into two time intervals the reverse recovery time t_{rr} and gate recovery time t_{gr} .

Dynamic Characteristics of SCR

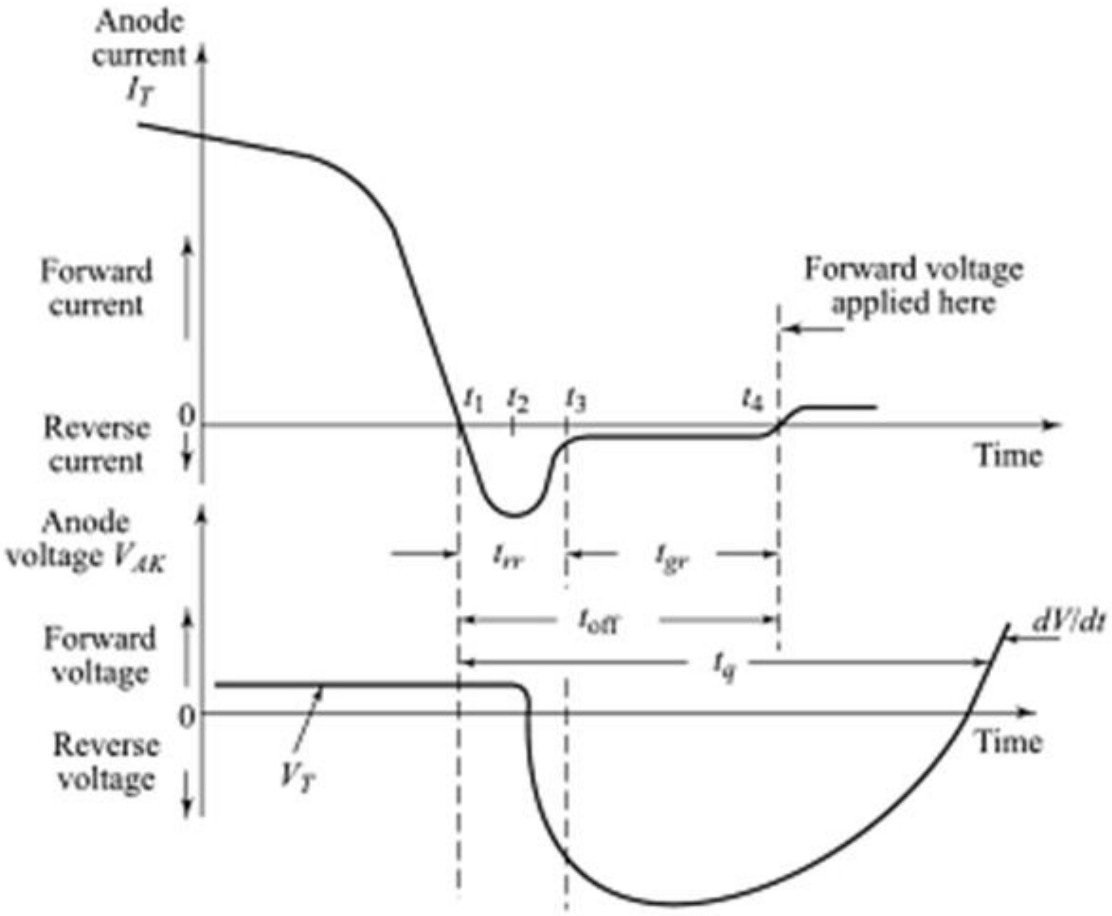


Fig.1.8 (b) Turn –off characteristics of SCR.

At instant t_1 forward anode current becomes zero. During reverse recovery time t_1 to t_3 anode current flows in reverse direction. At instant t_3 trapped charges are present at junction J_2 .During t_3 to t_4 these carriers recombine. At instant t_4 recombination is complete .Thus SCR turn-off time is the interval between t_4 and t_1 .

Dynamic Characteristics of SCR

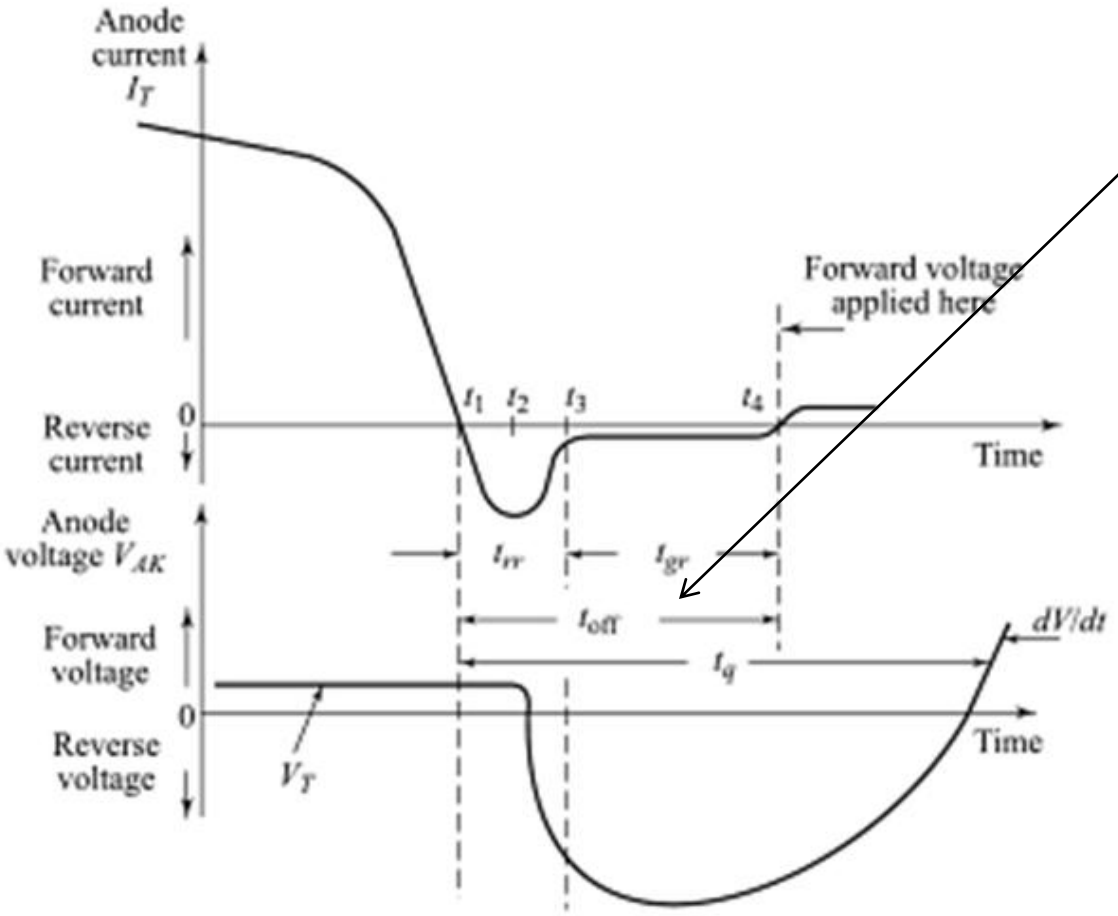


Fig.1.8 (c) Turn –off characteristics of SCR.

- **Turn-off Time (T_{off}):** The turn-off time of SCR is defined as the minimum time interval between the instant at which anode current becomes zero and the instant at which the device is capable of blocking the forward voltage.

Ratings of SCR

The reliable operation can be done when a thyristor does not violate its voltage and current rating during working period. Generally these ratings are specified in the data sheet given by manufacturer.

❑Voltage Ratings

- **Anode Voltage Rating**

  This rating gives us a brief idea about withstanding power of a thyristor in forward blocking mode in the absence of gate current.

- **Peak Working Forward Blocking Voltage (V_{DWM})**

  It specifies the maximum forward voltage that can be withstand by the SCR at the time of working.

- **Peak Repetitive Forward Blocking Voltage (V_{DRM})**

  It specifies the peak forward transient voltage that a SCR can block repeatedly or periodically in forward blocking mode

Ratings of SCR

- **Peak Non-Repetitive or Surge Forward Blocking Voltage (V_{DSM})**

  It is the peak value of the forward transient voltage that does not appear periodically. This type of over voltage generated at the time of switching operation of circuit breaker.

- **Peak reverse working voltage (V_{RWM})**

  It is the peak reverse working voltage that the thyristor can withstand in the reverse direction.

- **Peak repetitive reverse voltage (V_{RRM})**

  It is the maximum permissible instantaneous value of repetitive applied reverse voltage that the thyristor can block in reverse direction.

- **Peak surge reverse voltage (V_{RSM})**

  This rating occurs for transient conditions for a specified time duration.

Ratings of SCR

- **Forward dv/dt rating**
  This is the maximum rate of rise of anode voltage which can turn on the SCR without gate current.

- **Voltage safety factor (V_{SF})**
  It is described as the ratio of peak repetitive reverse voltage to the maximum value of input voltage.

- **Gate Voltage (V_{GT})**
  It is the specified value of gate voltage to turn on the SCR.

Ratings of SCR

❑Current Rating of SCR

- **Maximum RMS Current Rating (I_{RMS})**

  It is the on-state rms current of SCR. I_{RMS} rating of the SCR must be a suitable value so that its maximum heat capability does not exceed.

- **Maximum Average Current Rating (I_{AV})**

  It is the allowable average current that can be applied safely such that maximum junction temperature and rms current limit cannot be exceeded.

- **I^2t Rating of SCR**

  This rating specifies the energy that the device can absorb for a short time before the fault is cleared.

Ratings of SCR

- **di/dt Rating**

  This rating indicates the maximum rate of rise of current from anode to cathode without any harm to the device.

- **Holding Current I_H:-**

  It is the minimum anode current required to turn on SCR.

- **Latching Current** I_L:-

  It is the minimum anode current required to maintain SCR in on state after removal of gate supply.

- **Peak Forward Gate Current (I_{GRM})**

  This is the rating of maximum forward gate current that should not be exceeded to reliable and safe operation.

- **Gate current (I_{GT})**

  It is the required gate current to trigger the SCR.

Series & Parallel Connection of SCRs

There is need of connecting SCRs in series or parallel due to following reasons:

- The total voltage or current to be handled is greater than available voltage and current rating of a single SCR.
- SCRs with power rating are not easily available
- If fault occurs on system then small rating SCR can be easily replaced by a new SCR.
- It is economical to connect number of SCRs in series or parallel than using a single SCR of high rating.

Series & Parallel Connection of SCRs

Group of SCRs connected in series or parallel is referred as 'string'. The degree of utilization of SCRs in a string is given by string efficiency.

String Efficiency :

It is defined as the ratio of actual voltage or current rating of the whole string to the product of individual voltage or current rating of SCR and the number of SCRs in the string.

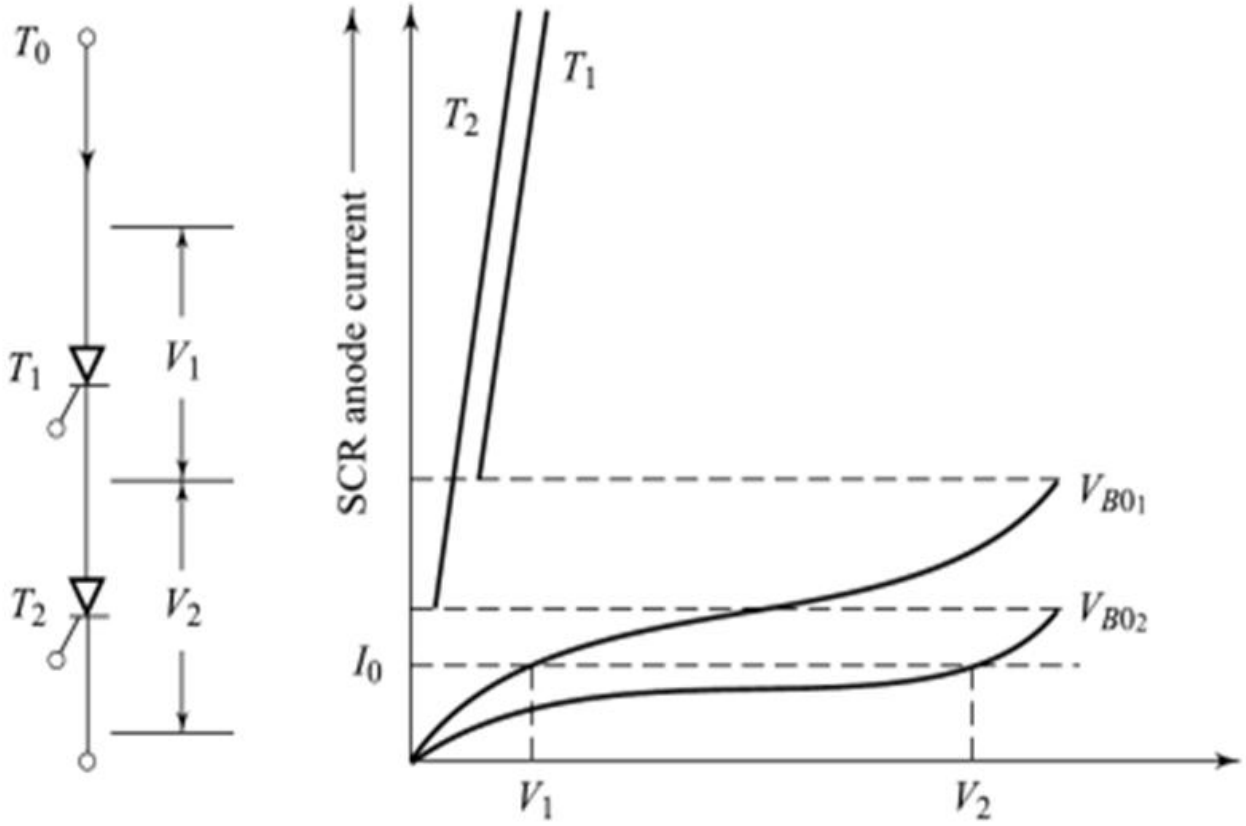
$$\text{String Efficiency} = \frac{\text{Actual voltage or current rating of the whole string}}{(\text{Individual voltage or current rating of SCR})(\text{Number of SCRs in the string})}$$

Derating Factor :

For safe operation SCRs are operated at less current or voltage than their combined rating. This is referred as derating of SCRs. A measure of reliability of string is given by derating factor.

$$\text{Derating Factor} = 1 - \text{String Efficiency}$$

Series operation of SCRs :



Series operation of SCRs :

When the required voltage rating exceeds the SCR voltage rating, a number of SCRs are required to be connected in series to share the forward and reverse voltage. As it is not possible to have SCRs of completely identical characteristics, deviation in characteristics lead to the following two major problems during series connections of the SCRs: (i) Unequal distribution of voltage across SCRs. (ii) Difference in recovery characteristics.

- For steady-state conditions, voltage sharing is achieved by using a resistance in parallel with each SCR.
- For transient voltage sharing a low non-inductive resistor and capacitor in series are placed across each SCR, as shown in figure. Diodes D1 connected in parallel with resistor R, helps in dynamic stabilization.

Series operation of SCRs :

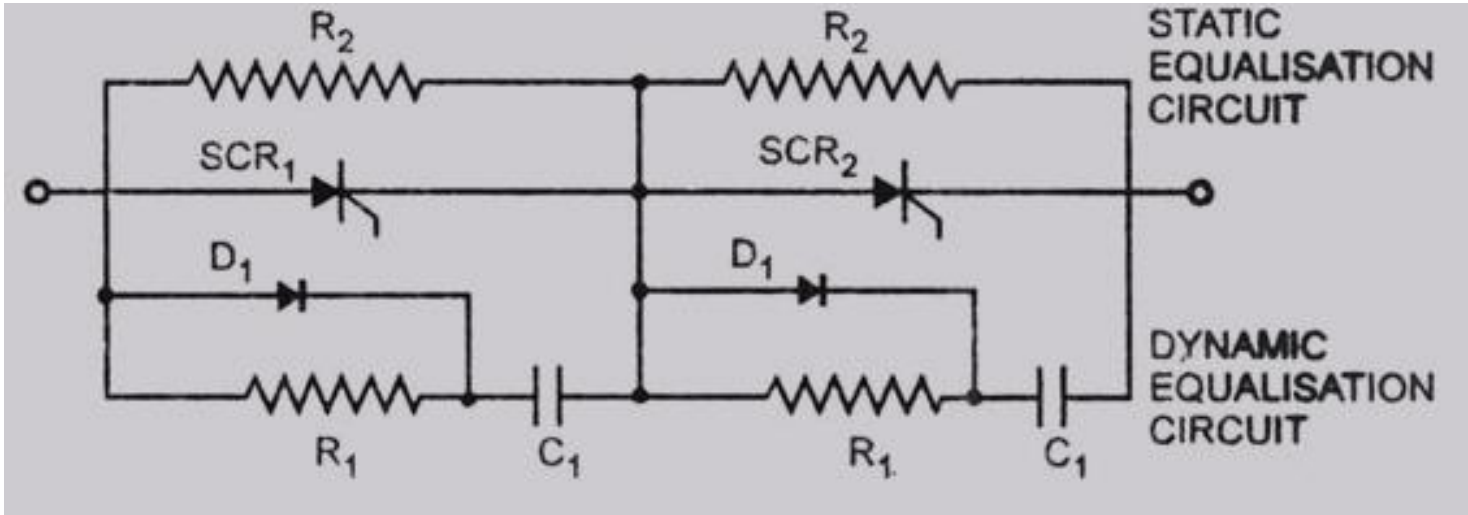


Fig.1.9 Equalization for series connection

Series operation of SCRs :

- This circuit reduces differences between blocking voltages of the two devices within permissible limits.
- If ΔQ is the difference in recovery charge of two devices arising out of different recovery current for different time and ΔV is the permissible difference in blocking voltage then

$$C1 = \Delta Q / \Delta V$$

Series operation of SCRs :

- A practical way of obtaining a uniform voltage distribution is to connect the same value of resistance in parallel with each SCR.
- The value of the shunt resistance to be connected across each SCR for uniform voltage distribution is given as-

$$R < (ns.\ ED - Es)/(ns-1).\ \Delta Ib$$

Parallel operation of SCRs :

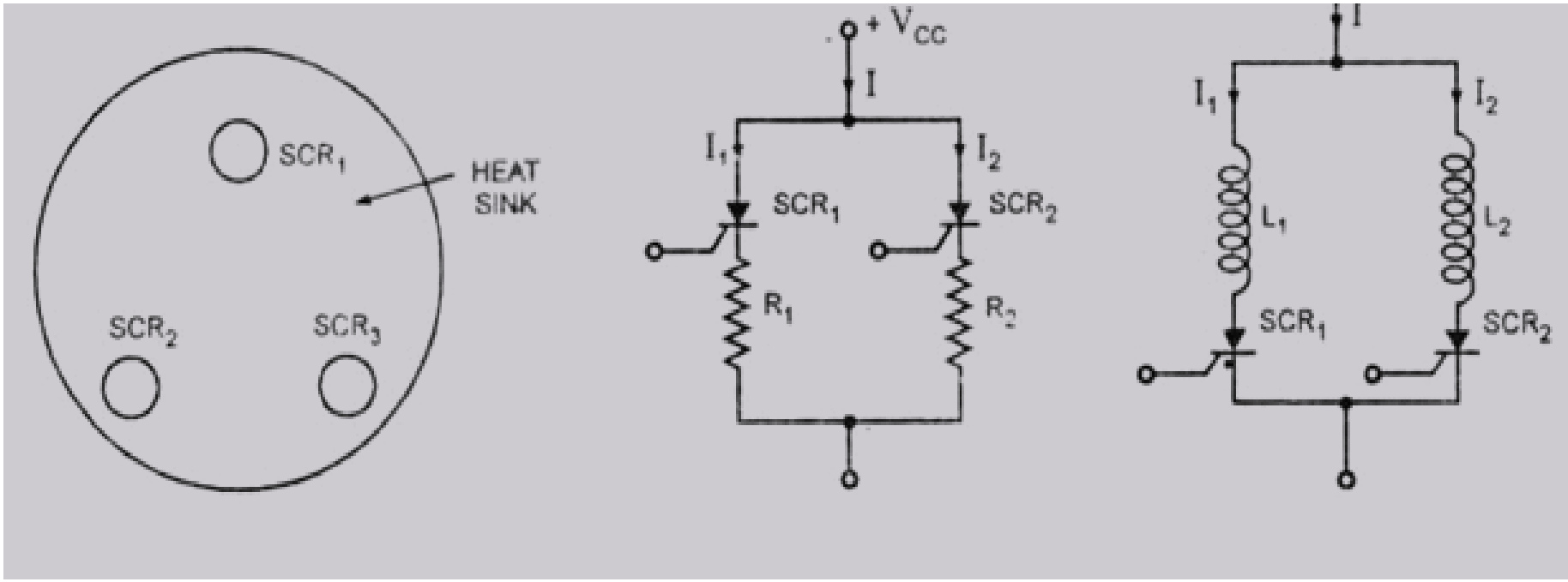


Fig.1.10 Equalization for parallel connection

Parallel operation of SCRs :

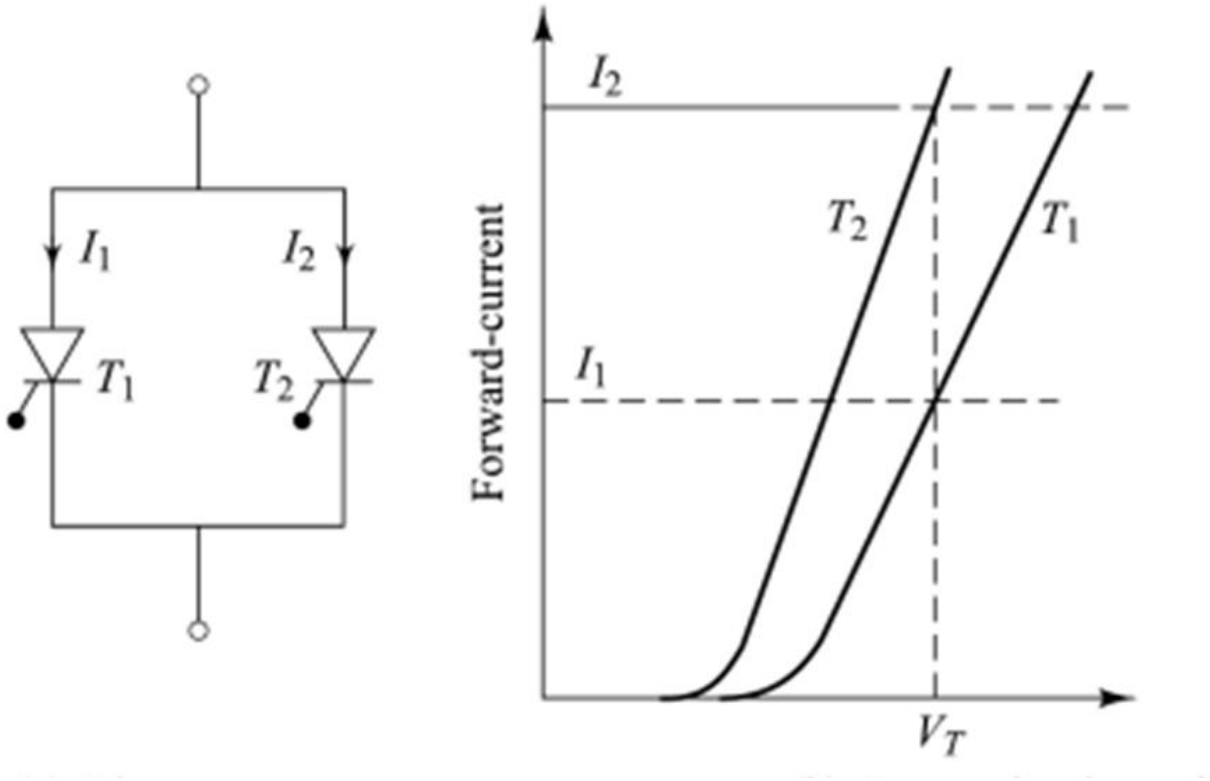


Fig.1.10 Equalization for parallel connection

Parallel operation of SCRs :

- When the load current exceeds the SCR current rating, SCRs are connected in parallel to share the load current.
- But when SCRs are operated in parallel, the current sharing between them may not be proper. The device having lower dynamic resistance will tend to share more current
- When the SCRs are connected in parallel, it must be ensured that the latching current level of the all the SCRs is such that when gate pulse is applied, all of them turn-on and remain on when the gate pulse is removed.

Parallel operation of SCRs :

- For equal sharing of currents by the devices voltage drop across the parallel paths must be equal. For operation of all the SCRs connected in parallel at the same temperature, it becomes necessary to use a common heat sink for their mounting, as illustrated in figure.
- Resistance compensation used for dc circuits is shown in figure. In this circuit the resistors are chosen so as to cause equal voltage drop in both arms. Inductive compensation used for ac circuits. The difference in characteristics due to different turn-on time, delay time, finger voltage, latching current.

Protection of SCR

Protection of a device is an important aspect for its reliable and efficient operation. SCR is a very delicate semiconductor device. So we have to use it in its specified ratings to get desired output. SCR may face different types of threats during its operation due to over voltages, over currents etc. There are different types of thyristor protection schemes available for satisfactory operation of the device like

1) Over voltage protection.
2) Over current protection.
3) High dv/dt protection.
4) High di/dt protection.
5) Thermal protection.

Protection of SCR

Overvoltage Protection :

- SCR may be subjected to internal or external over-voltages.
- **Internal Over-Voltages**

  After commutation of SCR ,reverse recovery current decays abruptly with high di/dt which causes a high reverse voltage that can exceed the rated break-overvoltage and the device may be damaged.
- **External Over-Voltages**

  These are caused due to various reasons in the supply line like lightning, surge conditions etc. External over voltage may cause different types of problems in SCR operation like increase in leakage current, permanent breakdown of junctions, unwanted turn-on of devices etc. So, we have to suppress the over-voltages. The effect of over-voltages can be minimized by using non-linear resistors.

Protection of SCR

Overvoltage Protection :
Snubber Circuit

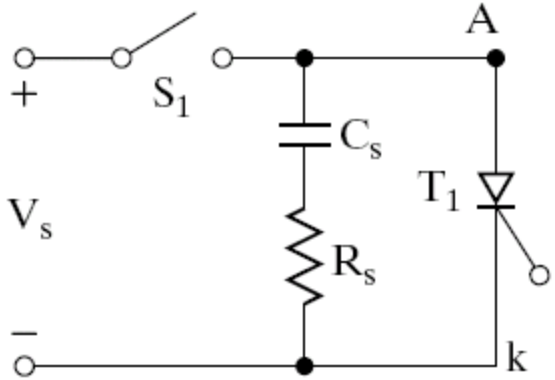


Fig.1.11 Snubber Circuit for over-voltage protection

- The dv/dt across the thyristor is limited by using snubber circuit .
- If switch S1 is closed at t = 0, the rate of rise of voltage across the thyristor is limited by the Capacitor C_S .
- When thyristor T_1 is turned on, the discharge current of the capacitor is limited by the resistor R_S as shown in figure 1.11.

Protection of SCR

Over current Protection :

- Over current mainly occurs due to different types of faults in the circuit.
- Due to over current i^2R loss will increase and high generation of heat may take place that can exceed the permissible limit and burn the device.
- SCR can be protected from over current by using Circuit breaker and fast acting current limiting fuses (FACLF). Circuit breakers are used for protection of SCR against continuous overloads or against surge currents of long duration as a Circuit breaker has long tripping time. But fast-acting fuses is used for protecting SCR against high surge current of very short duration.

Protection of SCR

Gate protection :

- Like thyristor, Gate circuit should also be protected from over voltages and over currents. Over voltages in the gate circuit can cause false triggering and over current can cause high junction temperature.

  Over voltages thyristor protection is achieved by using a zener diode and a resistor can be used to protect the gate circuit from over current. Noise in gate circuit can also cause false triggering which can be avoided by using a resistor and a capacitor in parallel.
- A diode may be connected in series or in parallel with the gate to protect it from high reverse voltage.

Complete Protection Scheme of SCR :

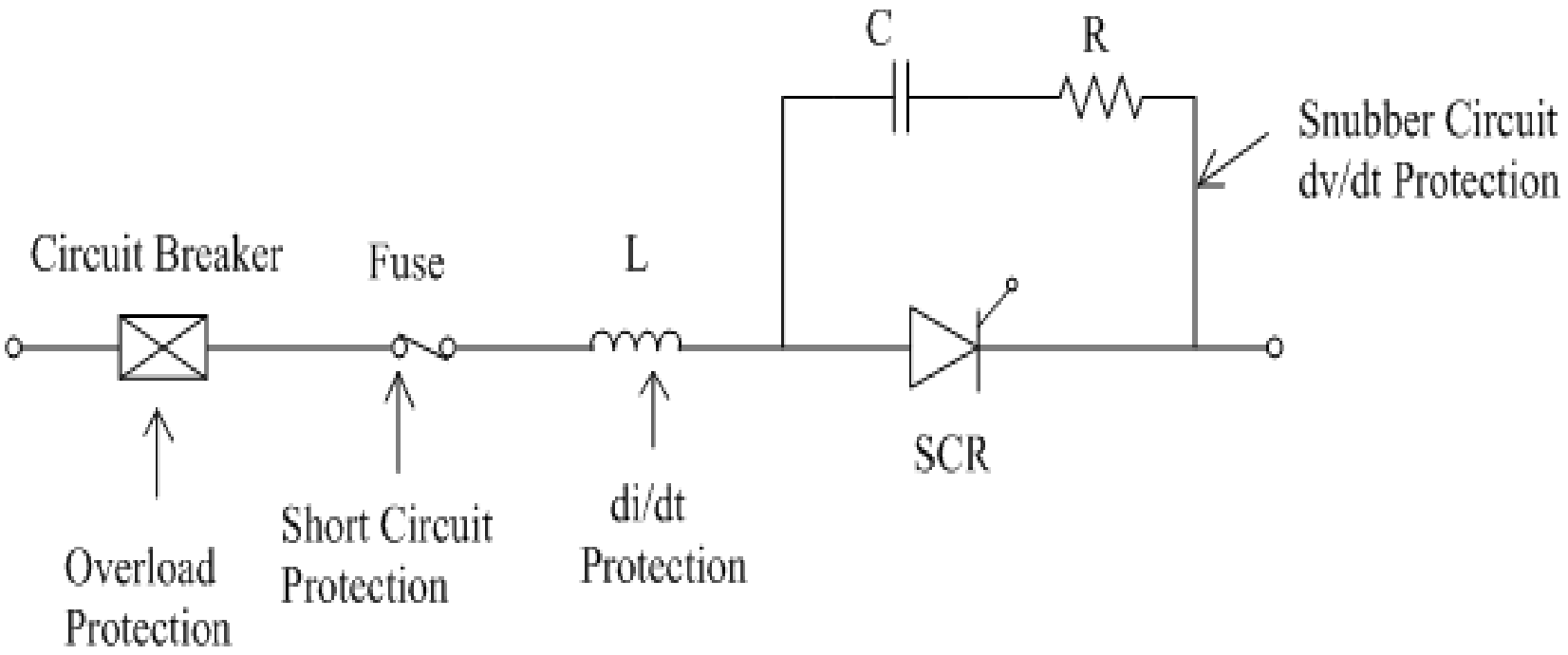


Fig.1.10 Complete Protection Scheme of SCR

Commutation :-

The process of turning off any device is called as commutation.

Commutation is basically of two types :

1) Natural Commutation

If the supply available is ac then naturally after every half cycle, SCR current will pass through zero value and it is naturally turned off. So, it is called as natural commutation.

2) Forced Commutation

When the supply is dc then naturally it is not possible to turn off SCR. So it has to be forcefully turned off using components such as inductance and capacitance. So, it is called as forced commutation.

Commutation :-

The process of turning off any device is called as commutation.
On the basis of the method employed for turning off SCR Commutation are of two types :

1) Voltage Commutation

When the SCR is reverse biased by applying reverse voltage across it with the help of commutating components, it is turned off. This is called as Voltage Commutation

2) Current Commutation

When the anode current of SCR is reduced below its holding current level SCR turns off. This is called as Current Commutation

Types of Commutation :-

- **Forced Commutation**
  - Class A Commutation (Self commutation by resonating load)
  - Class B Commutation (Self commutation by an LC Circuit)
  - Class C Commutation (Complementary Commutation)
  - Class D Commutation (Auxiliary Commutation)
  - Class E Commutation (External Pulse Commutation)

- **Natural Commutation**
  - Class F Commutation (AC line Commutation)

Class A Commutation

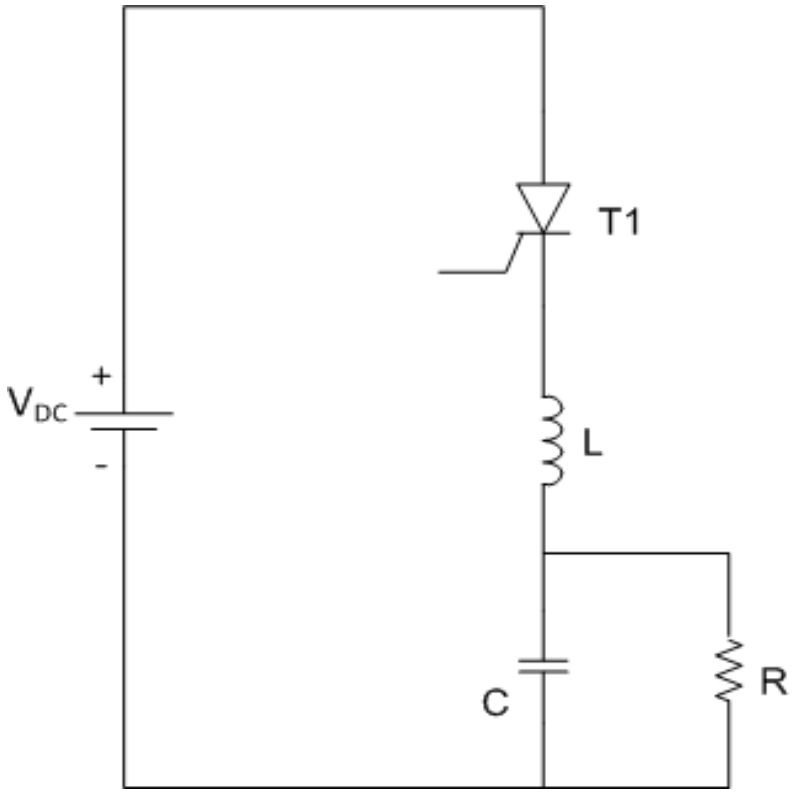


Fig.1.11 Circuit Diagram

Class A Commutation

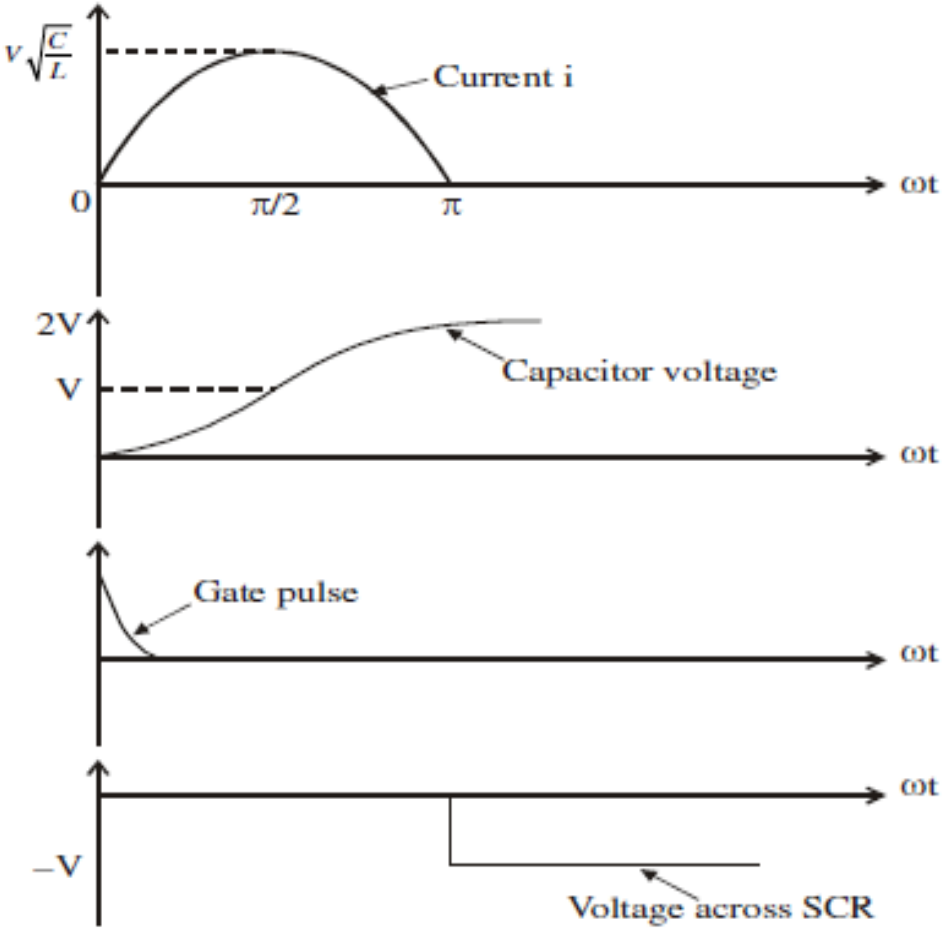


Fig.1.12 Waveforms of Class A Commutation

Commutation Methods

Class A Commutation is also called as resonant commutation.

- In this process of commutation the forward current passing through the device is reduced below holding current .Hence it is also called as current commutation.
- The load resistance and commutating components L and C are so selected such that their combination forms an under damped resonant circuit.
- When such under damped circuit is excited by dc source the current through the circuit is oscillating in nature and so it will pass through zero value.
- At zero crossing of current, the SCR turns off.
- When the SCR is on, it carries only the charging current of capacitor and when it is charged up to supply voltage V_{DC} the current reduces to a value less than the holding current of SCR.Thus , the SCR turns off.
- This type of commutation is used in series inverters.

Class B Commutation

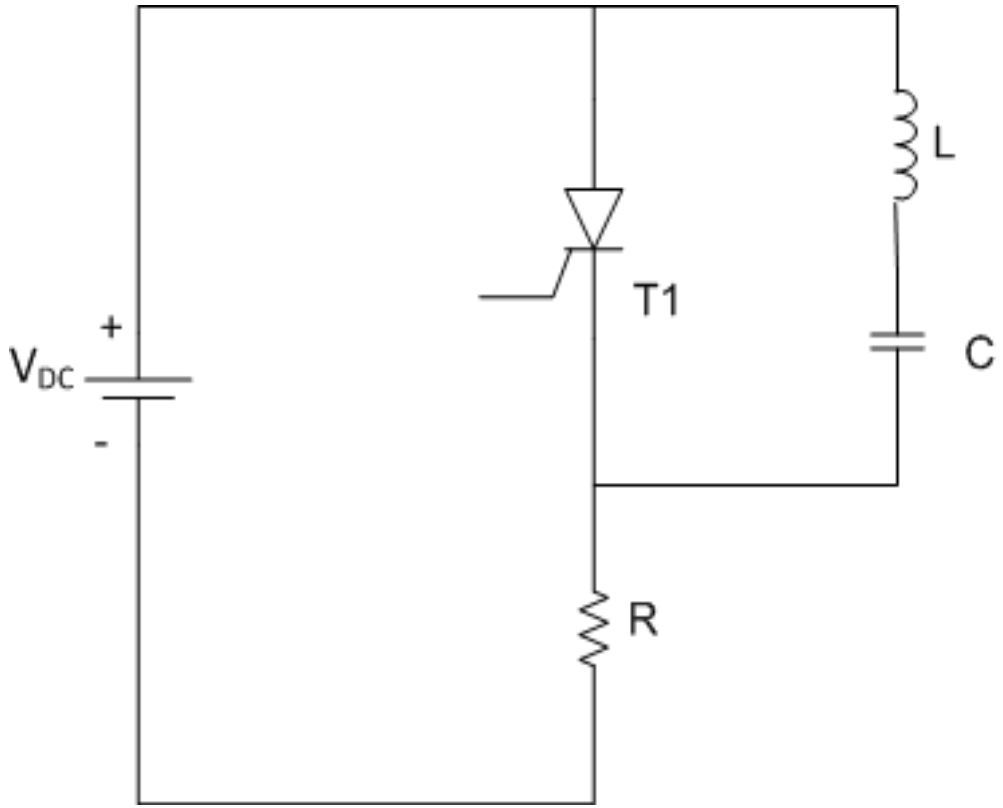


Fig.1.13 Circuit Diagram

Class B Commutation

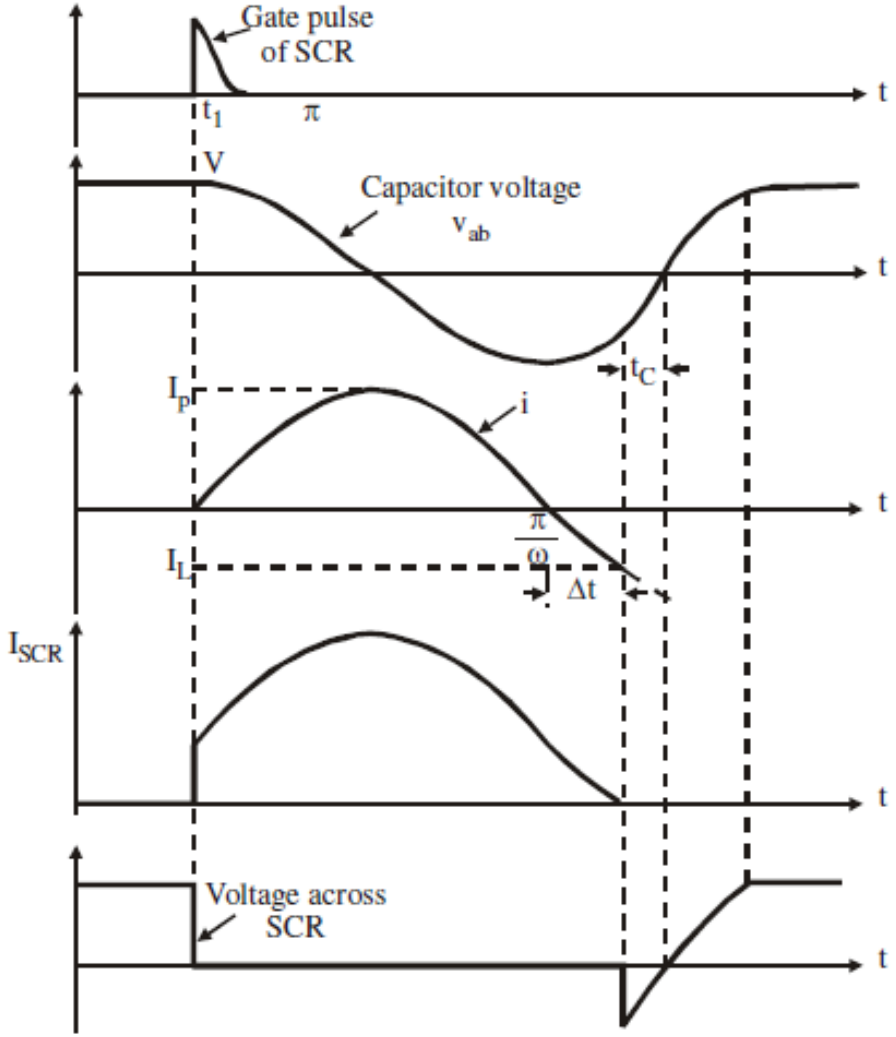


Fig.1.14 Waveforms of Class B Commutation

Commutation Methods

- This is a type of commutation in which a LC series circuit is connected across the SCR. Since the commutation circuit has negligible resistance it is always under-damped i.e.,the current in LC circuit tends to oscillate whenever the SCR is on.
- Initially the SCR is off and the capacitor is charged to V_{DC} volts with upper plate positive.
- When SCR is turned on by giving a gate pulse a current I_L flows through the load and this is assumed to be constant. At the same time SCR short circuits the LC combination which starts oscillating. A current ‘i’ starts flowing and when it reaches its maximum value, the capacitor voltage reduces to zero and then the polarity of the capacitor voltage reverses.

Commutation Methods

- When ‘i’ falls to zero this reverse voltage becomes maximum, and then direction of ‘i’ reverses i.e., through SCR the load current I_L and ‘i’ flow in opposite direction. When the instantaneous value of ‘i’ becomes equal to I_L , the SCR current becomes zero and the SCR turns off. Now the capacitor starts charging and its voltage reaches the supply voltage.
- This type of commutation is used in dc chopper circuits.

Class C Commutation

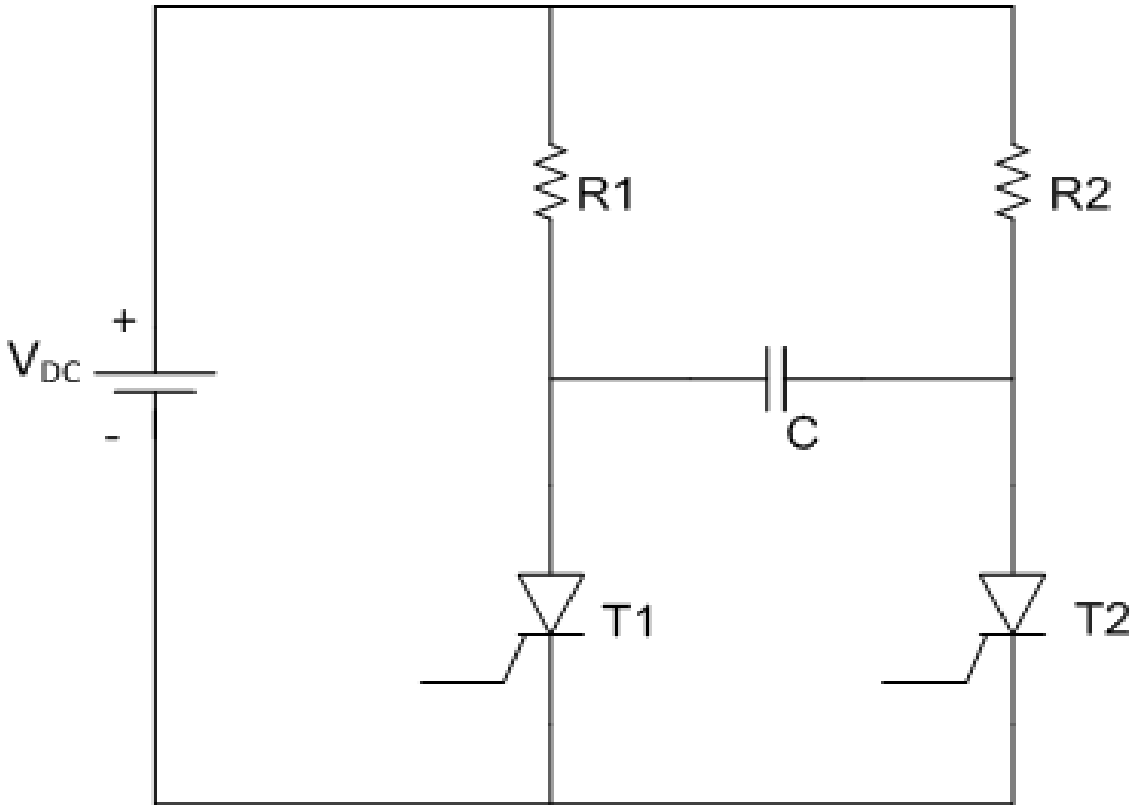


Fig.1.15 Circuit Diagram

Class C Commutation

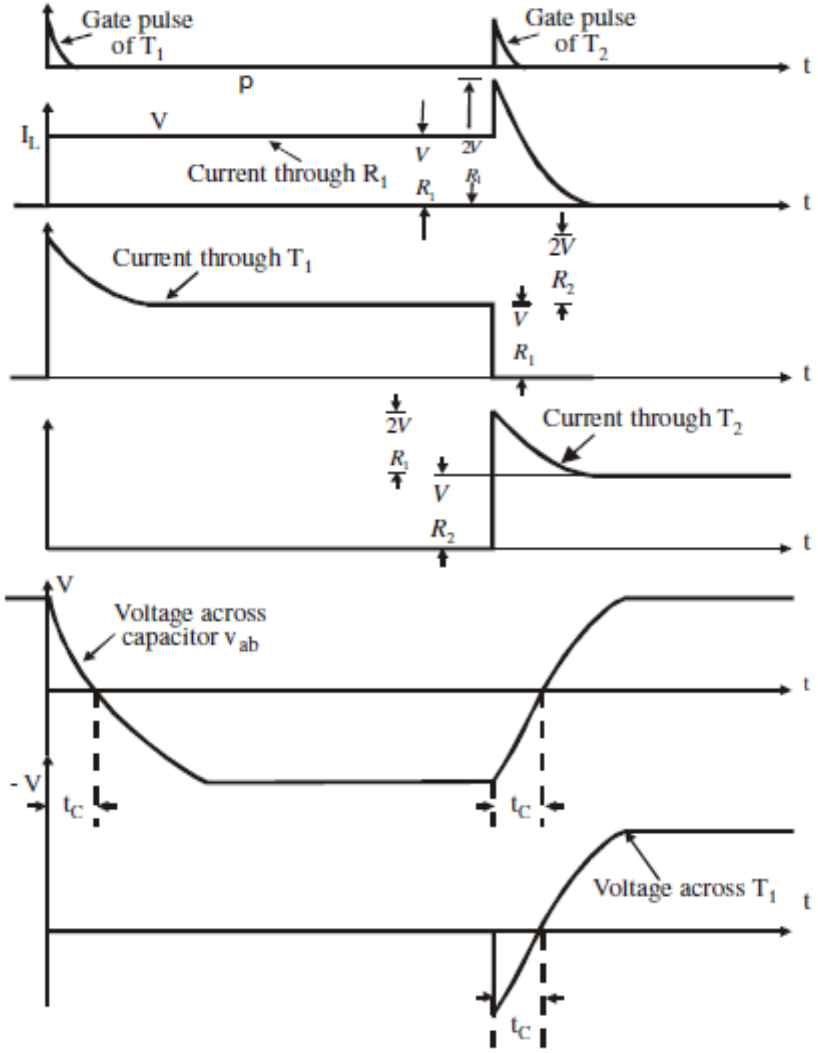


Fig.1.16 Waveforms of Class C Commutation

Class C Commutation

- Initially both T_1 and T_2 are off.
- When T_1 is triggered, load current I_L flows through R_1.At the same time, capacitor C gets charged to V_{DC} volts through R_2 and T_1 with right plate positive and left plate negative.
- When capacitor gets fully charged, its current becomes zero.
- To turn off T_1, T_2 is fired ;the voltage across capacitor comes across T_1 and reverse biases it, hence T_1 turns off.
- At the same time, the load current flows through R_2 and T_2. The capacitor charges towards V through R_1 and T_2 with left plate positive and right plate negative and is finally charged to V_{DC} volts.
- When capacitor is fully charged, its current becomes zero.
- To turn off T_2, T_1 is triggered, the capacitor voltage comes across T_2 and T_2 turns off.
- This type of commutation is used in parallel inverters.

Class D Commutation

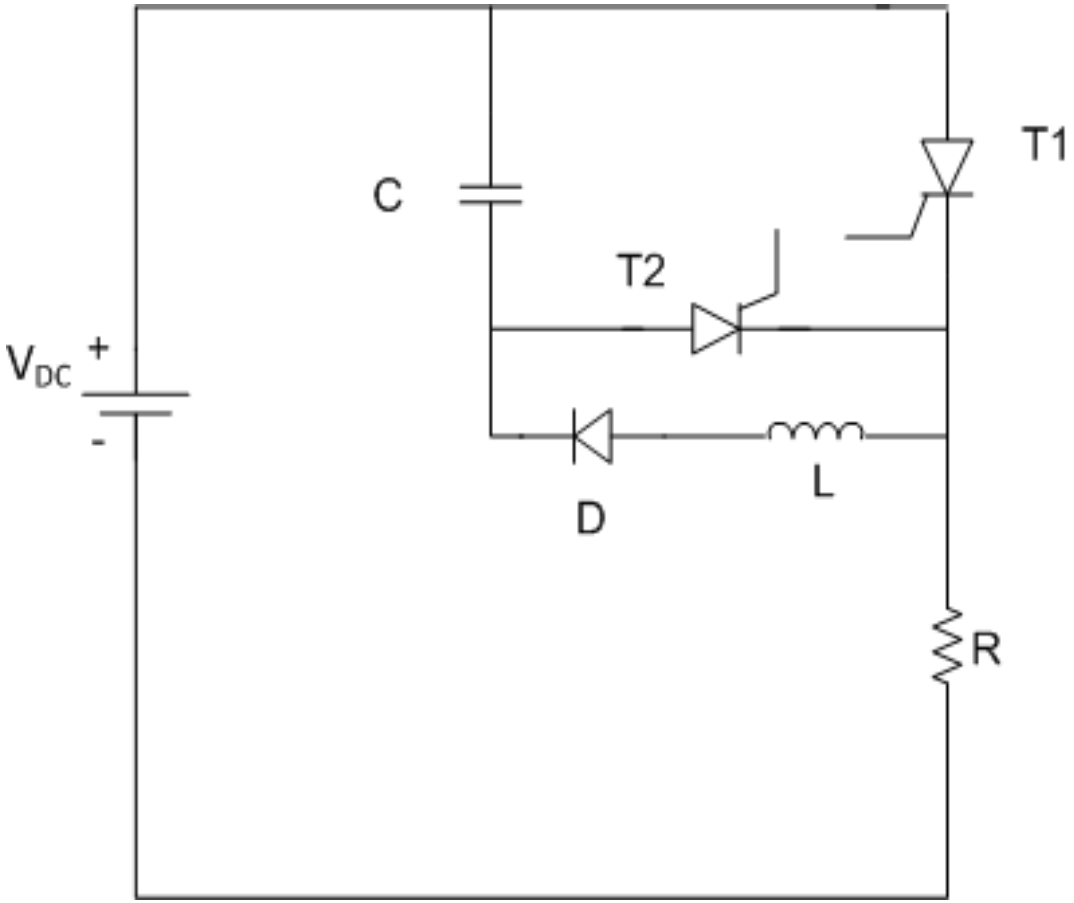


Fig.1.17 Circuit Diagram

Class D Commutation

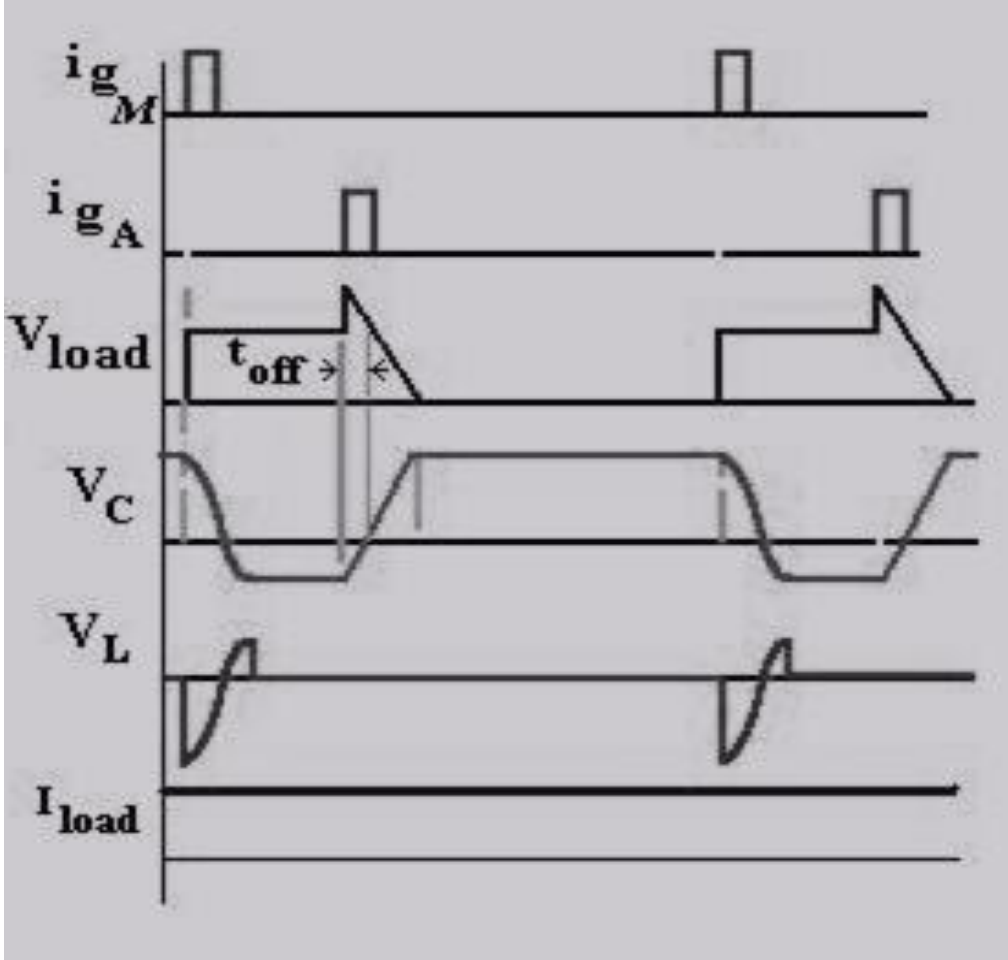


Fig.1.18 Waveforms of Class D Commutation

Commutation Methods

The working of the circuit can be explained as follows.

- It is assumed that initially the capacitor C is charged to a voltage V_C with upper plate positive and lower plate negative.
- Let the thyristor T_1 be conducting and carry a load current I_L. If the thyristor T_1 is to be turned off, T_2 is fired.
- The capacitor voltage comes across T_1 , it is reverse biased and it turns off. Now the capacitor starts charging through T_2 and the load. The capacitor voltage reaches V with top plate being positive. By this time the capacitor charging current i.e. current through T_2 would have reduced to zero and T_2 automatically turns off. Now T_1 and T_2 are both off.
- Before firing T_1 again, the capacitor voltage should be reversed. This is achieved by discharging of capacitor through diode and inductance.

Class E Commutation

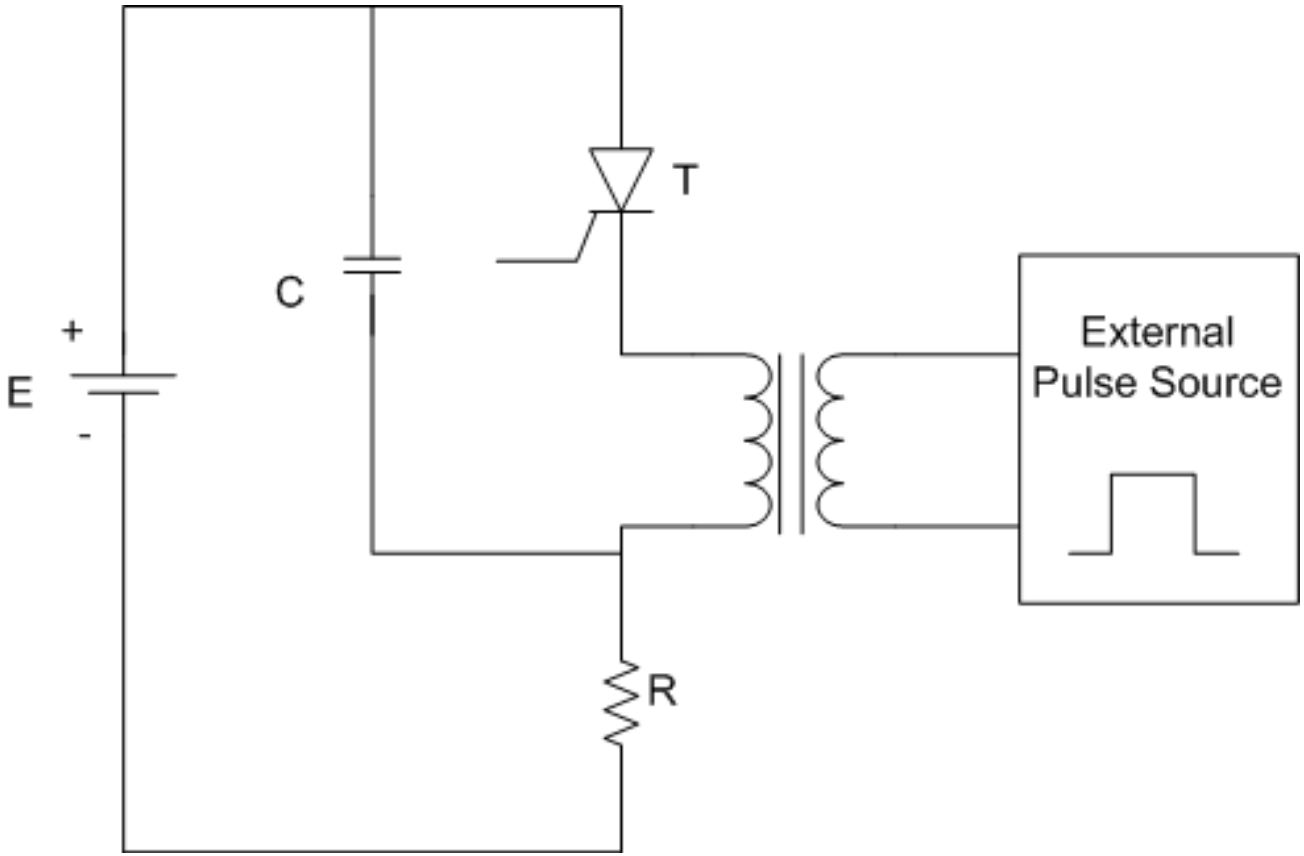


Fig.1.19 Circuit Diagram

Class E Commutation

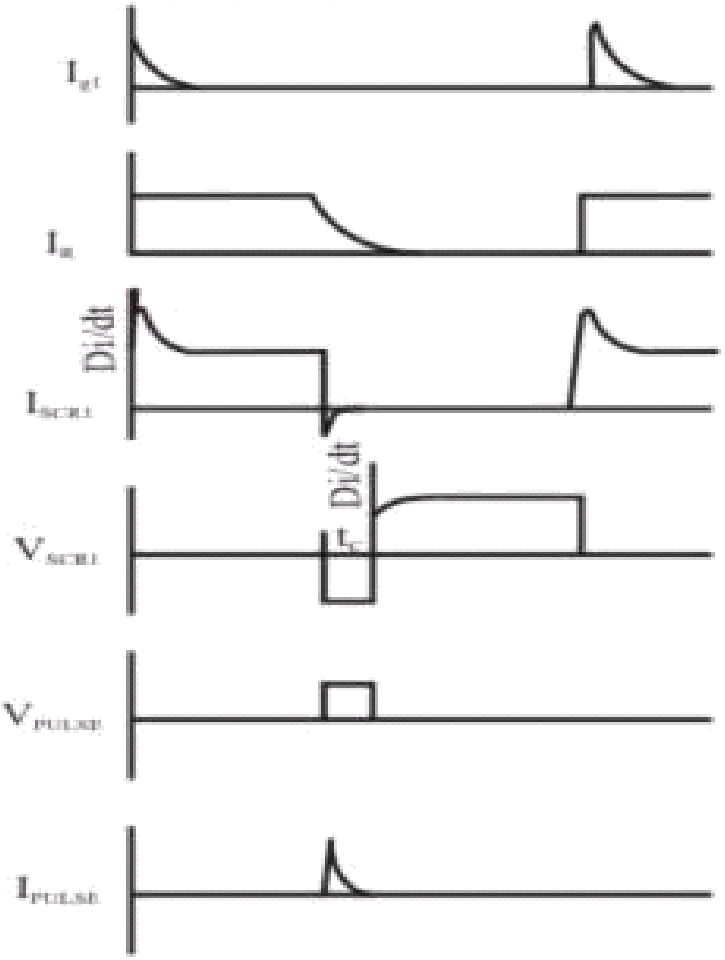


Fig.1.20 Waveforms of Class E Commutation

Commutation Methods

Class E Commutation

- In this commutation method, the transformer is designed with sufficient iron and air gap so as not to saturate. It is capable of carrying the load current with a small voltage drop compared with the supply voltage.
- When SCR1 is triggered, current flows through the load and pulse transformer.
- To turn SCR1 off a positive pulse is applied to the cathode of the SCR from an external pulse generator via the pulse transformer.
- The capacitor C is only charged to about 1 volt and for the duration of the turn-off pulse it can be considered to have zero impedance.
- Thus the pulse from the transformer reverses the voltage across the SCR, and it supplies the reverse recovery current and holds the voltage negative for the required turn-off time.

Class F Commutation

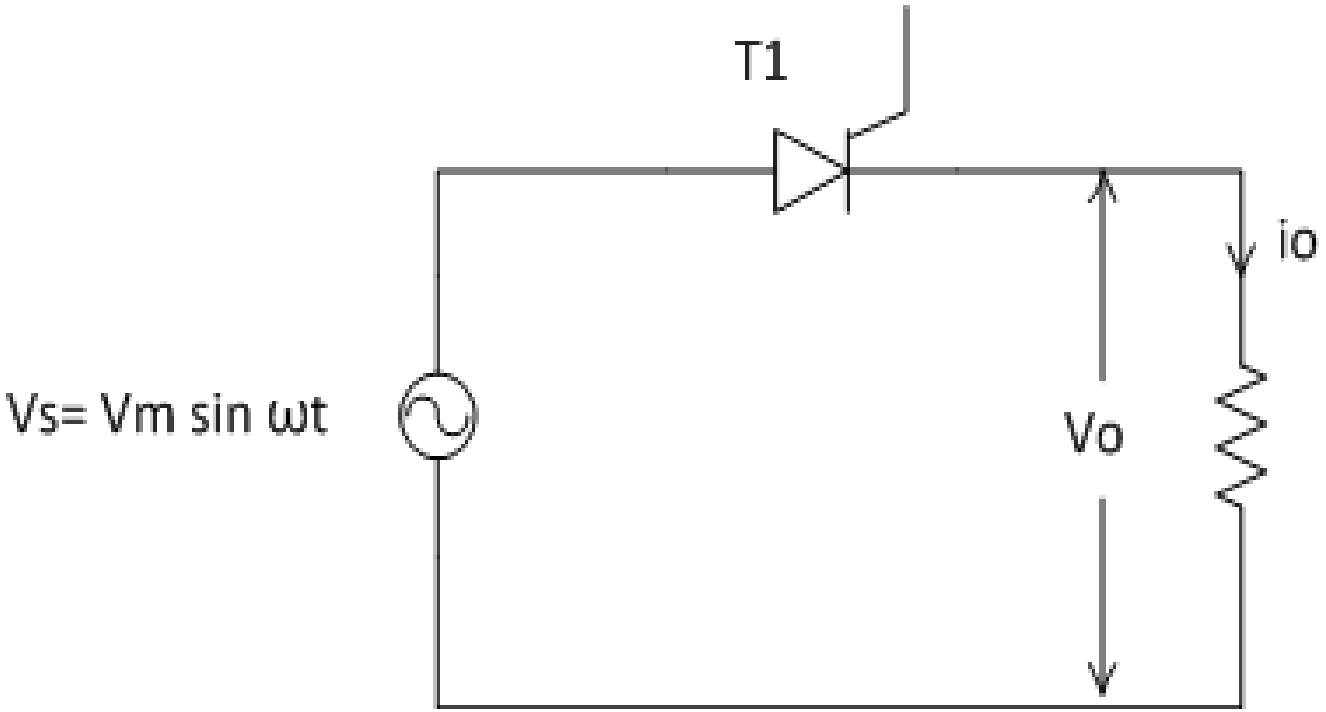


Fig.1.21 Circuit Diagram

Class F Commutation

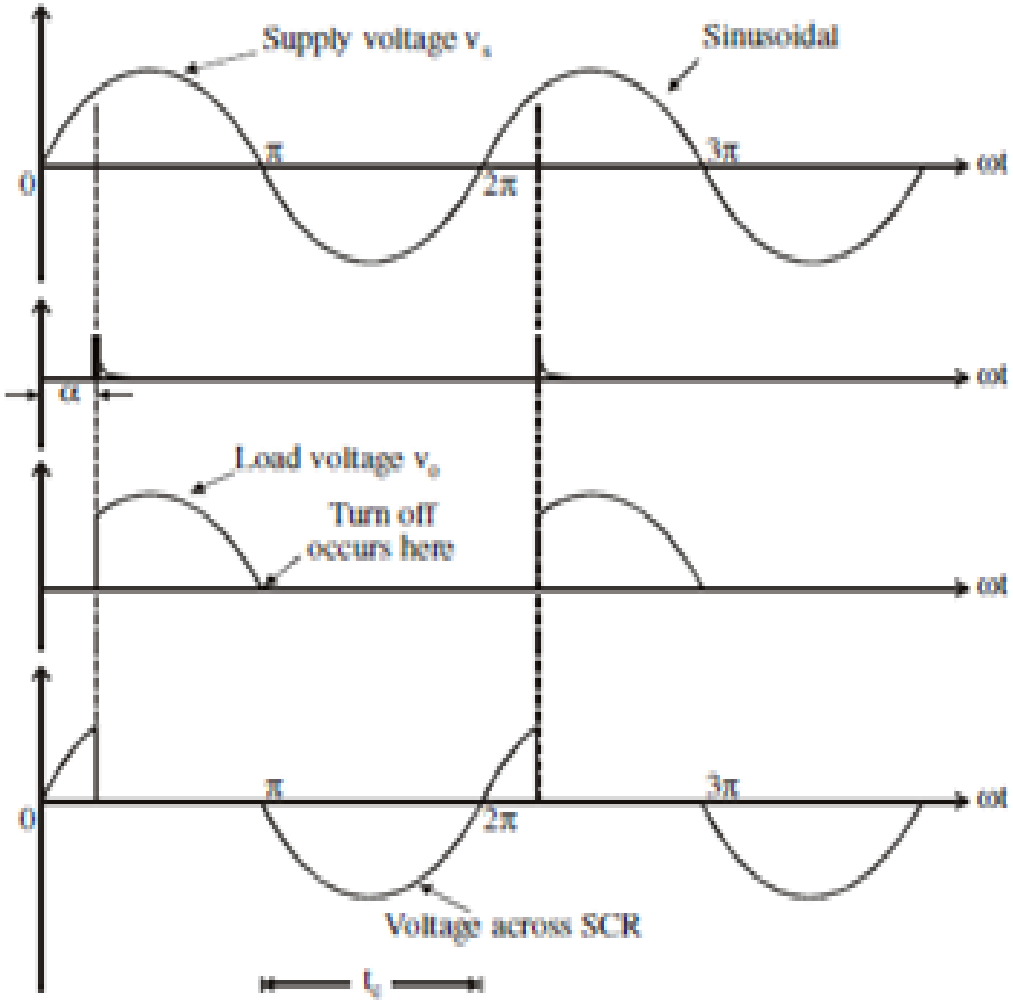


Fig.1.22 Waveforms of Class F Commutation

Commutation Methods

- If the available supply is ac then load current will flow during the positive half cycle.
- During negative half cycle SCR will turn off due to negative polarity across it.
- The duration of the half cycle must be longer than the turn-off time of SCR.
- The maximum frequency at which the circuit operates depends upon the turn-off time of SCR.
- This commutation is used in rectifiers and cycloconverters.