Lecture (02) Power Semiconductor Devices (2)

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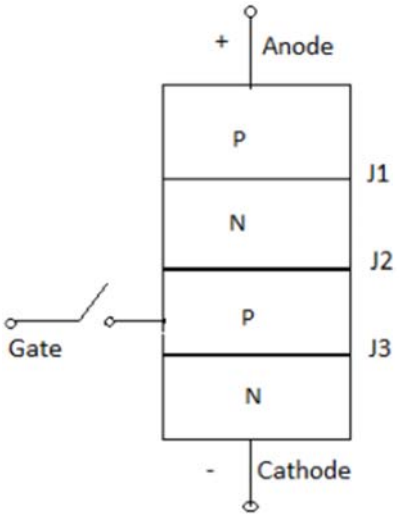
Different turn ON methods for SCR

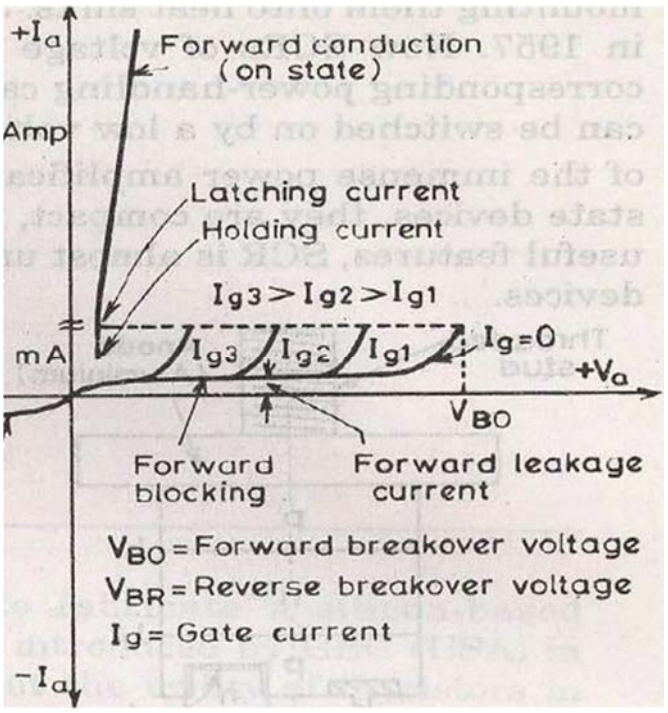
- 1. Forward voltage triggering
- 2. Gate triggering
- 3. dv/dt triggering
- 4. Light triggering
- 5. Temperature triggering

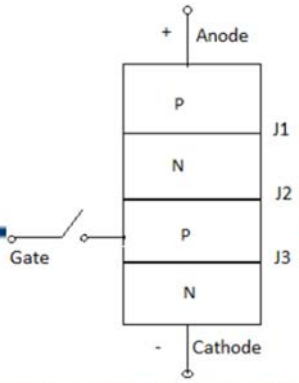
Forward voltage triggering

- A forward voltage is applied between anode and cathode with gate circuit open.
  - Junction $J1$ and $J3$ is forward biased.
  - Juntion $J2$ is reverse biased.
  - As the anode to cathode voltage is increased breakdown of the reverse biased junction $J2$ occurs.
  - This is known as avalanche breakdown and the voltage at which this phenomena occurs is called forward breakover voltage.

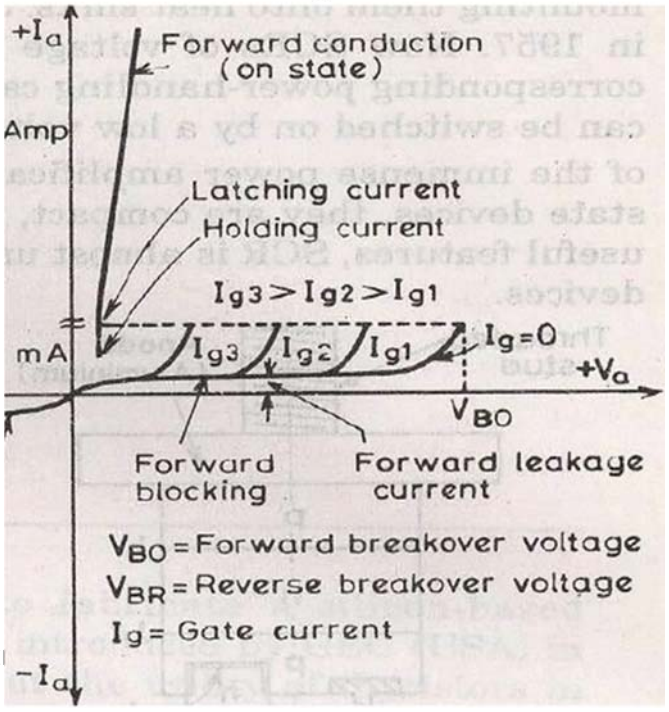


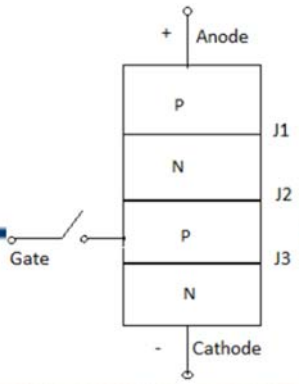
- The conduction of current continues even if the anode cathode voltage reduces below VBOtill Ia will not go belowIh.
- Where Ih is the holding current for the thyristor.



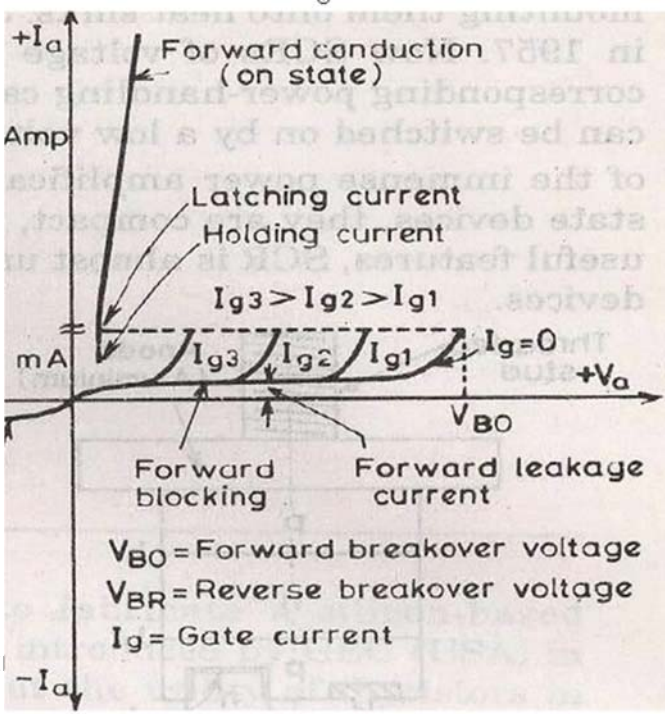


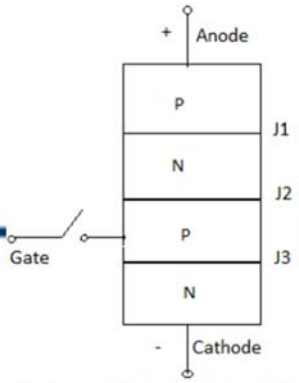
- **Gate triggering**
- This is the simplest, reliable and efficient method of firing the forward biased SCRs.
- First SCR is forward biased.
- Then a positive gate voltage is applied between gate and cathode.



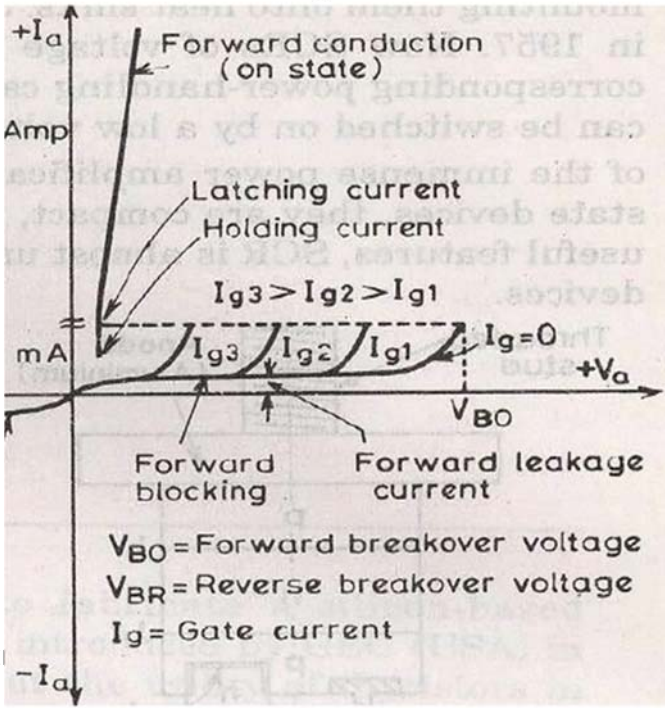


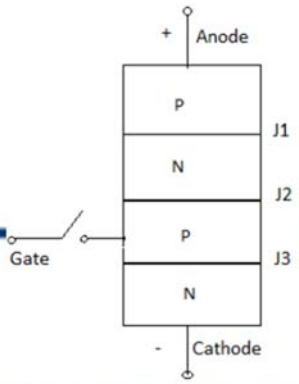
- In practice the transition from OFF state to ON state by exceeding VBO is never employed as it may destroy the device.
- The magnitude of VBO, so forward breakover voltage is taken as final voltage rating of the device during the design of SCR application.



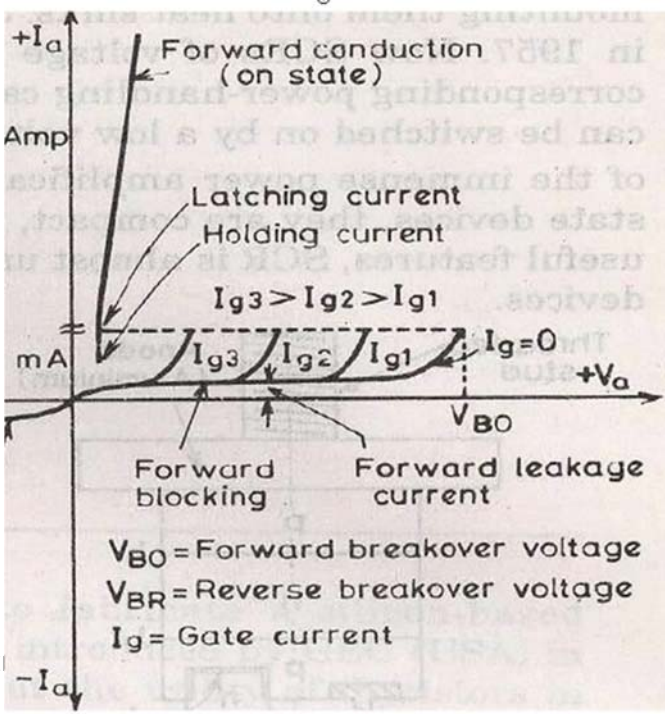


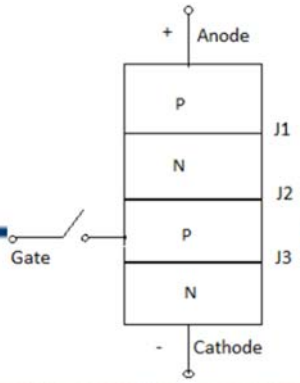
- First step is to choose a thyristor with forward breakover voltage (say 800V) higher than the normal working voltage.
- The benefit is that the thyristor will be in blocking state with normal working voltage applied across the anode and cathode with gate open.



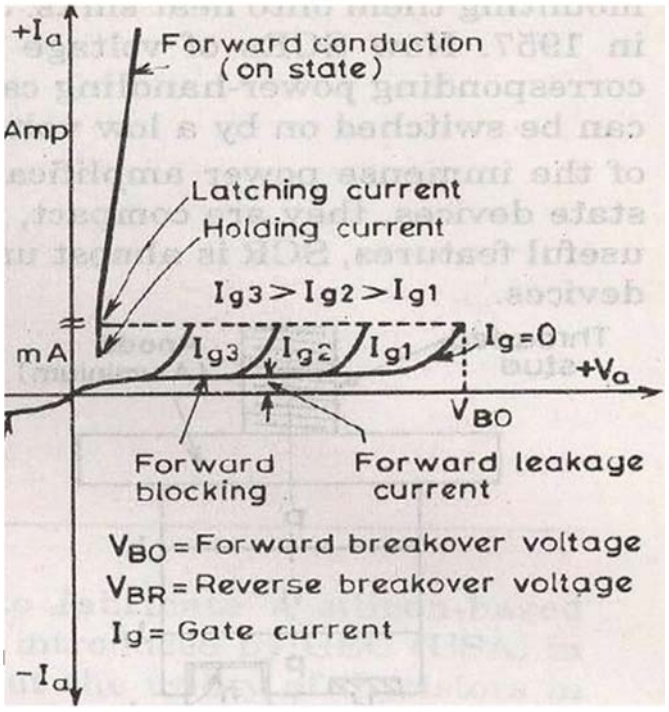


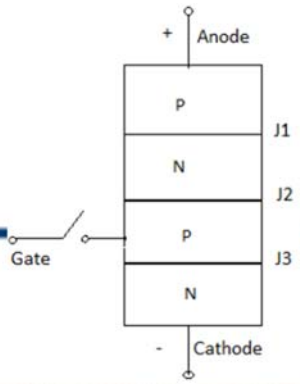
- When we require the turning ON of a SCR a positive gate voltage between gate and cathode is applied.
- The point to be noted that cathode n- layer is heavily doped as compared to gate p-layer.
- So when gate supply is given between gate and cathode gate p-layer is flooded with electron from cathode n-layer.



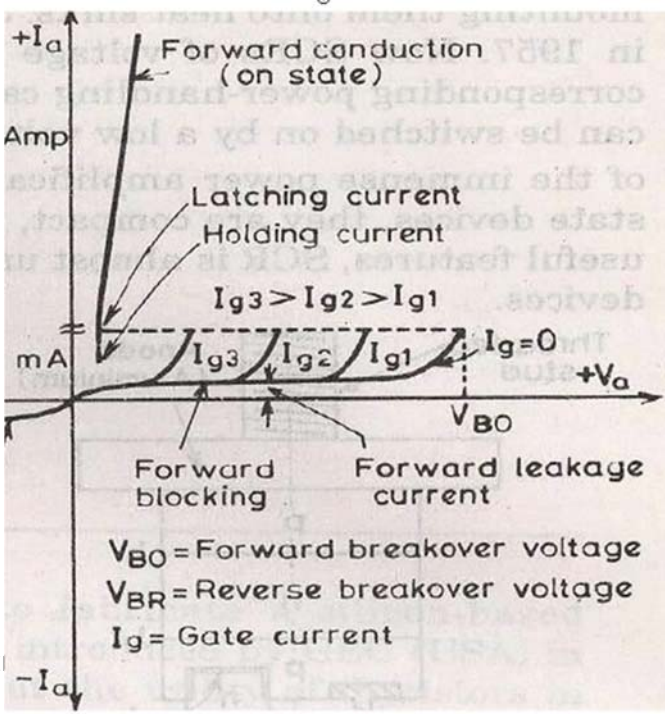


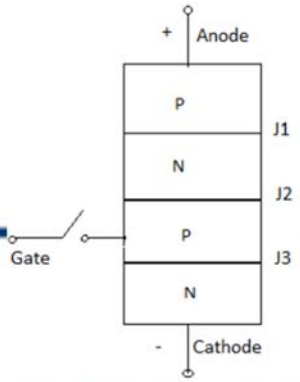
- Now the thyristor is forward biased, so some of these electron reach junction $J2$.
- As a result width of $J2$ breaks down or conduction at $J2$ occur at a voltage less than VBO.
- As Ig increases VBO reduces which decreases then turn ON time.
- Another important point is duration for which the gate current is applied should be more then turn ON time.



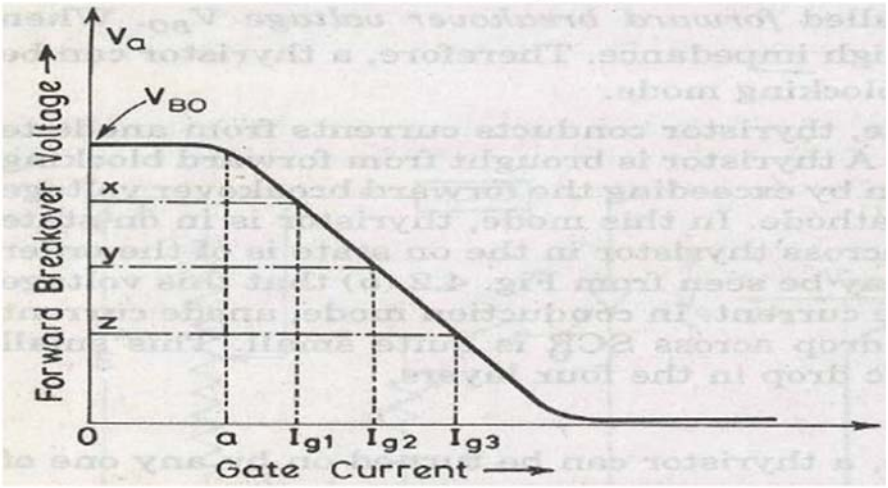


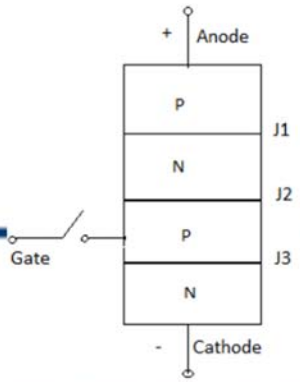
- This means that if the gate current is reduced to zero before the anode current reaches a minimum value known as holding current, SCR can't turn ON.
- In this process power loss is less and also low applied voltage is required for triggering.



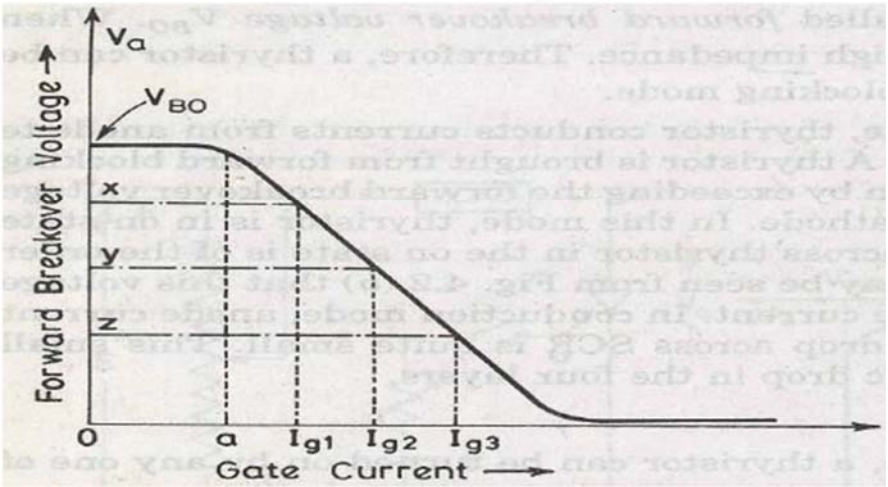


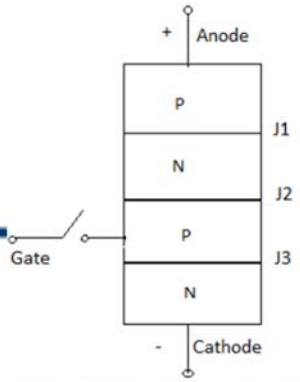
- **dv/dt triggering**
- This is a turning ON method but it may lead to destruction of SCR and so it must be avoided.
- When SCR is forward biased, junction $J1$ and $J3$ are forward biased and junction $J2$ is reversed biased so it behaves as if an insulator is place between two conducting plate.



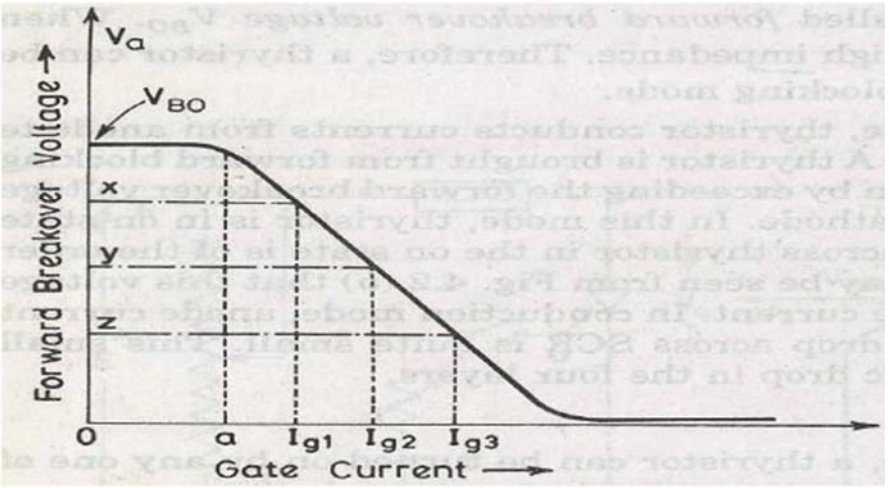


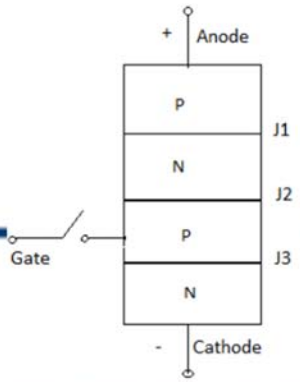
- Here $J1$ and $J3$ acts as a conducting plate and $J2$ acts as an insulator.
- $J2$ is known as junction capacitor.
- So if we increase the rate of change of forward voltage instead of increasing the magnitude of voltage.





- Junction $J2$ breaks and starts conducting.
- A high value of changing current may damage the SCR.
- So SCR may be protected from high dv/dt.

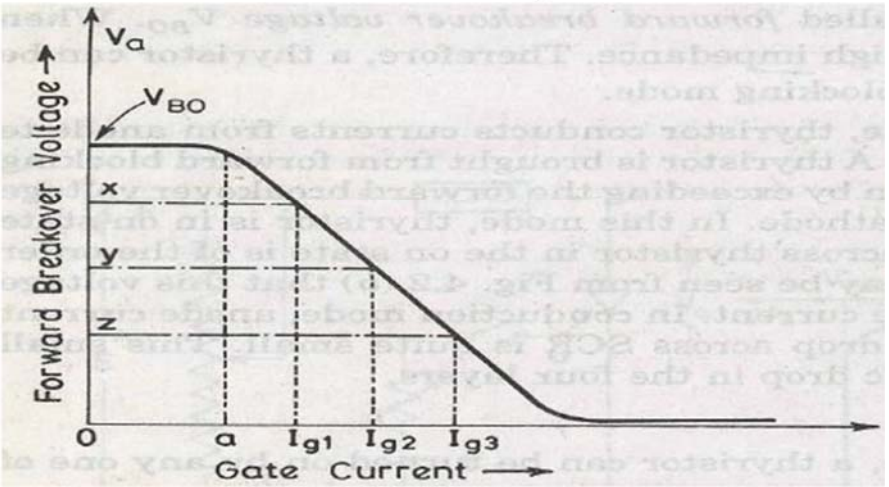




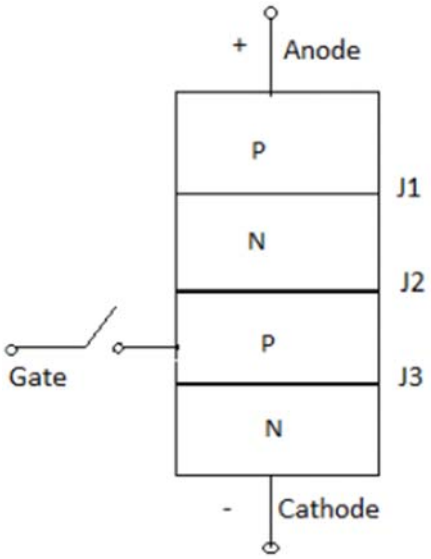
$$q = cv$$

$$I_a = c\frac{dv}{dt}$$

$$I_a \, \alpha \, \frac{dv}{dt}$$

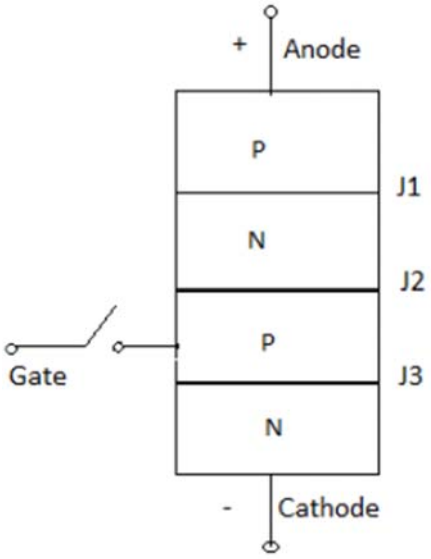


- **4. Temperature triggering**
- During forward biased, $J2$ is reverse biased so a leakage forward current always associated with SCR.
- Now as we know the leakage current is temperature dependent, so if we increase the temperature the leakage current will also increase and heat dissipation of junction $J2$occurs.
- When this heat reaches a sufficient value $J2$ will break and conduction starts.

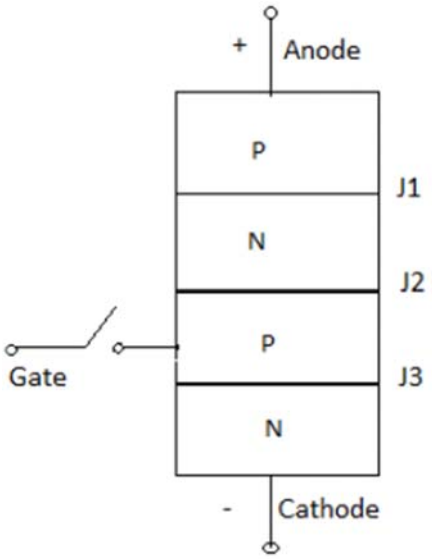


Disadvantages

- This type of triggering causes local hot spot and may cause thermal run away of the device.
- This triggering cannot be controlled easily.
- It is very costly as protection is costly.



- **Light triggering**
- First a new recess niche is made in the inner p-layer.
- When this recess is irradiated, then free charge carriers (electron and hole) are generated.
- Now if the intensity is increased above a certain value then it leads to turn ON of SCR.
- Such SCR are known as Light activated SCR (LASCR).



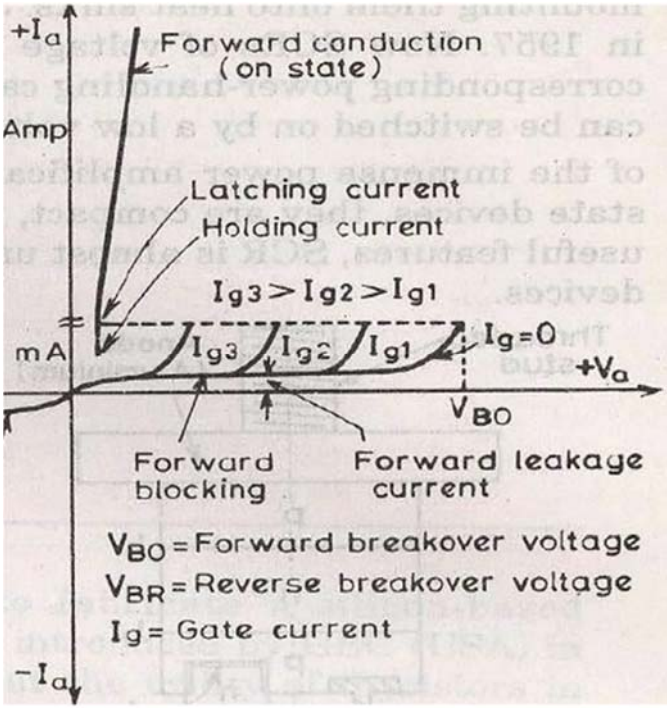
- ***Some definitions:***

Latching current

- The latching current may be defined as the minimum value of anode current which at must attain during turn ON process to maintain conduction even if gate signal is removed.

Holding current

- It is the minimum value of anode current below which if it falls, the SCR will turn OFF.



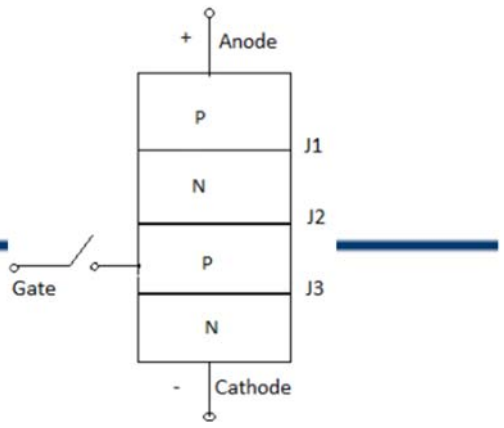
Switching characteristics of thyristors :

- The time variation of voltage across the thyristor and current through it during turn on and turn off process gives the dynamic or switching characteristic of SCR.

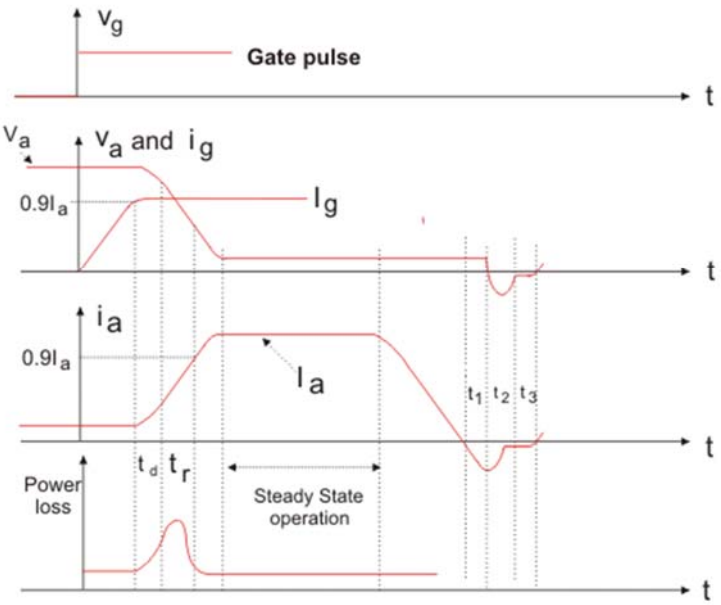
Switching characteristic during turn on

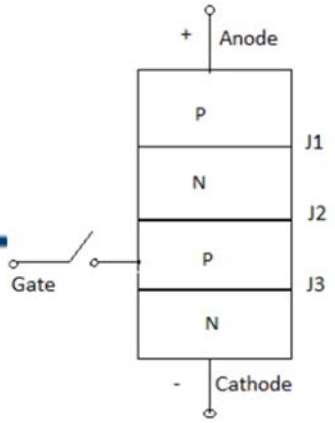
Turn on time

- It is the time during which it changes from forward blocking state to ON state. Total turn on time is divided into 3 intervals:
- 1. Delay time
- 2. Rise time
- 3. Spread time

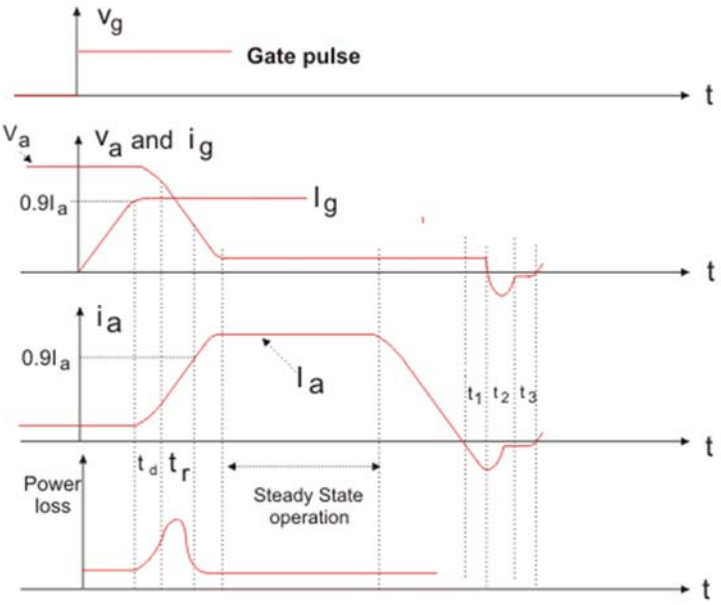


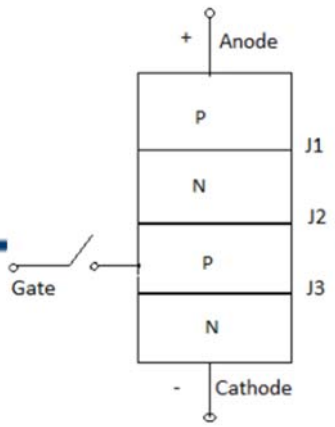
- **Delay time**
- If $Ig$and Ia represent the final value of gate current and anode current.
- Then the delay time can be explained as time during which the gate current attains 0.9 Ig to the instant anode current reaches 0.1 $I a$. or the anode current rises from forward leakage current to 0.1 Ia.





- 1. Gate current 0.9 Ig to 0.1 Ia.
- 2. Anode voltage falls from Va to 0.9Va.
- 3. Anode current rises from forward leakage current to 0.1 Ia.



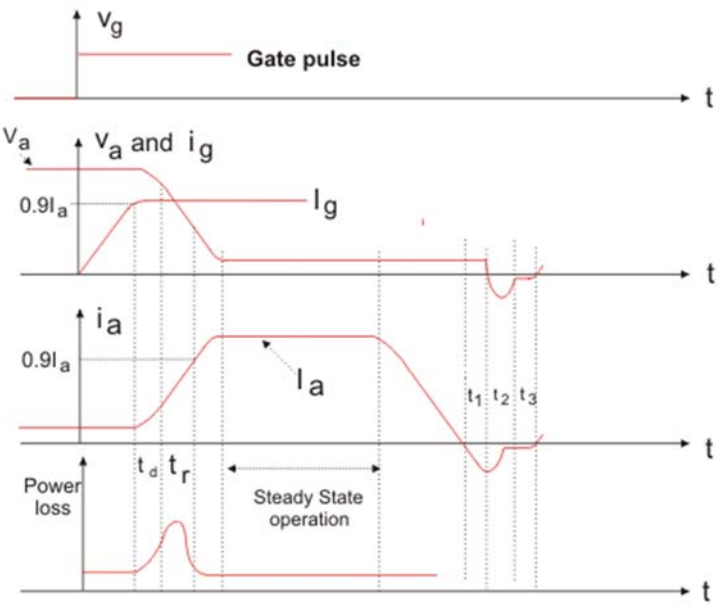


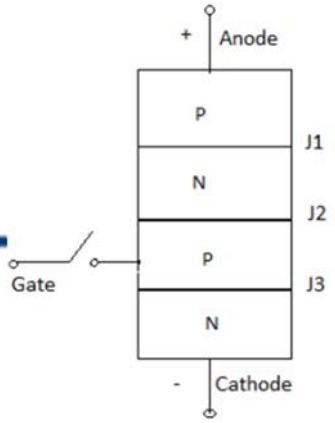
Rise time (tr)

Time during which

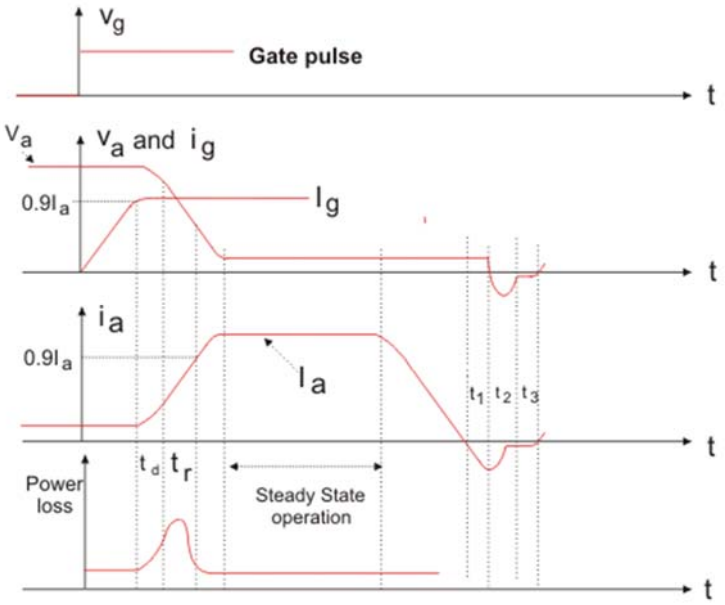
- 1. Anode current rises from 0.1 Ia to 0.9 Ia
- 2. Forward blocking voltage falls from 0.9Va to 0.1Va.

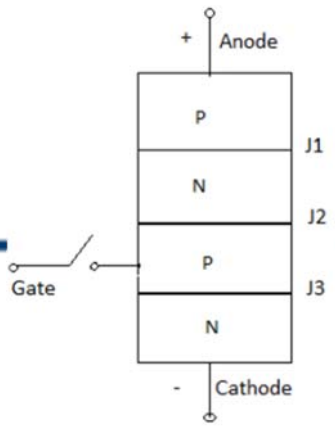
*Va is the initial forward blocking voltage



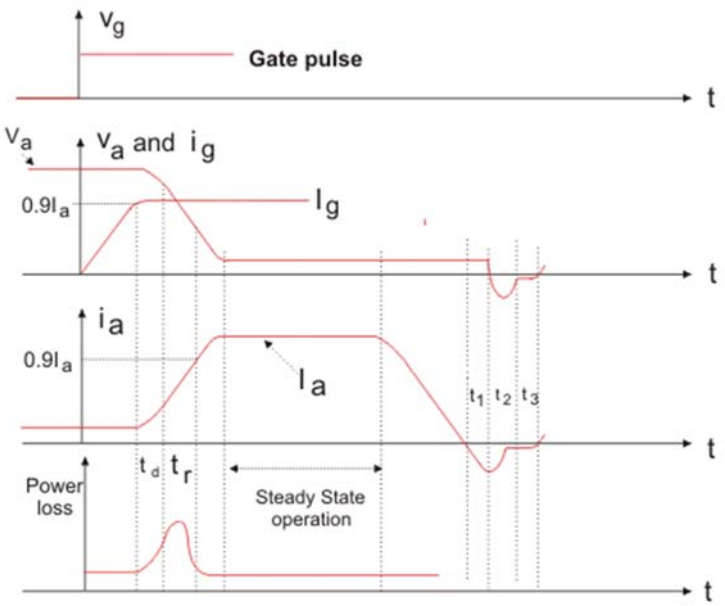


- **Spread time (tp)**
- 1. Time taken by the anode current to rise from 0.9Ia to Ia.
- 2. Time for the forward voltage to fall from 0.1Vo to on state voltage drop of 1 to 1.5V.
- During turn on, SCR is considered to be a charge controlled device.

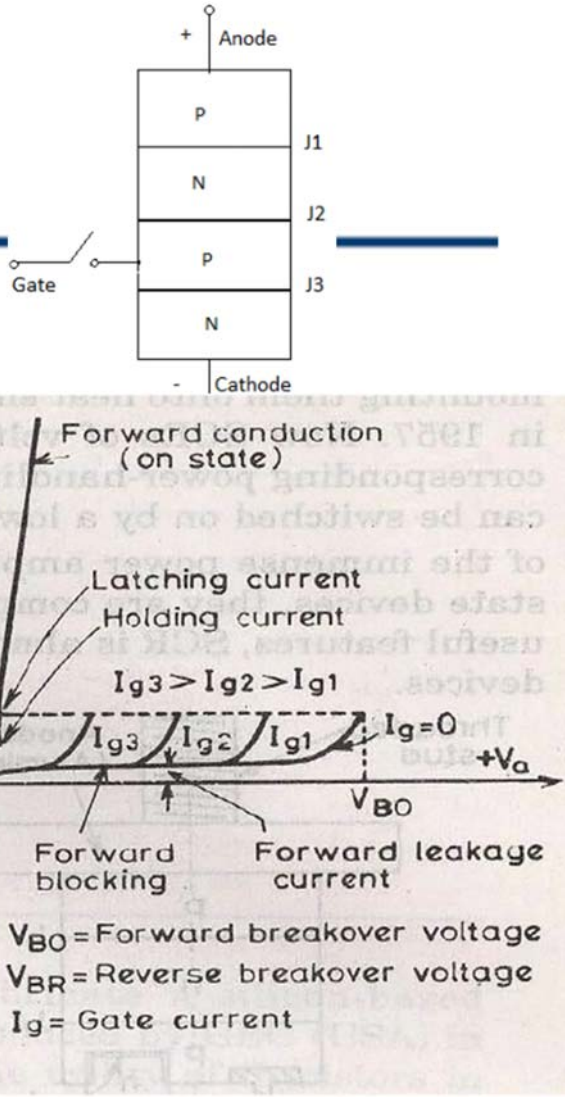




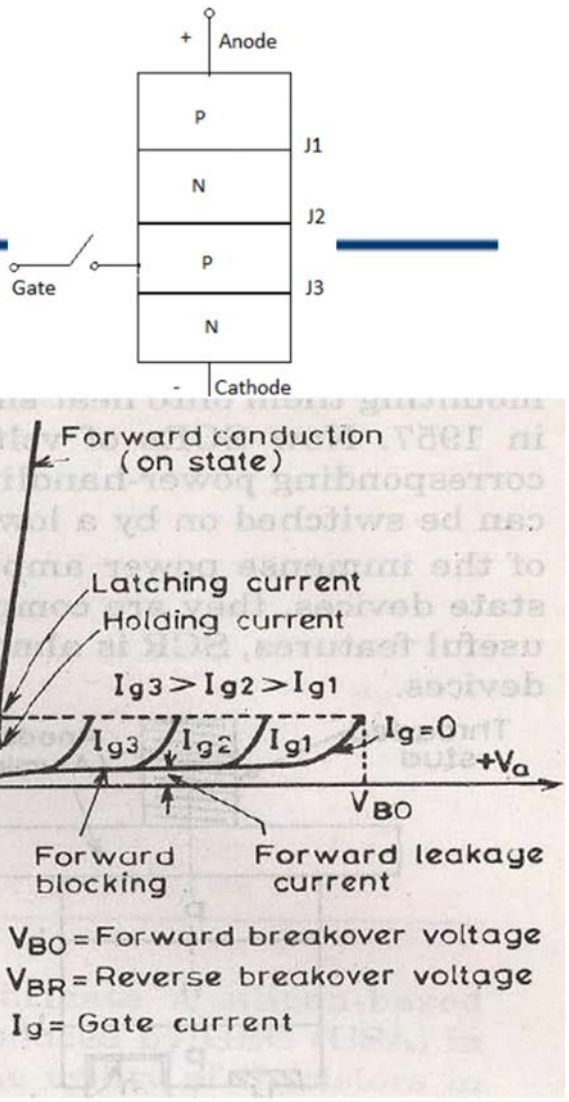
- A certain amount of charge is injected in the gate region to begin conduction.
- So higher the magnitude of gate current it requires less time to inject the charges.
- Thus turn on time is reduced by using large magnitude of gate current.



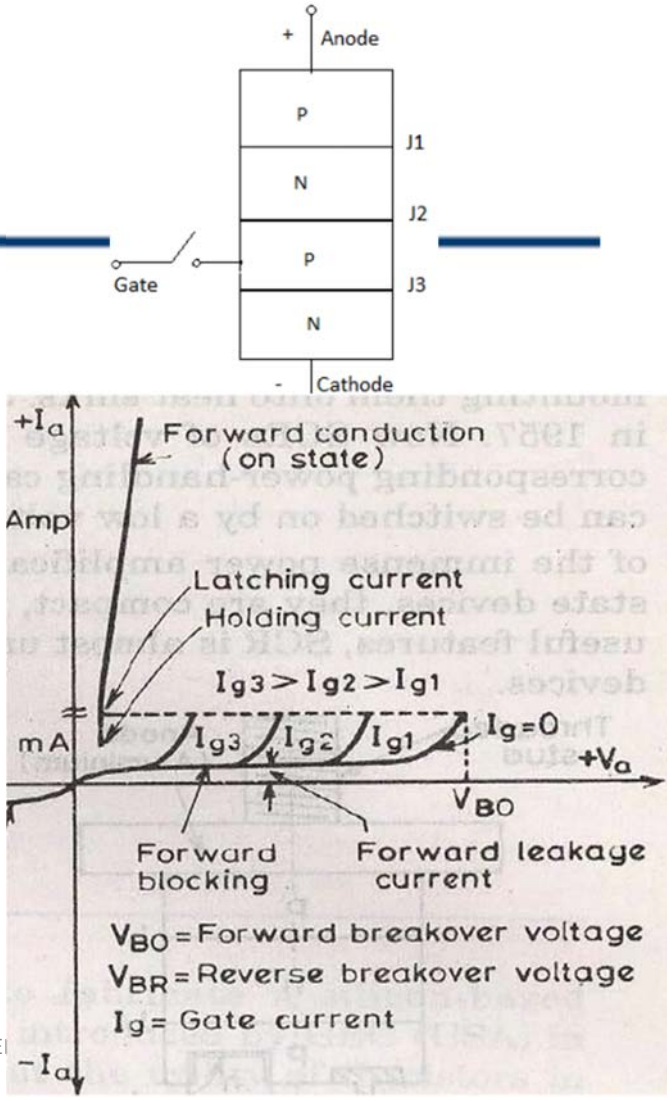
- **How the distribution of charge occurs?**
- As the gate current begins to flow from gate to cathode with the application of gate signal.
- Gate current has a non uniform distribution of current density over the cathode surface.



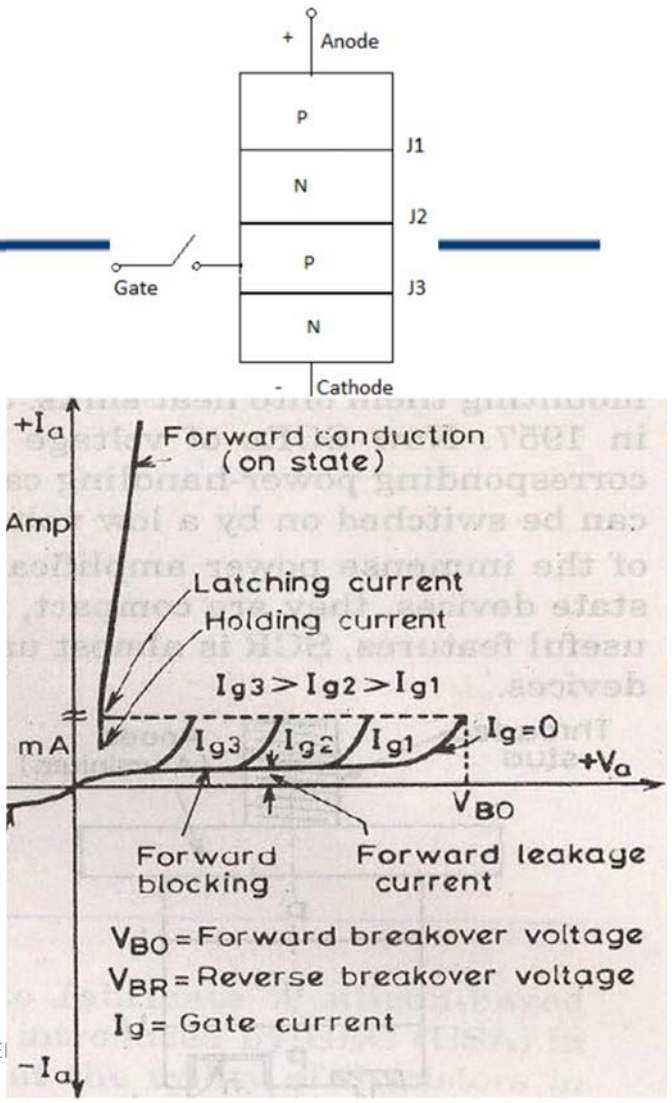
- Distribution of current density is much higher near the gate.
- The density decrease as the distance from the gate increases.
- So anode current flows in a narrow region near gate where gate current densities are highest.

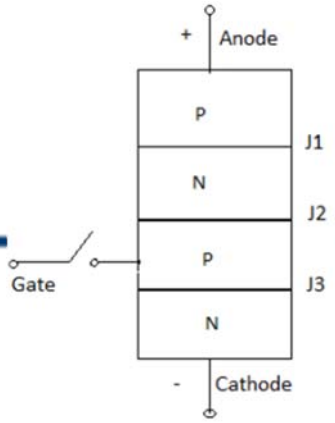


- From the beginning of rise time the anode current starts spreading itself.
- The anode current spread at a rate of 0.1mm/sec.
- The spreading anode current requires some time if the rise time is not sufficient then the anode current cannot spread over the entire region of cathode.

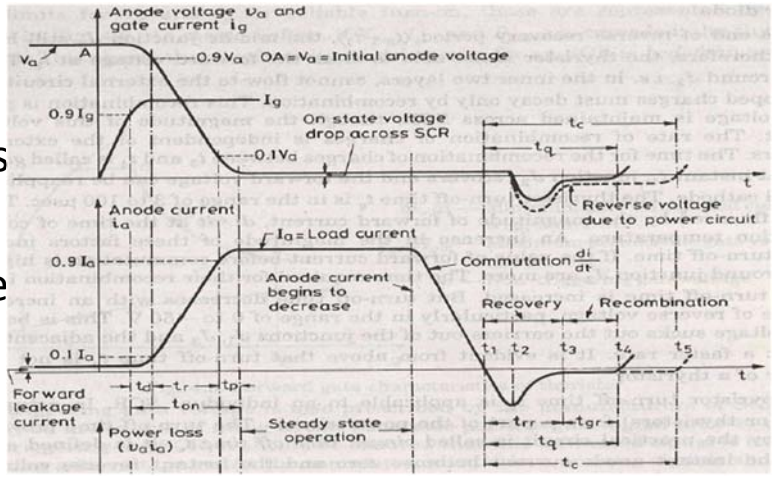


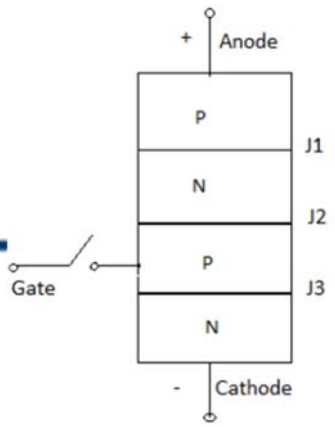
- Now a large anode current is applied and also a large anode current flowing through the SCR.
- As a result turn on losses is high.
- As these losses occur over a small conducting region so local hot spots may form and it may damage the device.



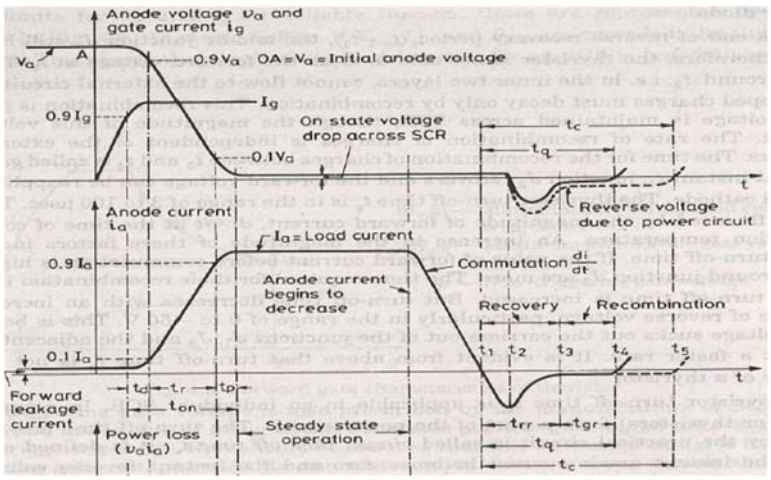


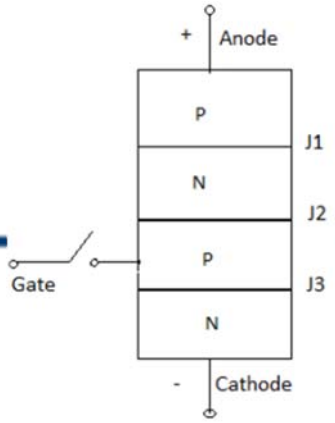
- **Switching Characteristics During Turn Off**
- Thyristor turn off means it changed from ON to OFF state.
- Once thyristor is ON there is no role of gate.
- As we know thyristor can be made turn OFF by reducing the anode current below the latching current..



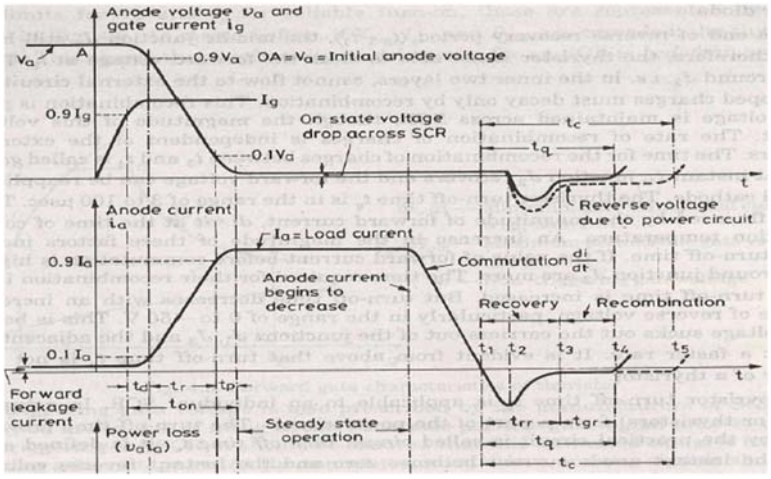


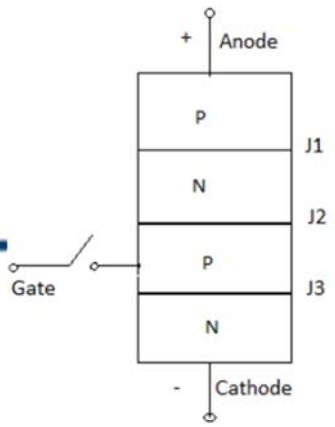
- Here we assume the latching current to be zero ampere.
- If a forward voltage is applied across the SCR at the moment it reaches zero
- then SCR will not be able to block this forward voltage.
- Because the charges trapped in the 4-layer are still favourable for conduction and it may turn on the device.



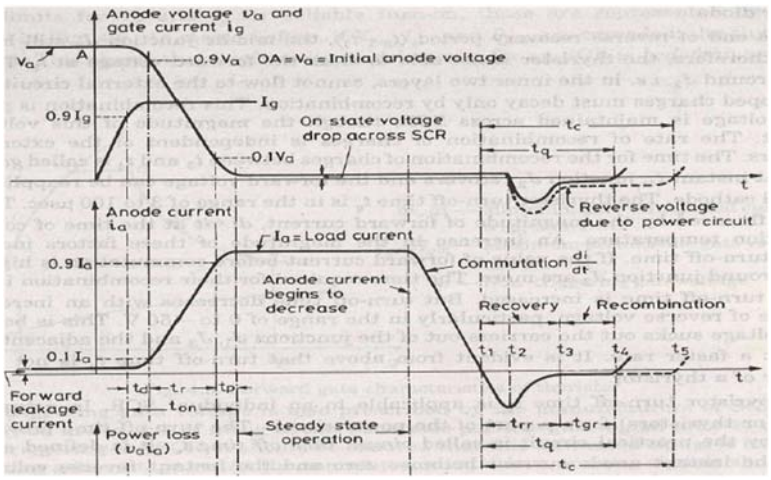


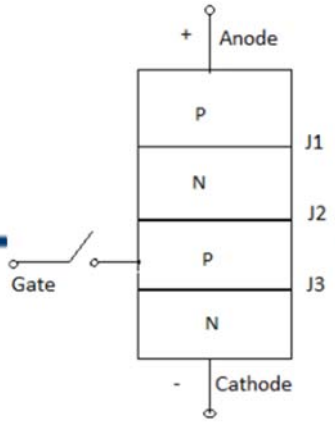
- So to avoid such a case, SCR is reverse biased for some time even if the anode current has reached to zero.
- So now the turn off time can be different as the instant anode current becomes zero to the instant when SCR regains its forward blocking capability



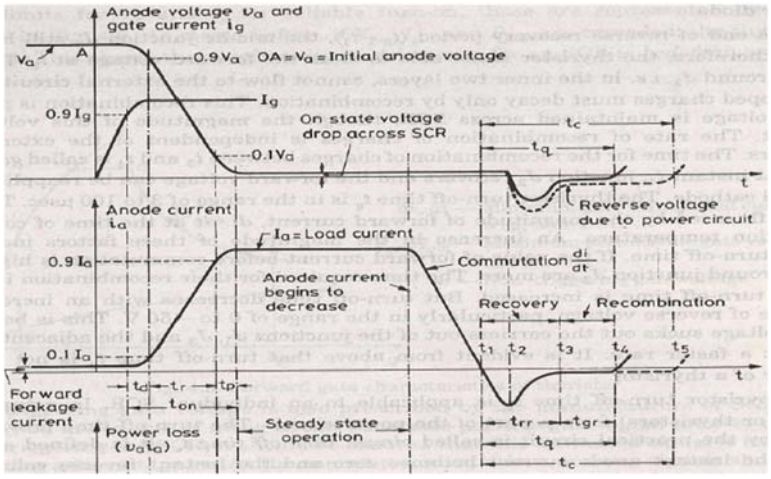


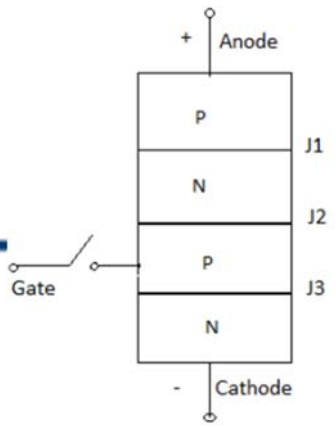
- tq=trr+tqr
- Where,
- tq is the turn off time,
- trr is the reverse recovery time,
- tqr is the gate recovery time
- At $t1$ anode current is zero.
- Now anode current builds up in reverse direction with same dv/dt slope.



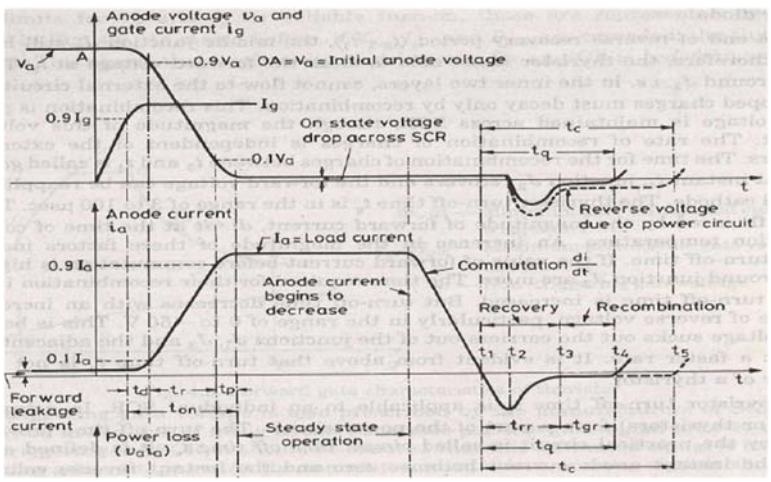


- This is due to the presence of charge carriers in the four layers.
- The reverse recovery current removes the excess carriers from $J1$ and $J3$ between the instants $t1$ and$t3$.
- At instant $t3$ the end junction $J1$ and $J3$ is recovered.





- But $J2$ still has trapped charges which decay due to recombination only so the reverse voltage has to be maintained for some more time.
- The time taken for the recombination of charges between $t3$ and $t4$ is called gate recovery time tqr.
- Junction $J2$ recovered and now a forward voltage can be applied across SCR.



- The turn off time is affected by:
  - 1. Junction temperature
  - 2. Magnitude of forward current di/dt during commutation.
- Turn off time decreases with the increase of magnitude of reverse applied voltage.