Lectures Notes

of Industrial Control Device & Data Aquisition

By

Shishir Kumar Sahoo.

INTRODUCTION OF POWER ELECTRONICS

power engg. deals with generation of power transmission, distribution and utilization in efficient manner.

→ on other hand electronics engineering deals with transmission and reception of signals without distribution.

→ power electronics is defined as the application of electronics concept to the moment of electron and hole, to the semiconductor devices at power level.

Exa→ power electronics devices are SCR, GTO IGBT etc.

CONVERTERS:

converters are the devices which converts AC to DC, DC to AC, DC to DC, AC to AC.

CLASSIFICATION OF CONVERTERS:-

→ Diode Rectifier (AC-DC converter)

→ Diode rectifier converts the variable AC to fixed DC.

2. phase controlled rectifier (AC-DC converter) it converts fixed AC to variable DC.

3. inverter (DC-AC converter) it converts fixed DC to variable AC.

4. DC chopper converts fixed DC to variable DC.

5. AC-A.C converter

AC-A.C converters are of 2 types

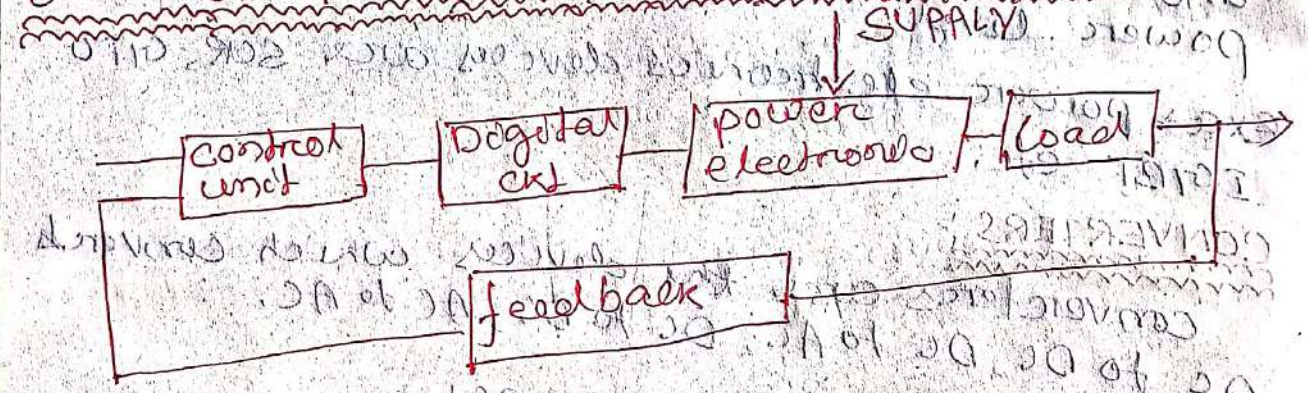
(a) A.C VOLTAGE REGULATOR:-

it converts fixed AC - variable A.C according to the requirement.

(b) CYCLO CONVERTER:-

it converts the AC signal at one frequency to the a.c signal of another frequency at constant amplitude.

BLOCK DIAGRAM OF POWER ELECTRONICS



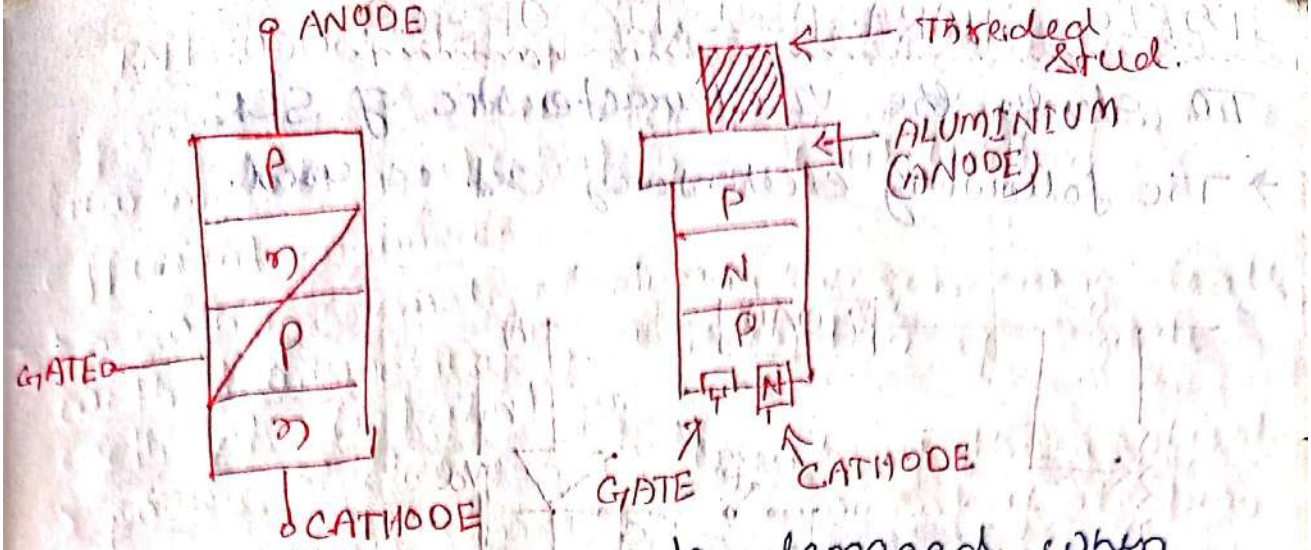
THYRISTER:

→ The term thyristor is coined form 2 words thyratron and transistor. The chardeteristics of thyristors is similar to thyratron but the construction is similar to transistor.

→ Thyristor is a 4 layer semiconductor device (P-n-P-n). The outer P-layer is anode terminal, outer n layer is cathode terminal and the gate terminal is connected to the inner P-layer.

→ Thyristor can also be constructed by using 2-transistors (PNP & NPN)

→ Schematic diagram of SCR (Silicon Controlled Rectifier)

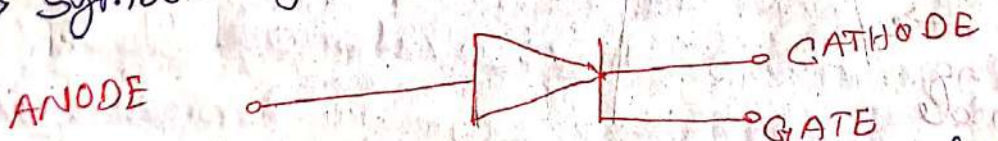


→ The resistor may gets damaged when operated at high voltage and high current. As the current flow increases the temprature of the thyristor also increases.

→ Threaded stud is present to attach heat sink to the thyristor. The function of the heat sink is to absorve the heat form the thyristor that is heat sink is present for cooling purpose of thyristor.

→ The voltage rating and current rating of SCR are 10kV and 3000A, respectively

→ Symbol of SCR



→ Thyristor is defined as four layered and junction switching device.

→ It is called as SCR.

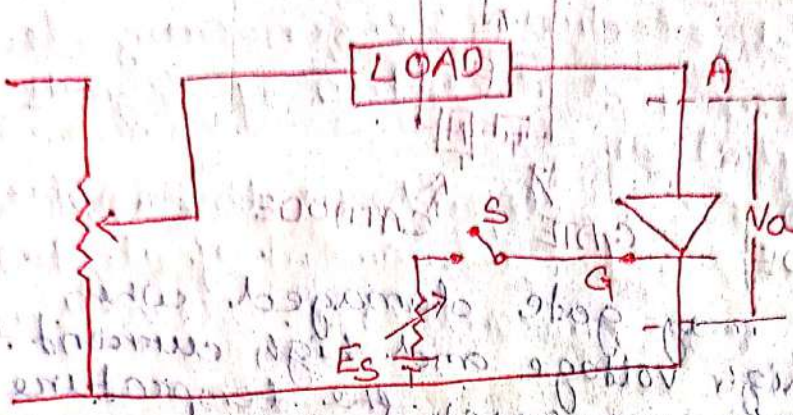
→ It is called as so because it is made up of silicon and it works like Rectifier. (very low resistance offers forward biased and offers very high regelstance when reverse biased.)

→ power handling capacity of SCR is 30mw

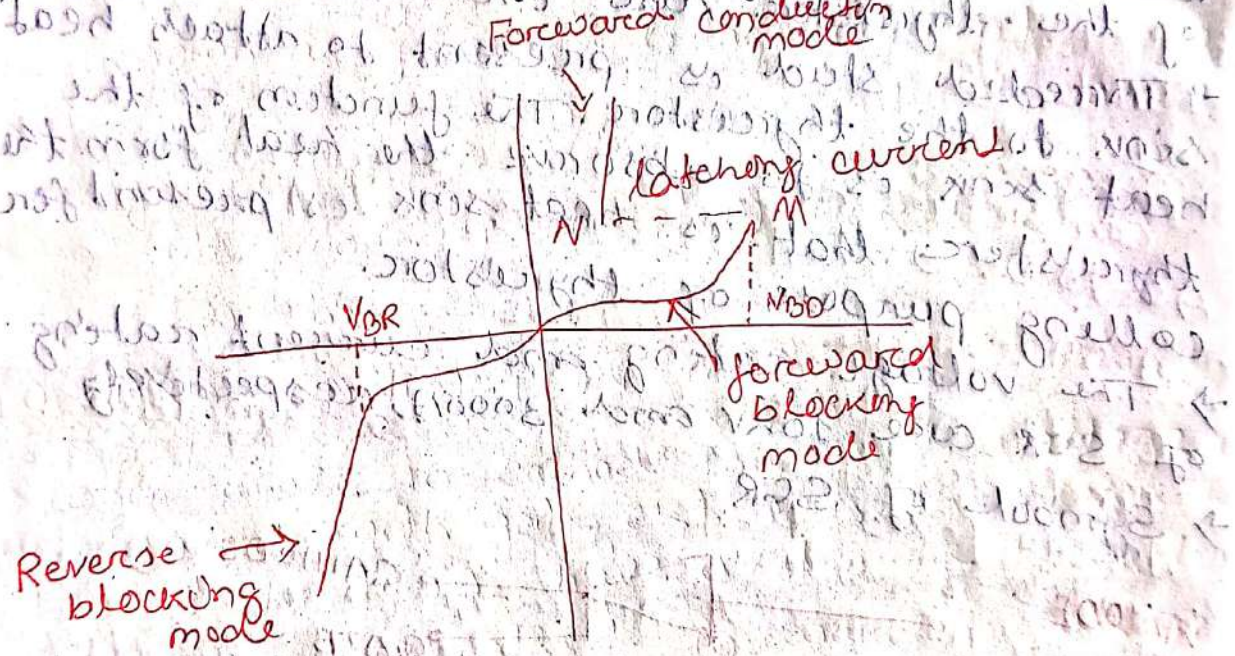
STATIC CHARACTERISTIC OF SCR:

TO Study the VI Characteristic of SCR

→ The following elementary ckt is used.



→ VI characteristics of SCR is given as below



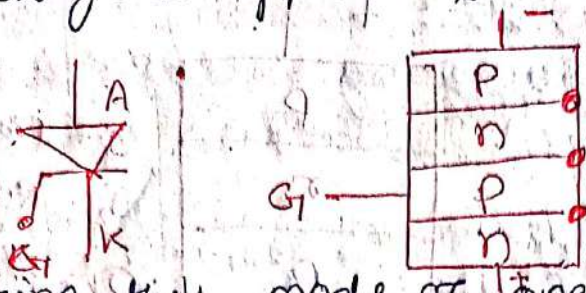
→ on the elementary ckt anode and cathode are connected to main voltage source through load.

→ A voltage source Es is applied between Gate and cathode. +ve voltage is applied to the gate.

→ Different mode of operation are revelled during the analysis of the ckt.

a. Reverse blocking mode
b. forward blocking mode
c. forward conduction mode.

No voltage is applied to the gate.

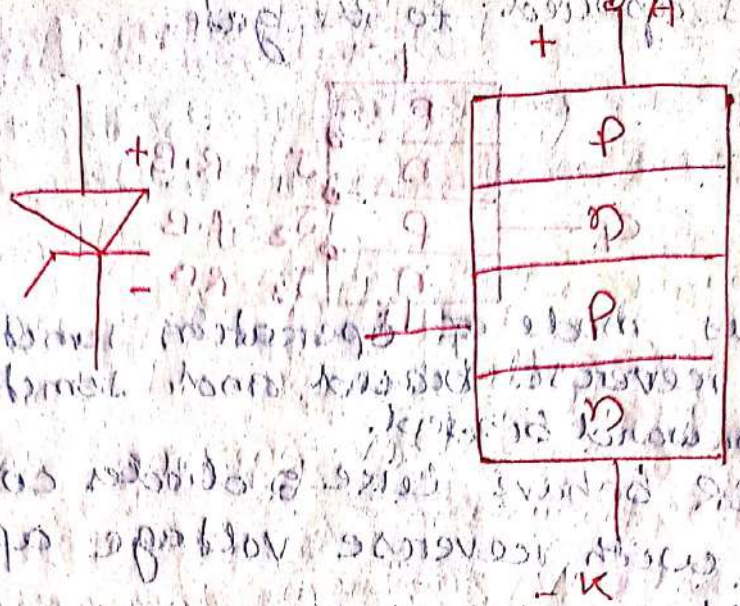


→ During this mode of operation junction J_1 & J_3 becomes reverse biased and junction J_2 is becomes forward biased.
→ Here SCR behave like 2 diodes connected in series with reverse voltage applied across them.
→ A small amount of leakage current flow across the SCR depending upon the rating (few milli amp or micro amperc.
→ This mode is known as forward block mode or off state of thyristor.
→ If the reverse voltage is increased then at a critical break down level the reverse break down voltage (V_{BR}), break down of junction J_1 & J_2 occurs. due to which the reverse current increases sharply.
→ The large current dissipated with V_{BR} causes more amount of loss.
→ As a result the temp of junction raises and thyristor gate damaged. Therefore it should be ensured that reverse voltage should not exceed V_{BR}.

FORWARD BLOCKING MODE

In this mode of operation +ve voltage applied to anode and -ve voltage is applied to cathode with gate terminal open.

→ Here junction J_1 & J_3 are forward biased and J_2 is reversed biased.



In this mode of operation small amount of leakage cage current flows which is known as forward leakage current.

→ Here the curve ON represents forward leakage current.

→ In this mode of operation SCR behaves open switch.

FORWARD CONDUCTION MODE

→ When anode to cathode forward voltage is increased with gate ckt open, the reverse biased function J_2 have avalanche breakdown.

→ At a voltage called forward break over voltage (V_{BO}).

→ Thyristor can be brought to forward blocking mode to forward conduction mode by 2 method.

① By applying gate pulse across gate and cathode.

② forward break over voltage between anode and cathode.

TURN-ON METHODS OF SCR

→ When anode is +ve with respect to cathode, SCR can be turn on by various methods.

① Forward voltage triggering.
② Gate voltage triggering.
③ $\frac{dv}{dt}$ voltage triggering.
④ Temprature triggering.
⑤ Light triggering.

1. FORWARD VOLTAGE TRIGGERING:

→ When forward voltage is applied to an anode and cathod with gate ckt. open, Jcn J_2 is reverse biased. Depletion layers is formed across J_2 the width of this layer decreases with increase in anode-cathode voltage.

→ At a forward voltage called forward break over voltage, Avalanche break down of Jcn J_2 occurs.

→ SCR shifts UP state to on state.

→ J_1 & T_3 are already forward biased and break down of Jcn J_2 allow free moment of carries.

→ As a result Rated forward anode current flows.

→ The voltage at which the Jcn J_2 is destroyed is known as forward break over voltage.

2. GATE TRIGGERING :-

→ This method of triggering is simple, reliable, and efficent, therefore this method is mostly used.

→ In forward voltage triggering method forward breakover voltage is higher than normal working voltage that means the SCR remain in forward blocking mode with normal working voltage.

→ A +ve gate voltage is applied to close on the thyristor when gate current flows charges are injected into inner P layers & forward break over voltage is reduced.

→ when +ve gate is applied, gate player is flooded with electrons from cathod because the cathod n layer is heavily doped.

→ These electron reach junction J_2 & the depletion layer near J_2 is reduced, as result thyristor gate turn on.

③ $\frac{dv}{dt}$ TRIGGERING :-

During forward conduction mode junction J_1 & T_3 are already forward biased and junction J_2 reverse biased. This junction J_2 have the characteristics of capacitor due to the presence of charges near the junction J_2.

→ when voltage across the junction J_2 is applied suddenly the capacitance C_j

may turn on the SCR. The current through the SCR when voltage V_a is applied is given by

$$Q = C_j V_a$$

$$I_a = \frac{dQ}{dt} = \frac{d(C_j V_a)}{dt}$$

$$= C_j \frac{dV_a}{dt} + V_a \frac{dC_j}{dt}$$

$$= C_j \frac{dV_a}{dt}$$

→ If the rate of change of applied voltage is more then current through the SCR is more.

→ If V_a is small then the rate of change of V_a play the vital role for turning on SCR.

4. TEMPRATURE TRIGGERING:-

→ During forward blocking mode, most of the voltage appears across junction J_2. This voltage give raise to leikage current. as the result the temp. at the junction increases. width increase in temprature depletion layer decreases.

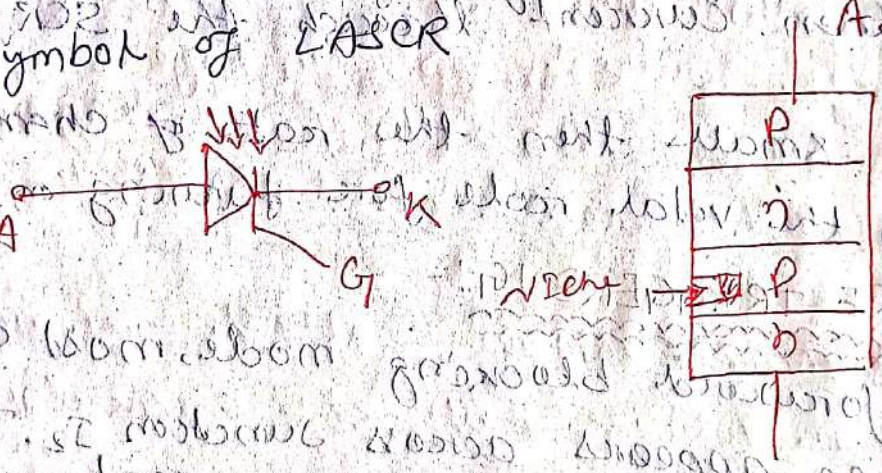
→ Due to the depletion more leikage current flows and further temp. increases. At some higher value of temp. the depletion layer vanishes and the SCR is turn ON.

5. LIGHT TRIGGERING:

In light triggering method, a recess or niche is made in p-layer. When this recess is irradiated. The free charge carrier are Generated.

→ A propodate pulse of light guided by optical fibre is through to the inner p-layer when the intensity of this light exceeds limit than the SCR gate turn on this SCR is known as LASCR (Light activated Silicon control Rectifier).

Symbol of LASCR



→ Sometimes combination of both light source and gate signal is used to turn-on the SCR.

→ The intensity of light depends upon the voltage applied to the gate.

LATCHING CURRENT:

Latching current is defined as the minimum value of anode current that must be attend during the turn on process of SCR to maintain the conduction when gate signal is remove.

HOLDING CURRENT :-

→ It is defined as the minimum value of anode current below which is required for turn off thyristor.

→ Latching current is always greater than holding current.

→ Latching current is 2 to 3 times of holding current.

SWITCHING CHARECTERISTICS OF THYRYSTOR :-

Switching characteristics is always taken into consideration for reliable and economic car design of convertor equipment.

→ Static characteristics of thyristor during turn on and turn off process.

→ Thyristor is subjected to different voltage and different current.

→ This variation of voltage and current gives the dynamic characteristics of thyristor.

TURN ON SWITCHING CHARECTERISTICS

A forward biased thyristor is turn ON by applying +ve gate voltage both gate and cathod.

→ The transmission from forward off state to forward ON state is known as thyristor turn ON time.

→ The total turn ON time is divided into 3 intervals

t_d → Delay time

t_r → Rise time

t_p → Spread time

DELAY TIME

Delay time is measured form the time at which gate current reaches 0.9 I_g to the instant at which the anode current reaches 0.1 Ia to the instant at which the anode current reaches 0.1 Ia. Here I_g is dc final value of gate current and anode current.

→ Delay time also depend as the time during which the anode voltage falls form V_a to 0.9 V_a.

→ Another way of defined delay time the time during which the current rises form forward leakage current to 0.1 Ia.

→ During turn ON process the anode current rises form the small forward leakage current.

→ As gate current began to flow form gate to cathod with the application of gate signal.

→ The gate current has non uniform distribution of current density.

→ The delay time t_d as high the gate current is less. The delay time can be decrease by increasing gate current.

RISE TIME :-

→ It is defined as the time taken by the anode current to raise form 0.1 Ia to 0.9 Ia
→ The raise time is also defined as the time required for the forward blocking of state voltage to fall from 0.9 Va to 0.1 Va
→ The raise time is inversely proportional to gate current.
→ Thus t_r can be reduced by increasing current pulse.

Tp SPRED TIME :-

The Spread time is the time taken by the anode current to raise form 0.9 Ia to Ia
→ It can also be defined for forward blocking current to fall form 0.1 of its one time value to state voltage drop. During the time conduction spreads over the entire crossection of the cathod of SCR
→ After the spread time anode current attend steady state value and the voltage is equal to on state voltage drop
→ The total turn on time of SCR is equal to the some of delay time, Raise and spread time. Thyristor manufacture specifies the raise time in the order of 1-4 μs. The total turn-on time depend upon the anode ckt parameter and gate signal.
→ During turn on, SCR may be considered to be charge control device.
→ A certain amount of charge must be injected to the gate region for thyristor

conduction. This charge is directly proportional to gate current. Therefore the turn on time can be reduced by increasing the gate current.

SWITCHING CHARACTERISTICS DURING TURN OFF:

Thyristor turn off means that the change from ON to OFF state and is capable of blocking the forward voltage. The process of SCR from conduction state to forward blocking state is called commutation process or turn off process.

→ The SCR can be turn off by reducing anode current below holding current.

→ If the forward voltage is applied to the SCR at the moment the anode current falls to zero, the device will not be able to block this forward voltage. Therefore SCR will go to conduction even through gate signal is not applied.

→ The turn OFF time t_q of thyristor is defined as the time between the instant anode current becomes zero and the instant SCR regain forward blocking capability.

→ During time t_q all excess carriers are removed form SCR. This removal of excess carriers consists of removing out holes on outer p-layer and electrons for outer n layers.

→ The turn off time has two interval
① Reverse Recovery time (t_{rr})

② Gate Recovery time (t_{gr})

Thus $t_q = t_{rr} + t_{gr}$

→ At time t_1 anode current becomes zero after time t_1 anode current increase in reverse direction due to the presence of carriers store in 4-layers.

→ The reverse recovery current removes excess carrier from junction J_1 & J_3 between time t_1 & t_3

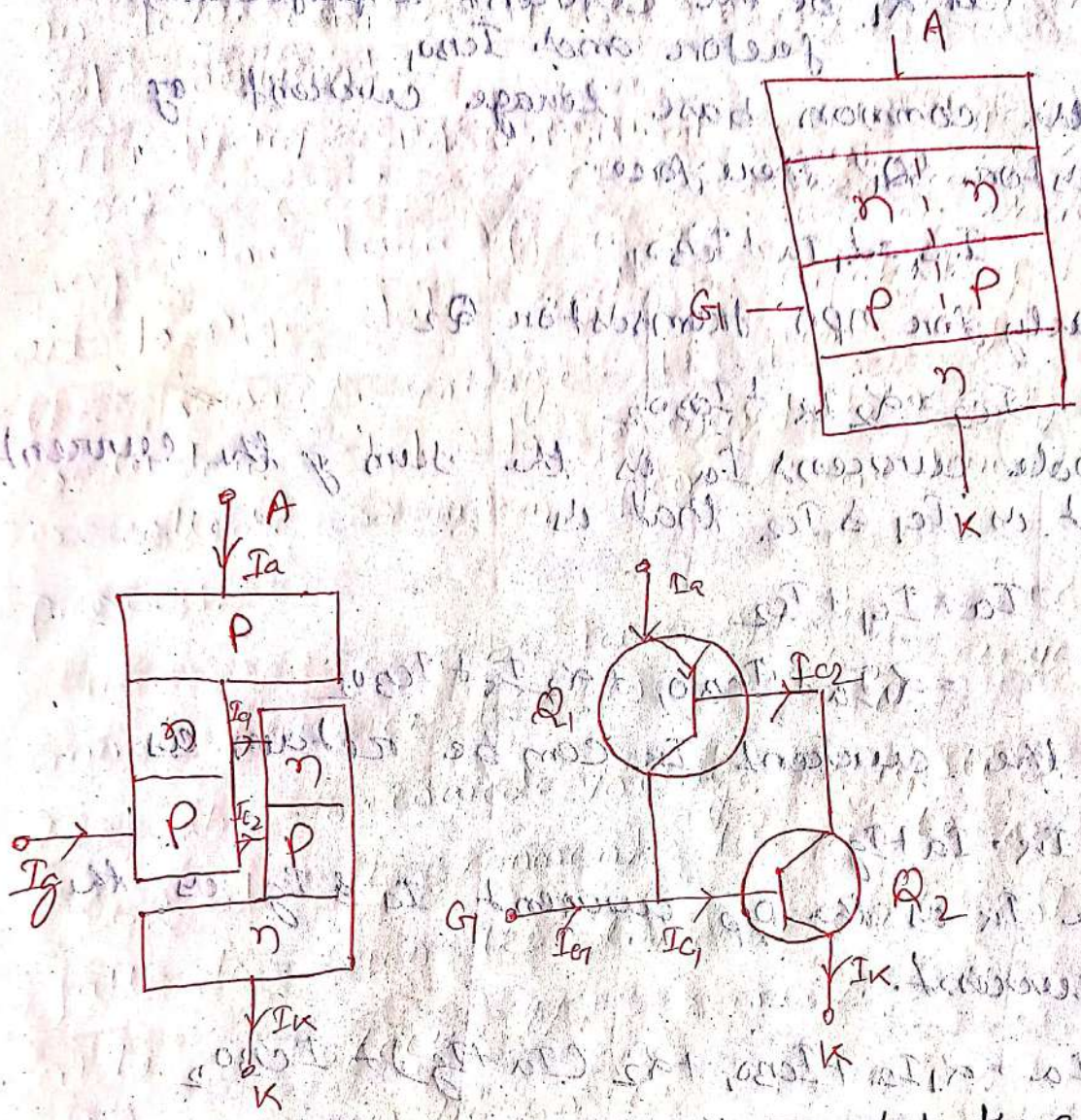
→ After the end of the reverse recovery time interval the middle junction J_2 still has trapped charges, the thyristor is not able to block the forward voltage at t_3

→ The rate of recombination of charges is independent of external ckt parameter.

→ The time interval between t_3 & t_q is known as gate recovery time and instant the junction J_2 becomes recovers and forward voltage can be applied betn anode & cathode.

Thyristor turn OFF the t_q the range of 3 to 100 μs.

2 TRANSISTOR MODE OR 2 TRANSISTOR ANALOGY SCR



→ According to 2 transistor model the above diagrams are drawn. Here 2 transistors pnp & npn are obtained.

→ The principle of thyristor operation can be explained using 2 transistor. 2-transistor can be obtained by bisecting the dotted lines.

→ Normally in transistor the collector current is given by

$$I_C = \alpha I_E + I_{CBO}$$

where α is current amplification factor

I_E = Emitter current

I_{CBO} = common base leakage current.

→ For transistor Q_1

Let α_1 be the current amplification factor and I_{CBO_1} be the common base leakage current of transistor Q_1 therefore

$$I_{C_1} = \alpha_1 I_a + I_{CBO_1}$$

Similarly for npn transistor Q_2

$$I_{C_2} = \alpha_2 I_k + I_{CBO_2}$$

→ Anode current I_a is the sum of the current that is I_{C_1} & I_{C_2} that is

$$I_a = I_{C_1} + I_{C_2}$$

$$= \alpha_1 I_a + I_{CBO_1} + \alpha_2 I_k + I_{CBO_2}$$

Now the current I_k can be written as

$$I_k = I_a + I_g$$

where I_k is the o/p current, I_a & I_g is the I/p current.

$$\therefore I_a = \alpha_1 I_a + I_{CBO_1} + \alpha_2 (I_a + I_g) + I_{CBO_2}$$

$$= \alpha_1 I_a + I_{CBO_1} + \alpha_2 I_a + \alpha_2 I_g + I_{CBO_2}$$

$$= I_a(\alpha_1 + \alpha_2) + \alpha_2 I_g + I_{CBO_1} + I_{CBO_2}$$

$$\Rightarrow I_a - I_a(\alpha_1 + \alpha_2) = \alpha_2 I_g + I_{CBO_1} + I_{CBO_2}$$

$$\Rightarrow I_a[1 - (\alpha_1 + \alpha_2)] = \alpha_2 I_g + I_{CBO} + I_{CBO_2}$$

$$\boxed{I_a = \frac{\alpha_2 I_g + I_{CBO_1} + I_{CBO_2}}{1 - (\alpha_1 + \alpha_2)}}$$

→ For Silicon transistor, the current gain is very low at low emitter current.

→ With increase in emitter current α also increases. When $I_g = 0$ then $\alpha_1 + \alpha_2$ is very

low. The forward leakage current that is $I_{CBO_1} + I_{CBO_2}$ flows. If the emitter current of 2-component transistor can be increased then α_1 & α_2 approaches unit.

Ia → by turning on the device.

THYRISTOR RATING:-

→ Thyristor rating indicates voltage, current power & temp limit with in which the SCR with out damage.

→ The rating and specification serve as link between the manufacturer and user.

→ For reliable operation of thyristor it should be ensured that the current and voltage rating should not exceed its working voltage and current.

→ The major disadvantage of thyristor is that they have low thermal time constant.

→ A thyristor has several rating such as voltage rating, power rating. $\frac{dv}{dt}$ rating turn on time, turn off time. For proper application of thyristor the knowledge of rating is necessary.

→ Some subscripts are associated with rating

F = Forward

D → forward blocking Reason, with get out open.

T = on state

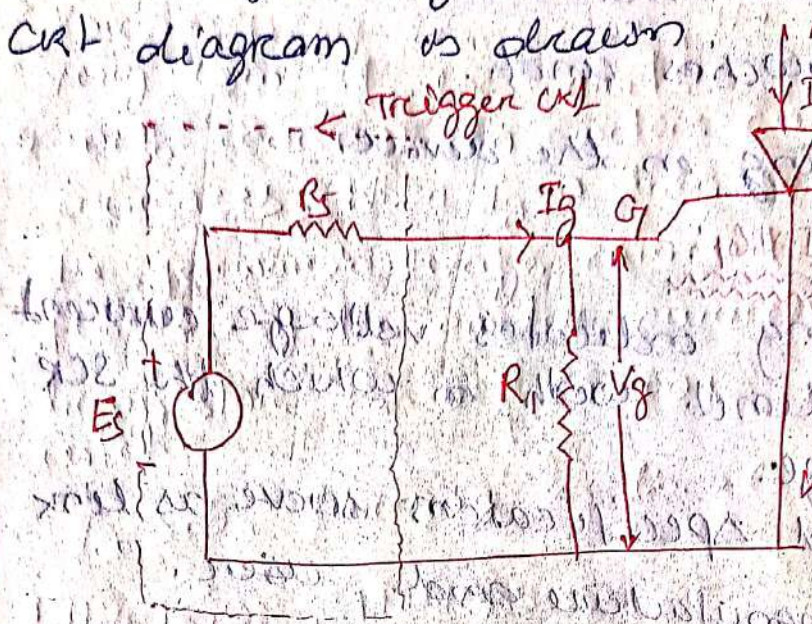
R = Reverse

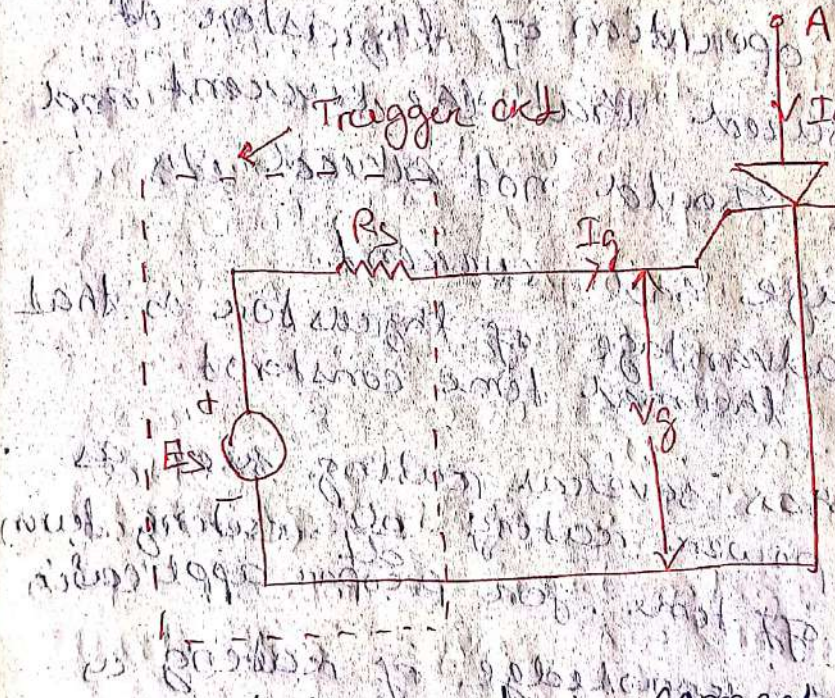
W = working value / R = Repetative value.

T = Trigger

GATE CHERECTERISTICS OF SCR

To study the gate characteristics following ckt diagram is drawn.





Here trigger ckt is connected to gate-cathode of SCR

$E_s = V_g + I_g R_s$

E_s = source voltage

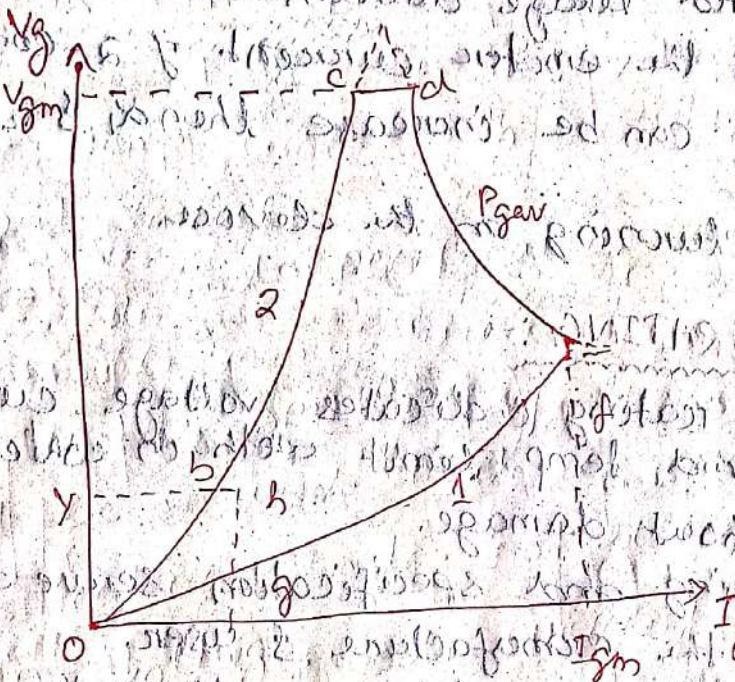
V_g = Gate voltage

I_g = Gate current

R_s = Resistance.

→ Gate cathode ckt of thyristor is a PN junction, the gate characteristic of device is similar to diode.

→ Gate voltage and Gate current characteristics that is has four curves that is Vg-Ig is shown in graph.



→ The curve 1 represent the lowest voltage value that must be applied to turn on the SCR.

→ Curve 2 represent has possible voltage that can be applied to the gate ckt.

→ Each thyristor has maximum limit Vgm forgave voltage and Igm for gate current there is also avarage power desipation.

→ The power desipation should not exceed the limit to avoid the permanent damage of junction Jb.

→ There are also minimum limit for Vg and Ia for reliable turn on of thyristor.

→ The minimum value of V_g & I_g is represented by O_Y and O_X respectively.

→ For Silicon transistors, the current gain is very low at low emitter current.
→ With increase in emitter current it also increases. When $I_g = 0$ then $\alpha_1 + \alpha_2$ is very low. The forward leakage current that is $I_{CBO_1} + I_{CBO_2}$ flows. If the emitter current of 2 component transistors can be increase then α_1 & α_2 approaches unity.

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→ The rating and specification serve as link between the manufacturer & user.
→ For reliable operation of thyristor it should be ensured that the current and voltage rating should not exceed its working voltage and current.
→ The major disadvantage of thyristor is that they have low thermal time constant.

→ If the SCR exceeds V_{gm}, I_{gm}, P_{gav} then the thyristor is destroyed, therefore the preforce gate area is b, c, D, E, F, G, H.
→ The internal resistance R_s of fig shows such that the current $\frac{E_s}{R_s}$ will not damaged the gate ckt when SCR is turn on in case R_s is an external resistance in series with must be connected.
→ The resistance R_1 is also connected across gate cathode terminal to provide easy path

to flow of leakage current.

→ The resistance R_1 is also connected across gate cathod terminal to provide easy path to flow of leakage current.

→ If I_{gm} are maximum gate current and voltage respectively then the current through R_1 is given by $\frac{V_{gmm}}{R_1}$ therefore Es is given by $E_s = \left(I_{gmm} + \frac{V_{gmm}}{R_1}\right) R_s + V_g$

THYRISTOR PROTECTION :-

→ Thyristors is delicate electronics device for Reliable operation of thyristor the rating should not be exceeded other wise thyristor is subjected to voltage and over current.

→ During SCR turn ON, $\frac{di}{dt}$ is large which may cause false triggering of SCR, by higher value of $\frac{dv}{dt}$.

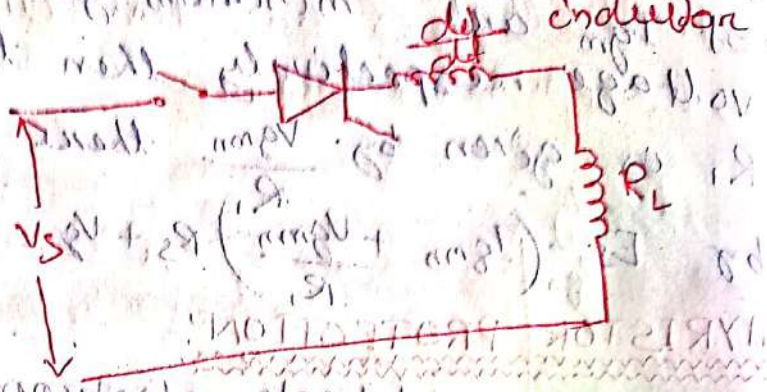
→ This may cause unwanted turn ON therefore thyristors should be protected against such situation. Different protection techniques are given below.

di/dt PROTECTION

→ when thyristor is forward biased and it is turn ON by gate current causes conduction and anode current begins to gate cathod junction. current spreads across whole area junction if the rate of rise of anode current $\frac{di}{dt}$ is large then local hotspot is formed near the gate connection. This localised heating may damage the thyristor.

→ The rate of rise of anode current should be not exceed the limit.

→ The value of $\frac{dv}{dt}$ can be kept below the limit by using a small inductor called $\frac{dv}{dt}$ inductor.



→ Local hot spot heating can be avoided by rapid spread of conduction area. This can be achive by applying gate current nearer to maximum special gate current.

dv/dt PROTECTION :-

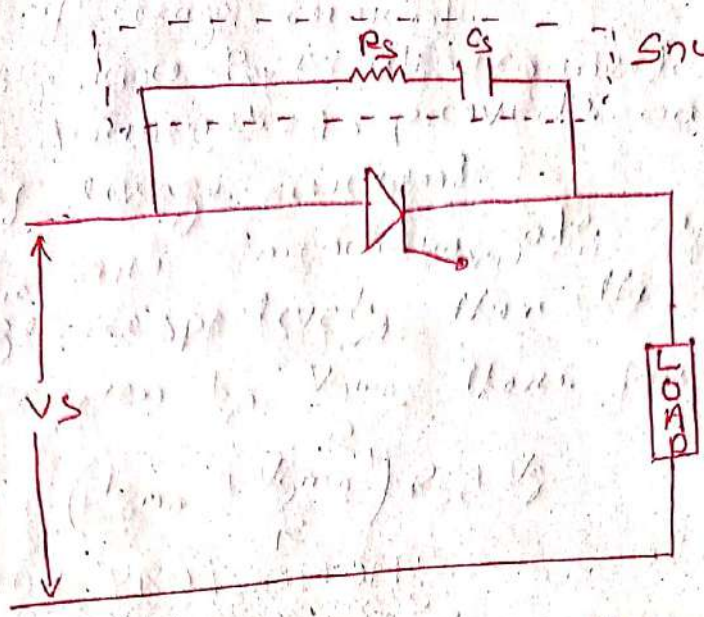
→ If the rate of rise of applied voltage across the thyristor is suddenly high then the thyristor may gate turn ON. This phenomena turning on of thyristor is known as $\frac{dv}{dt}$ turn ON.

→ The rate of rise of forward anode to cathode voltage that is $\frac{dv}{dt}$ must be kept below limit.

→ The typical value $\frac{dv}{dt}$ 20-500 V/μs to avoid the false turn on of thyristor snubber ckt in parallel with device.

SNUBBER CKT :-

Snubber ckt consist of series combination of Resistance R_s and capacitor C_s in parallel to with SCR.



→ capacitor Cs is sufficient to avoid unwanted $\frac{dv}{dt}$ triggering of thyristor when switch 'S' is closed when suddenly voltage is appear across ckt.

→ The capacitor behaves like a short ckt there fore the voltage across SCR is zero.

→ The voltage across (Cs) builds up at slow rate there fore the voltage across SCR is less.

→ To prevent the accidental turn on of the device resistance Rs is connected in series with Cs.

→ Before forcing the gate pulse Cs charges to full voltage Vs. when SCR is turn ON the capacitor discharges through SCR and the current is given Vs.

Vs. Resistence of Cs + Resistence of SCR.

→ In order to limit the magnitude of current discharge Resistence Rs is used in series with Cs. Now the initial discharge current is given by $\frac{Vs}{Rs}$.