GOVERNMENT POLYTECHNIC DHENKANAL

LECTURE NOTES

POWER ELECTRONICS AND PLC

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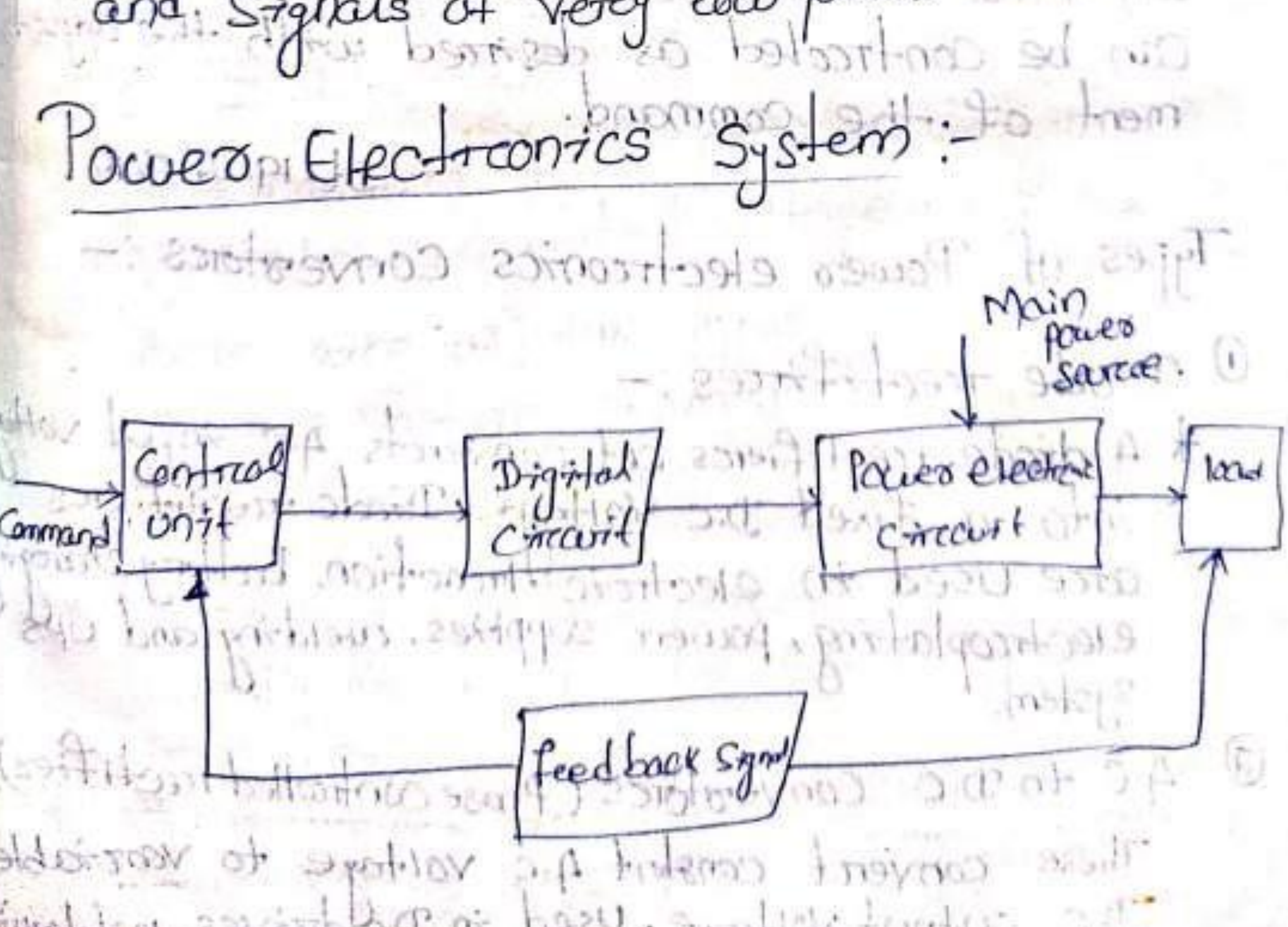
Power Electronics

- Power electronics may be defined as a subject that deals with the apparatus and equipment working on the principle of electronic but rated at power level rather than signal level.
- Power engineering is mainly concerned with generation, transmission, distribution of electric energy at high efficiency.
- electronics engg. is guided by distortionless production, transmission and reception of data and signals of very low power level.

Power Electronics System :-



↳ Main power source may be an A.C supply system or D.C supply system.

↳ The output from the power electronics ckt may be variable D.C or A.C voltage. Dependi on load requirement.

↳ The feedback component measure a parameter of the load and compaires with command

↳ The difference of the two through the Digital ckt componet controls the instant of turn ON OFF semiconductor devices forming the power electronics ckt.

↳ In this manner behaviour of the load ckt can be controlled as desired with the adjustment of the command.

Dt- 19.07.2019

Types of Power electronics Convertors :-

① Diode rectifiers :-

* A diode rectifiers ckt converts A.C input volt into a fixed D.C voltage. Diode rectifiers are used in electric traction, battery chargi electroplating, power supplies, welding and UPS system.

② A.C to D.C Convertors (Phase controlled rectifier

These convert constant A.C voltage to variabl D.C output voltage. Used in D.C drives, metalag and Chemical industries. excitation system for synchronous machine.

③ D.C to D.C converters :- (D.C choppers) :-

* A D.C chopper converts fixed D.C input voltage to controlable/variable D.C output voltage.
* These are widely used in D.C drives, Subway cars, trolitrucks, Battery driven. Veahicles

④ D.C to A.C converters :- (Inverters) :-

* A inverters converts a fixed D.C input voltage to a variable A.C voltage.
* Inveters used in induction motor and Synchronous motor drives, UPS, HVDC transmission etc.

⑤ A.C to A.C converters :-

↳ These convert fixed AC input voltage into variable A.C output voltage.
↳ These are of two types
 ① A.C voltage regulator
 ② cycloconveter

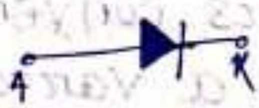
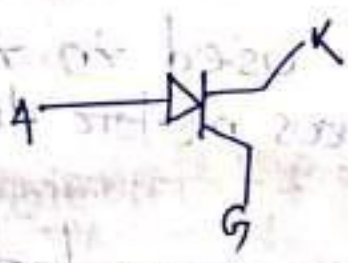
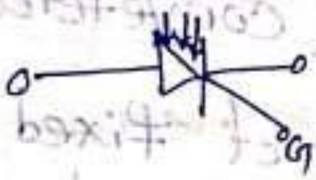
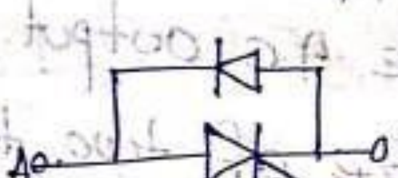
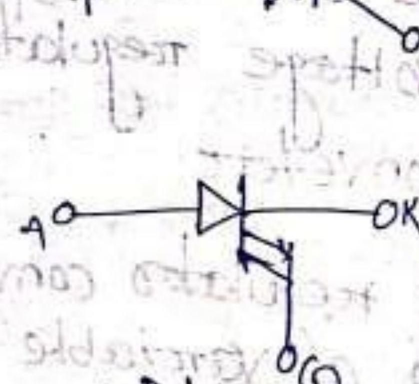
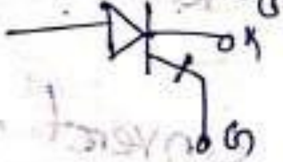
* A.C voltage regulator converts fixed A.C voltage directly to a variable A.C voltage at same frequancy
* Cycloconveters convert input power at one frequancy to output power at a different frequancy.

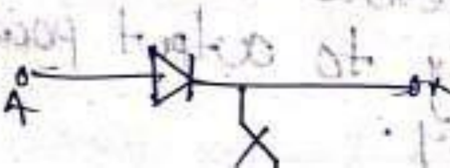
↳ uses

* A.C voltage regulator → lighting control, speed control of fans, pump.

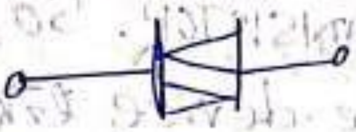
* Cycloconveters → slow speed large A.C drive.

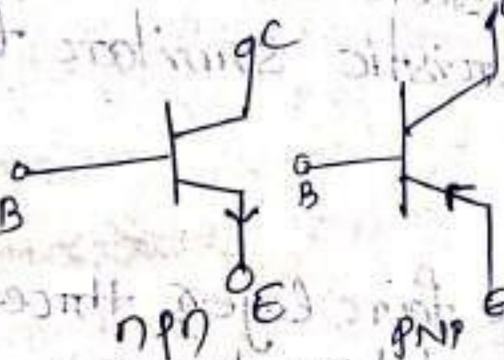
Power Semiconductor devices :-

Sl No.	Device	Symbol	Rating
1	Diode		5000V/5000A
2.	SCR		7000V/5000A.
3.	LASCR (Light Activated)		6000V/3000A.
4.	ASCR/RCT Asymmetric.		2500V/400A.
5.	GTO Gate turn off.		5000V/3000A
6.	SITH Static induction thyristor.		

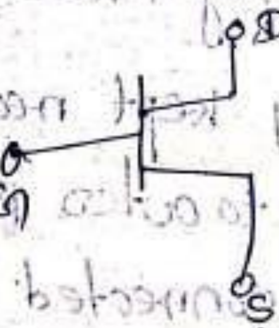


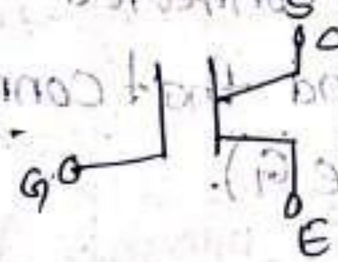
7 MOSCT -  1200 V/40 A.

8. Triac -  1200V/1000A.

9. BJT -  400V/400A

10. MOSFET -  1000V/50 A.

11. SIT  1200 V / ~~5000~~ 300A.

12. IGBT -  1200V/500A.

node.

Dt-30.07.2019

Thyristor

↳ The name thyristor is derived from THYRATRON + TRANSISTOR. So thyristor is a solid state device like a transistor and its characteristic similar to Thyratron tube.

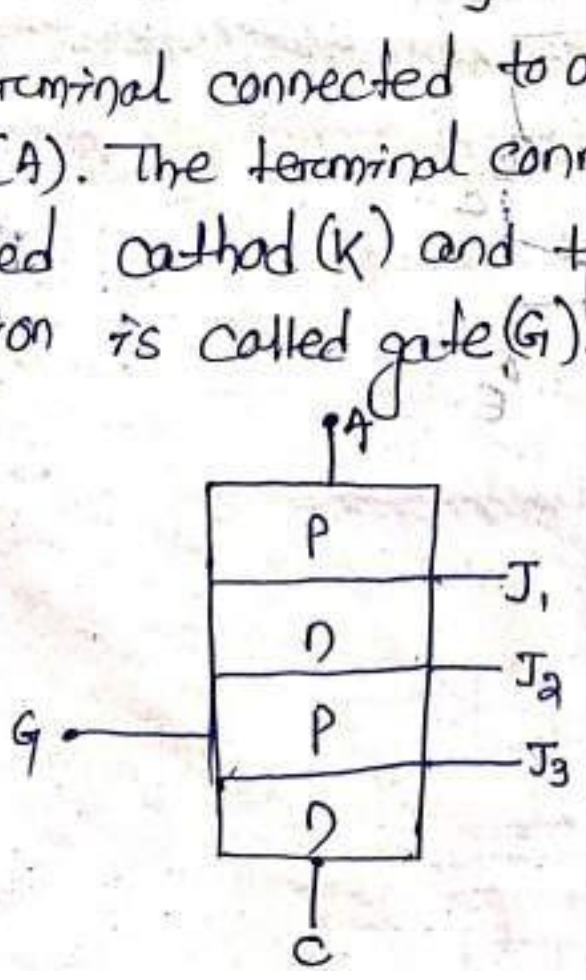
Dt-31.07.2019

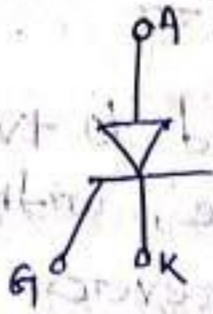
↳ Thyristor is a four layer, three junction p-n-p-n semiconductor switching device

↳ It has three terminals i.e. Anode, cathode, and gate. Four layers of alternate p-type and n-type sillicon semiconductor forming three junction J_1, J_2 and J_3

↳ Gate terminal is usually kept near cathode terminal

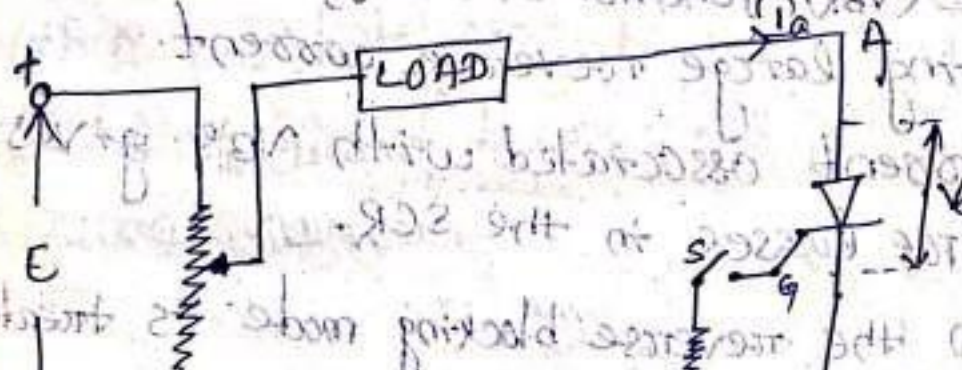
↳ The terminal connected to outer p-region is called anode (A). The terminal connected to outer n-region is called cathod (K) and that connected to inner p-region is called gate (G).





* like the diode SCR is an unidirectional device, that block current flow from cathode to anode.
* SCR voltage rating 10KV and rms current rating 3000A with corresponding power handling capacity 30MW
* Thyristor is also called as SCR (sillicon control rectifier)

Static V-I characteristics of SCR :-



↳ The circuit diagram shown is used for obtaing static V-I characteristic of thyristor

↳ Va is the anode voltage across thyristor terminal A and K and Ia is the anode current

↳ Thyristor has three basic mode of operation.
   ↳ Reverse blocking mode.
   ↳ forward blocking mode.
   ↳ forward conduction mode.

Reverse blocking mode :-

- when cathode is connected to +ve and and anode is connected to -ve, with switch 'S' open, Then thyristor is reverse biased.
- So junction J_1 and J_3 are reversed biased and J_2 forward biased.
- A small leakage current of few mA flows, from cathod to anode. This mode is called reverse blocking mode and also called off state of the thyristor.
- If the reverse voltage is increased, then at a critical breakdown level called reverse break down voltage (V_{BR}) junction J_1 and J_3 breakdown occurs causing large reverse current.
- A large current associated with V_{BR} gives rise to more losses in the SCR.
- The SCR in the reverse blocking mode is treated as open switch.

* Forward blocking mode :-

- when anode is connected +ve and cathode is connected to -ve then thyristor is said to be forward biased.
- So junction J_1 and J_3 are forward bias but Junction J_2 is reversed biased. In this mode a small current flow is called forward leakage current flow.

↳ As this current is small, SCR is treated as open switch.

* forward conduction mode :–

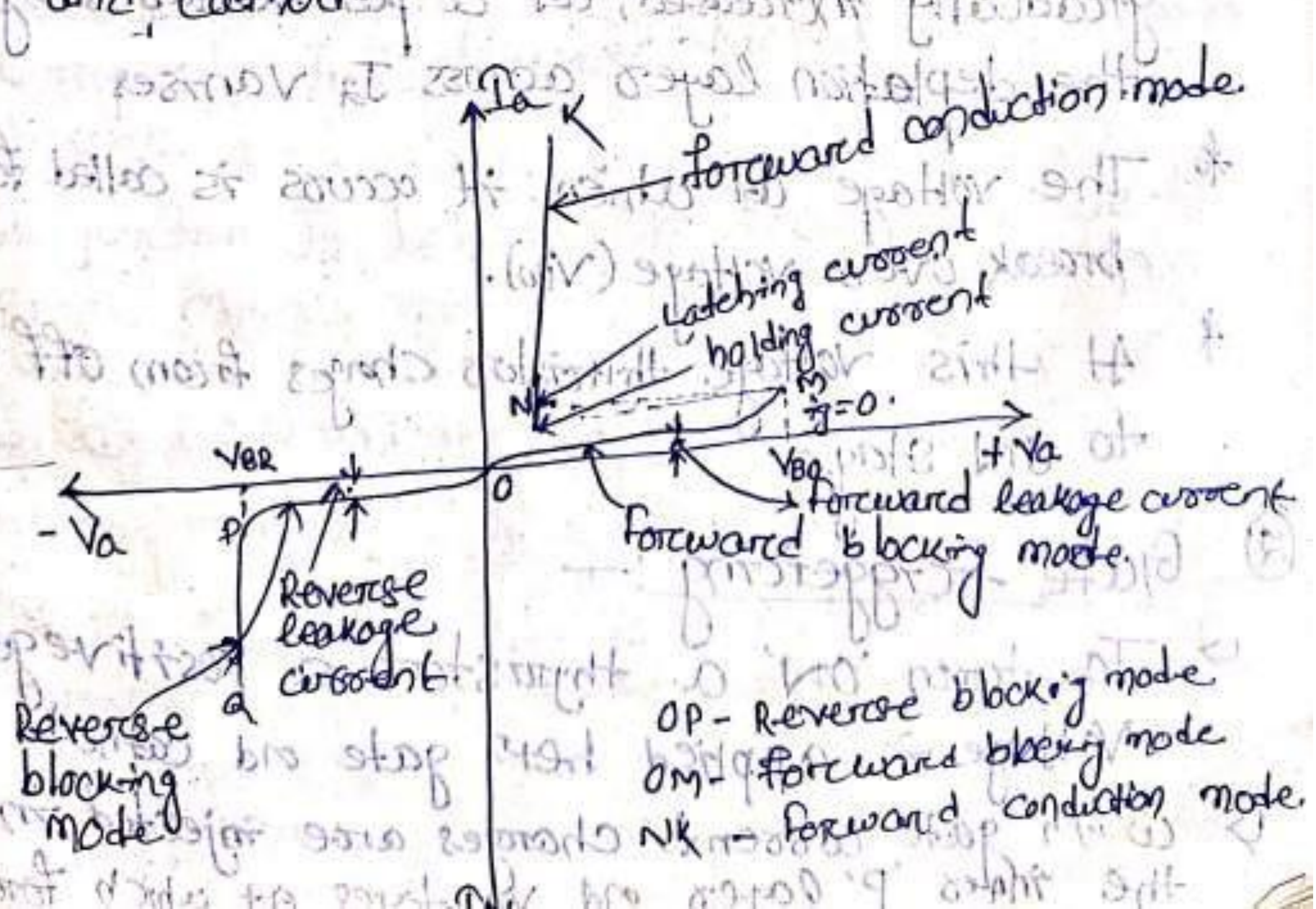
↳ when +ve anode to cathode voltage is increased with gate open, reverse biased junction J_2 will have an avalance breakdown at a voltage called forward break over voltage (V_{BO}).

↳ After this breakdown thyristor gates turned ON.

↳ A thyristor can be brought from forward blocking mode to forward conduction mode by applying

(i) A positive gate pulse betn gate and cathode.

(ii) A forward break over voltage across anode and cathod.



Turn-on Methods of Thyristor:-

> with Anode +ve and cathode -ve, a thyristor can be turned-on by following methodes.

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

① forward voltage triggering:-

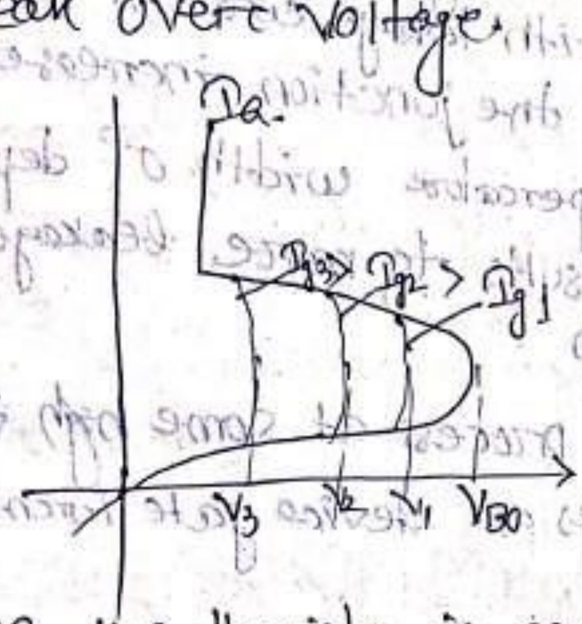
* If forward voltage across anode-cathode is gradually increased, at a particular stage the depletion layer across J_2 vanises.
* The voltage at which it occurs is called forward break over voltage (V_{BO}).
* At this voltage thyristor changes from off state to ON stage.

② Gate triggering:-

> To turn 'ON' a thyristor, a positive gate voltage is applied betn gate and cathode
> with gate current, charges are injected into the inner 'P' layer and voltages at which forward

break over occurs is reduced.

- Higher the gate current, lower is the forward break over voltage.



- Once the thyristor is conducting if the gate current is removed the conduction of current from anode to cathode unaffected.

③ $\frac{dv}{dt}$ triggering :—

- With forward voltage across anode and cathod of a thyristor J_1, J_3 forward biased and J_2 reverse biased.
- So junction J_2 behaves like a capacitor due to space changes exist
- current through capacitor

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

- If forward voltage is suddenly applied, a charging current through a junction, capacitance C_j may turn ON the SCR
- If $\frac{dV_a}{dt}$ is high the charging current I_c is more

④ Temperature triggering :-

- During forward blocking junction J_2 is associated with high voltage with leakage current as a result temperature of the junction increased.
- with increase in temperature width of depletion layer decreases so, results to more leakage current and more junction temp
- with the cumulative process at some high temp. depletion layer vanishes and device gate turned ON

⑤ Light triggering :-

- A Recess is made in the inner p- layer.
- when this recess is irradiated, free charge carriers are generated near the junction.
- If the intensity of light exceeds a certain value forward biased SCR is turned ON. This is called light activated SCR. (LASCR).

Latching current :-

- It is defined as the minimum value of anode current, which it must attain during turn ON process to maintain conduction, when gate signal is removed.

Holding current :-

- It is defined as the minimum value of anode current below which it must fall to turn off the thyristor.

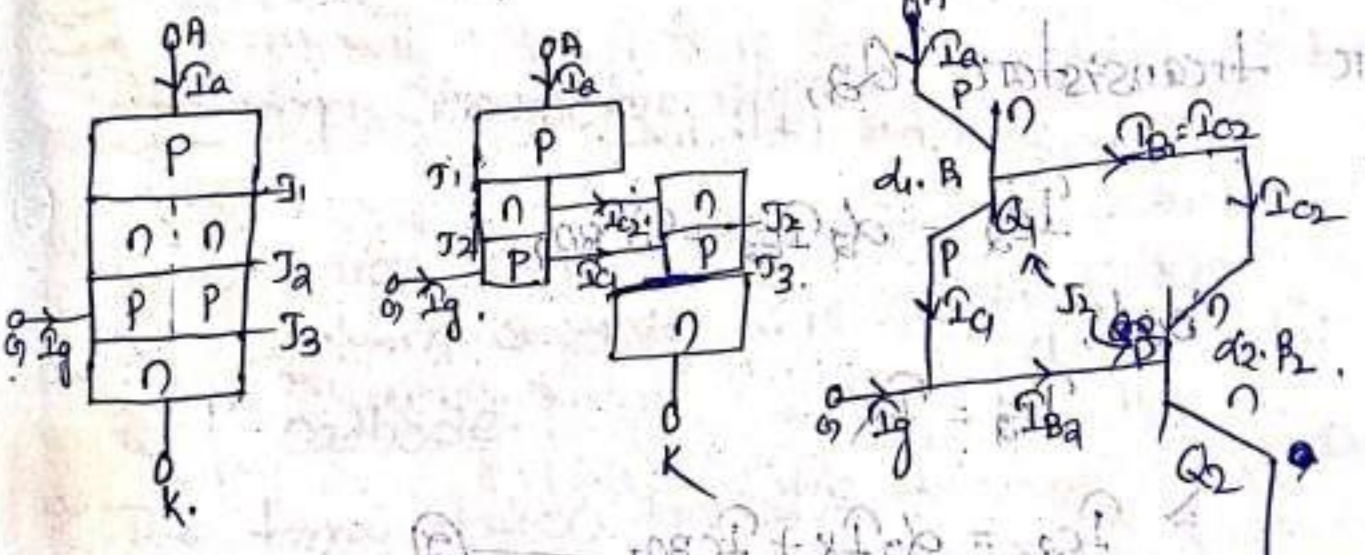
↳ Holding current is almost taken as '0'.

* Latching current is associated with turn ON process and holding current is associated with turn off process.

* Latching current is higher than holding current 2-2.5 times.

Dt - 07.08.2019

Two transistor Model of thyristor :~



↳ The thyristor operation can be explained with the use of its two transistor model.

↳ Junction J_1-J_2 constitute p-n-p transistor and junction J_2-J_3 make n-p-n transistor.

↳ In off state of a transistor the collector current I_C is related to emitter current I_E as

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

I_{CBO} = Common base leakage current of Q_1

α = Common base current gain.

For transistor Q_1,

$$I_{C_1} = \alpha_1 I_{E_1} + I_{CBO_1}$$

$$\Rightarrow I_{E_1} = I_a$$

$$\Rightarrow I_c = I_{C_1}$$

$$\therefore \Rightarrow I_{C_1} = \alpha_1 I_a + I_{CBO_1} \quad \text{---} (1)$$

For transistor Q_2,

$$I_{C_2} = \alpha_2 I_{E_2} + I_{CBO_2}$$

but,

$$I_{E_2} = I_K$$

$$\Rightarrow I_{C_2} = \alpha_2 I_K + I_{CBO_2} \quad \text{---} (2)$$

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

$$\Rightarrow I_a = \alpha_1 I_a + I_{CBO_1} + \alpha_2 I_K + I_{CBO_2} \quad \text{---} (3)$$

when gate current is applied.

$$I_K = I_a + I_g$$

Putting the value of I_K in eqn (3)

$\Rightarrow I_a = \alpha_1 I_a + I_{CBO1} + \alpha_2(I_a + I_g) + I_{CBO2}$

$$\Rightarrow I_a = \frac{\alpha_2 I_g + I_{CBO1} + I_{CBO2}}{1 - (\alpha_1 + \alpha_2)}$$

* If emitter current of two component transistor can be increased so that $\alpha_1 + \alpha_2$ reaches unity, I_a will tend to become hight there by turning on the device

Date- 09.08.2019

Switching Characteristics of SCR during turn-ON:

→ A forward biased thyristor is usually turn-ON by applying a +ve gate voltage betn gate and cathode.

→ The time taken for SCR to change from forward blocking state to forward conduction state is called turn on time.

→ Turn on time is devide into 3 intervals

1. Delay time (T_d)
2. Rise time (T_R)
3. Spread time (T_s)

① **Delay time (T_d):**

- It is measured from the instant gate current reaches $0.9 I_g$ to the instant at which anode current reaches $0.1 I_a$
- I_g = final value of gate current
  I_a = final value of anode current.
- The time taken for anode voltage to fall from V_a to $0.9 V_a$ is called delay time.
- The delay time can be decreased by applying high gate current and more forward voltage betn anode and cathode.

② **Rise time (T_r):**

- The time taken by anode current to increase from $0.1 I_a$ to $0.9 I_a$ is called rise time.
- It is also time taken by the anode voltage to fall from $0.9 V_a$ to $0.1 V_a$
- During rise time, turn on losses in the thyristor are highest due to high anode voltage and large anode current together.

③ Spread time (T_s) :—

- It is the taken by the anode current to rise from 0.9 Ia to Ia. It is also defined as the time for the forward blocking voltg to fall from 0.1 Va to ON-state voltage drop. (1 to 1.5 volt).
- During spread time conduction spreads over the entire cross section of the cathode of the SCR.
- Total turn one time = Delay time + Rise time + Spread time

Switching Characteristics during Turn OFF :—

- Thyristor turn-off means that it has change from ON state to OFF state, and is capable of blocking the forward voltage.
- This process is also called commutation process.
- SCR can be turned off by reducing the anode current below holding current.
- If forward voltage is applied to the SCR at the moment its anode current falls to zero, the device will not be able to block this forward voltage as the carries (holes and electrons) in the four layers still favourable for condition.

→ So thyristor is reversed biased for a finite period after the anode current as reached zero

→ The turn off time,

$$T_{off} = T_{rr} + T_{gr}$$

∴ T_{rr} = Reverse recovery time

T_{gr} = Gate recovery time.

→ T_{rr} is the time taken for the removal of excess carriers from top and bottom layer of SCR.

→ Gate recovery process is the removal excessive carriers from junction J_2 by application of reverse voltage.

→ T_{gr} is the time taken for removal of trapped charges from junction J_2.

$t_1 - t_3$ → Reverse recovery period

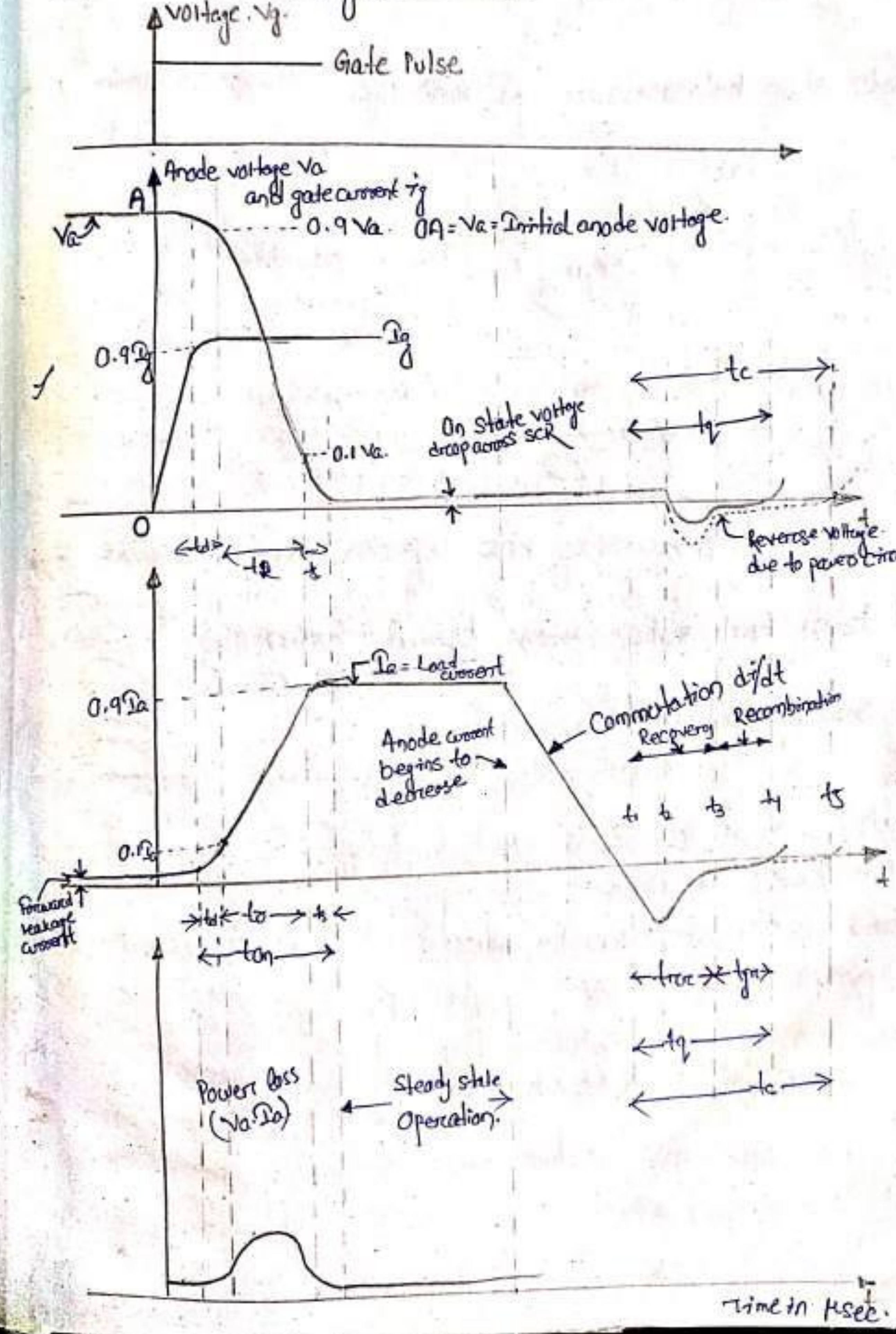
$t_3 - t_4$ → Gate recovery time.

→ Thyristor turn off time ~~taken for removal of~~ is the range of 3-100ms

→ Turn off time depends on magnitude of forward current, $\frac{di}{dt}$ at the time of commutation, junction temp.

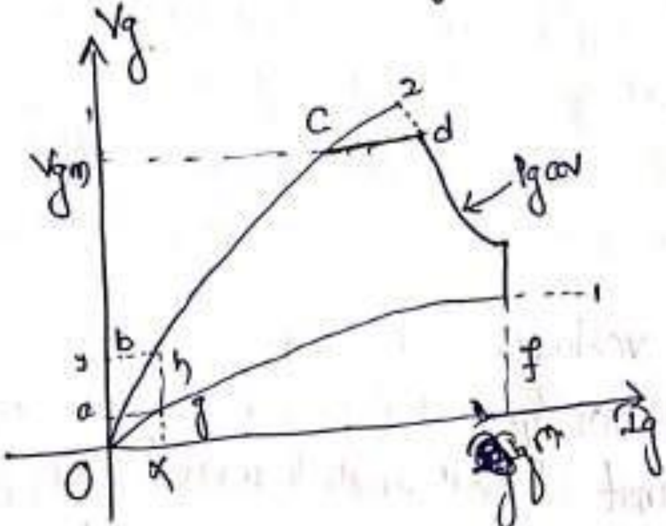
↳ Thyristor with slow turn off time (50-100ms) are called converter grade SCR.

↳ Thyristor with fast turn ON time (3-50ms) are called inverter grade SCR.



Gate characteristics of Thyristor :-

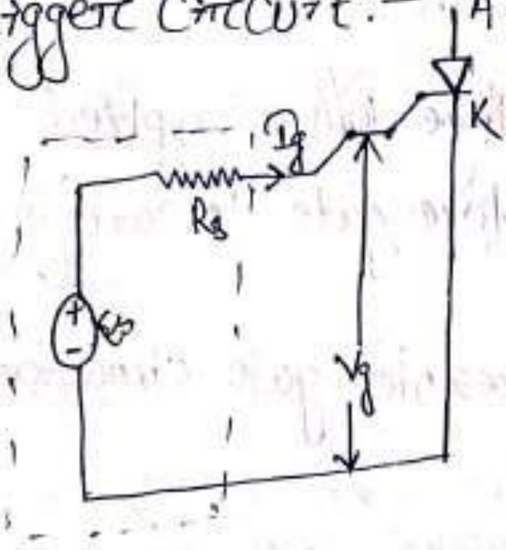
- A positive gate to cathode voltage V_g is applied
- E_g will be responsible to from positive gate to cathode curre I_g.
- A graph betn V_g and I_g represented gate characteristic



OY, OX - minm gate voltage and gate current.

- Curve-1 represent lowest voltage value that must be applied to turn ON the SCR.
- Curve-2 gives the highest possible voltage value that can be Safely applied to the gate circuit.
- At the time of manufacturing each SCR is specified with maxm gate voltage limit (V_{gmax}), Gate current limit (I_{gmax}) and maximum average gate power dissipation limit (P_{gav}). These limits should not be exceeded to protect of the SCR from damage.
- There is also a specified minimum voltage (V_{gmin}) and minimum current (I_{gmin}) for proper operation of thyristor.
- A non triggering gate voltage (Oa) is also taken into account during manufacture. All noise signal and unwanted signals should lie under this voltage to avoid unwanted turn ON of the thyristor.

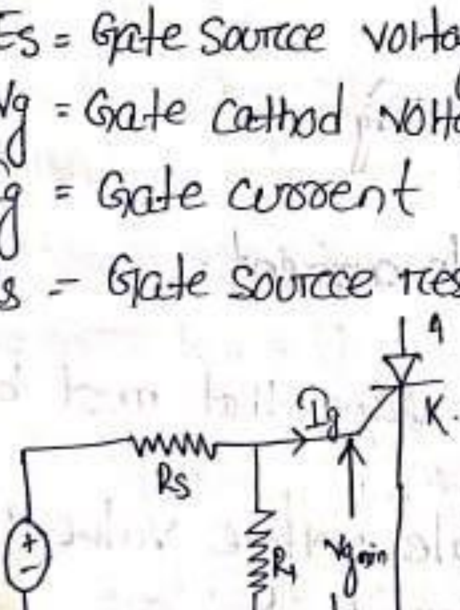
Trigger Circuit :-



$$E_s - I_g R_s - V_g = 0$$

$$\Rightarrow E_s = V_g + I_g R_s$$

where, E_s = Gate source voltage
V_g = Gate cathod voltage
I_g = Gate current
R_s = Gate source resistance.



$$E_s = V_g + I_g R_s$$

$$= V_{g\,min} + \left(I_{g\,min} + \frac{V_{g\,min}}{R_1}\right) R_s$$

* Resistance R_1 is connected across gate cathode terminals so as to provide as easy path to flow of leakage current between the SCR terminals.

V.V.I.I

Protection of Thyristor :-

1. Over voltage protection.
2. Over current protection.
3. Gate protection.

1. Over voltage protection :-

* Over voltage across thyristor may lead to thyristor failure.
* A thyristor may be subjected to internal over voltage or external over voltage.

↳ Internal over voltage :-

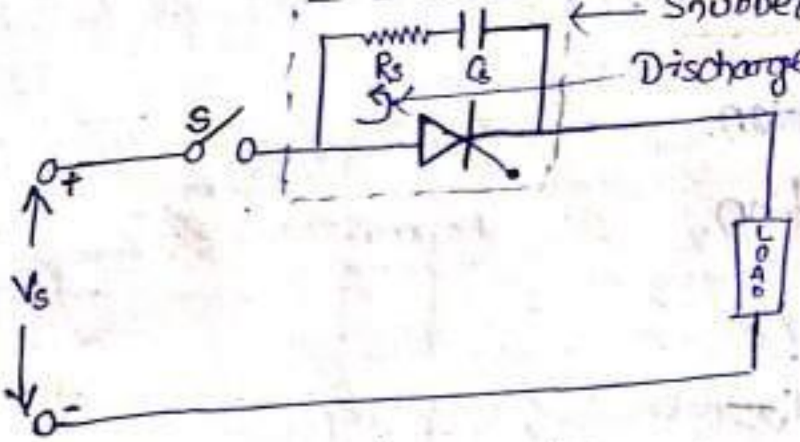
* It is caused by thyristor operation large voltage may be generated internally during turn off of a thyristor. As this internal over voltage may be several times the break over voltage of the device, the thyristor may be destroyed permanetly.

↳ External over voltage :-

* It is caused due to interruption of current flow in an inductive circuit and also due to due to lightning stroke on the lines feeding the thyristor system.

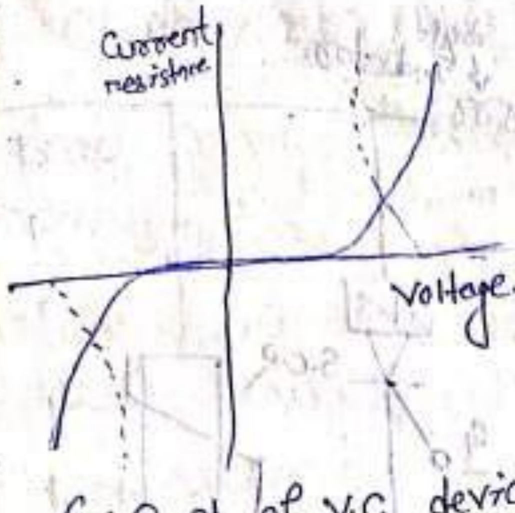
↳ Suppression of overvoltages :-

* The effect of over voltage is usually minimised by using snubber circuit and non linear resistor called voltage clamping device (VC).



* The R.C circuit called snubber circuit is connected across the device to be protected.
* It is helpful in minimise the over voltage transient spike and for limiting $\frac{dv}{dt}$ across the thyristor.
* When the SCR is turned ON capacitor discharges through the SCR and the resistance Rs show that initial discharge current and turn ON $\frac{di}{dt}$ is reduced.
* The voltage clamping device is a non linear resistor connected across SCR. under normal working condition of voltage the device has high resistance and draws only a small leakage current.
* When voltage surge appears, the device operates in low resistance region and produces a virtual short circuit across the SCR.
* As a result voltage across SCR is clamped to a ~~shape~~ safe value.

Ex:- Selenium, thyrector diode, metal oxide varistor are generally used against over voltage.



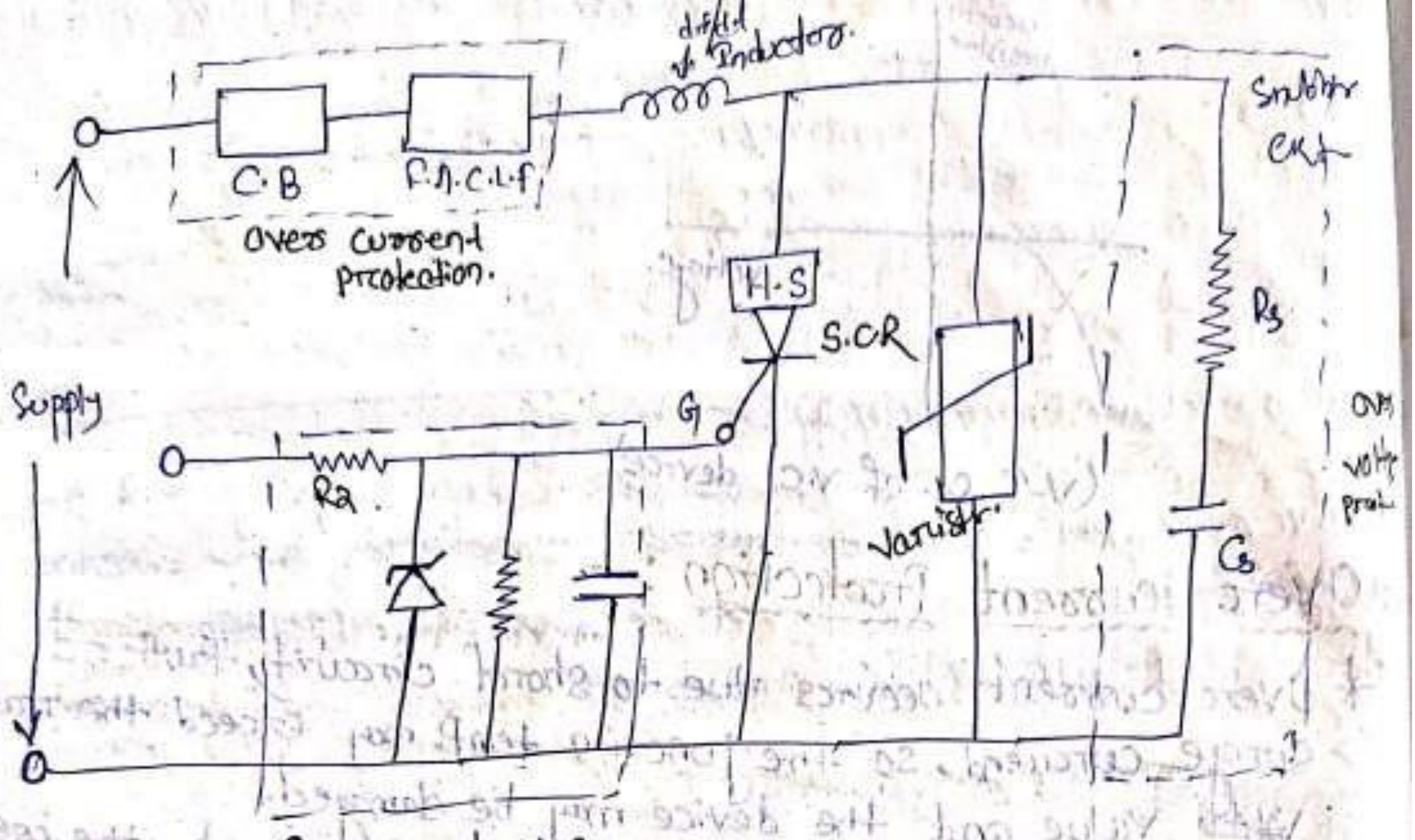
(V-I ch. of V.C device)

② Over current Protection :-

* Over current occurs due to short circuit, faults and the junction temp. may exceed the rated surge current, so the device may be damaged.
* Over current protection is achieved through the use of circuit breakers and fast acting fuse.
* Proper co-ordination betn the fast acting fuse and thyristor is required.

③ Gate Protection :-

* Gate circuit should be protected against over voltage and over current. protection against over voltage is achieved by connecting a zener diode across the gate circuit.
* A Resistor Rg connected in series with the gate circuit which provides protection against over current.
* A capacitor and a resistor are also connected across gate to cathod to by pass the noise signals.
* unwanted signal may turn ON the SCR leading to mal-operation of SCR. Gate protection against such signals is obtain by using shielded cable.



FACLF- Fast acting current limiting fuse.

Turn- off method of Thyristor:-

↳ A thyristor can be turned off when.

(i) its anode current falls below holding current

(ii) A reverse voltage is applied to thyristor for a sufficient time to enable it to recover to blocking state.

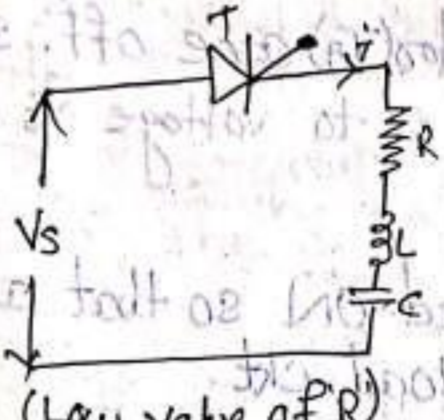
↳ Thyristor can be turned off by

① Load commutation.

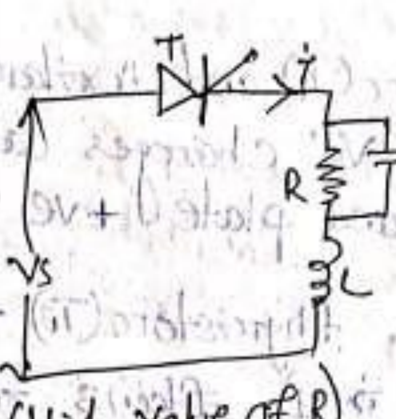
② Resonant Pulse Commutation. (Class-B)

① Load Commutation :- (Class-A commutation)

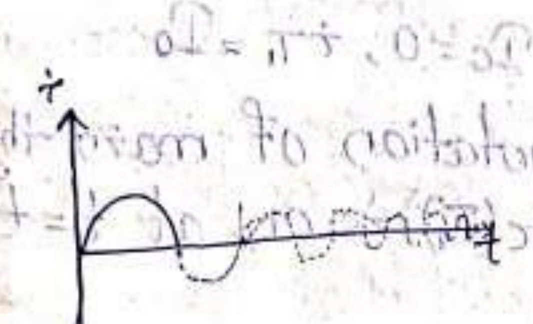
- For load commutation of a thyristor, commutating components L and C are used.
- For high value of R load R_L is connected across C.
- For low value of R, L and C are connected in series



(Low value of R)

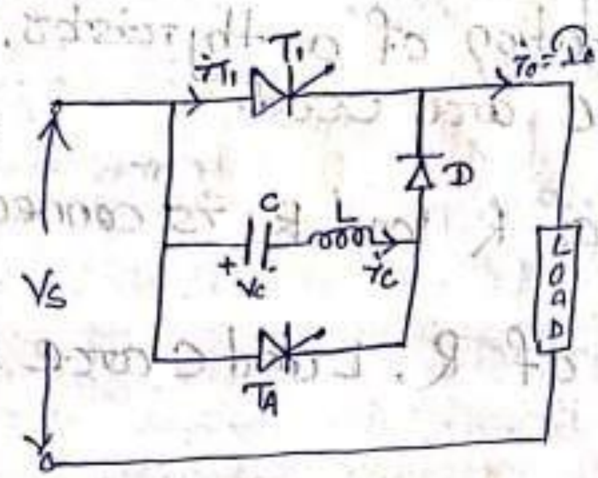


(High value of R)



- The nature of ckt should be such that the current must have tendency to decay to zero.
- When these ckt are energized from D.C, current 'i' first rises to max^m value and then begins to fall. When current decayes to zero and tends to reverse, thyristor (T) is turned of on its own.
- Load commutation is possible only in D.C ckt.

Class-B Commutation (Resonant pulse commutation)



↳ Thyristor (T_1) and Auxilary thyristor (T_A) are off. Source voltage Vs charges capacitor C to voltage Vs with left hand plate +ve

↳ At t=0, thyristor (T_1) is turned ON so that a constant current I_0 flows in the load ckt

↳ Till time t_1, $V_C = V_S$, $I_C = 0$, $i_{T_1} = I_0$

↳ For initiating the commutation of main thyristor (T_1), Auxilary thyristor (T_A) is ON at $t = t_1$

↳ with (T_A) ON a resonat current i_c begins to flow from C through T_A, L and back to C.

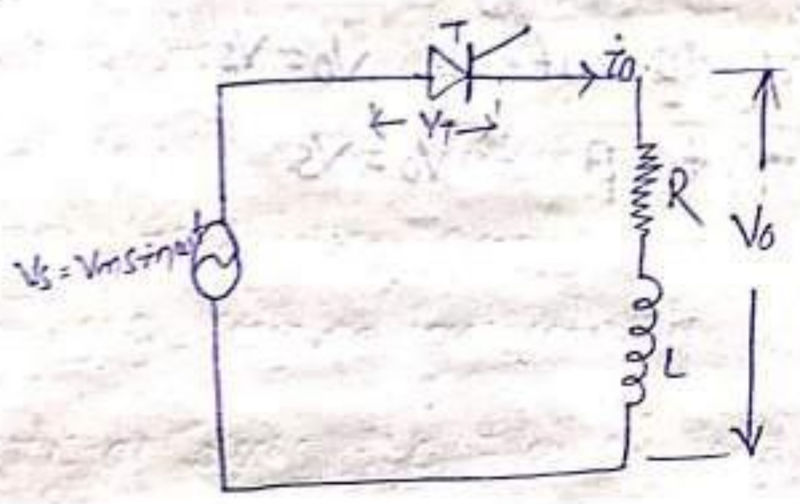
$$i_C = -I_p \sin\omega t$$

↳ Capacitor voltage $V_C = \frac{1}{C}\int i_c \, dt$

$$= V_s \cos\omega t$$

↳ After a half cycle of i_c from t_1, $i_c = 0$, $V_C = -V_S$ and $i_{T_1} = i_0$

Single-phase Half-wave circuit with R-L Load :-



- Circuit diagram shows a single phase supply feeding a R-L load through a thyristor.
- At $\omega t = \alpha$ thyristor is turned ON by gate signal so load voltage $V_0 = V_s$
- load current i_0 rises gradually due to inductance. After some time i_0 reaches max^m value and then begins to decreases.
- At $\omega t = \pi$, $V_0 = 0$, but i_0 is not zero because of load inductance 'L'. At some angle β, $\beta > \pi$, i_0 reduces to zero and SCR is turned OFF which is already reversed biased.
- At $\omega t = \beta$, $V_0 = 0$, $i_0 = 0$.
  At $\omega t = 2\pi + \alpha$ SCR is triggered again and V_0 is applied to the load and load current develops as before.