Controlled Rectifier (SCR)

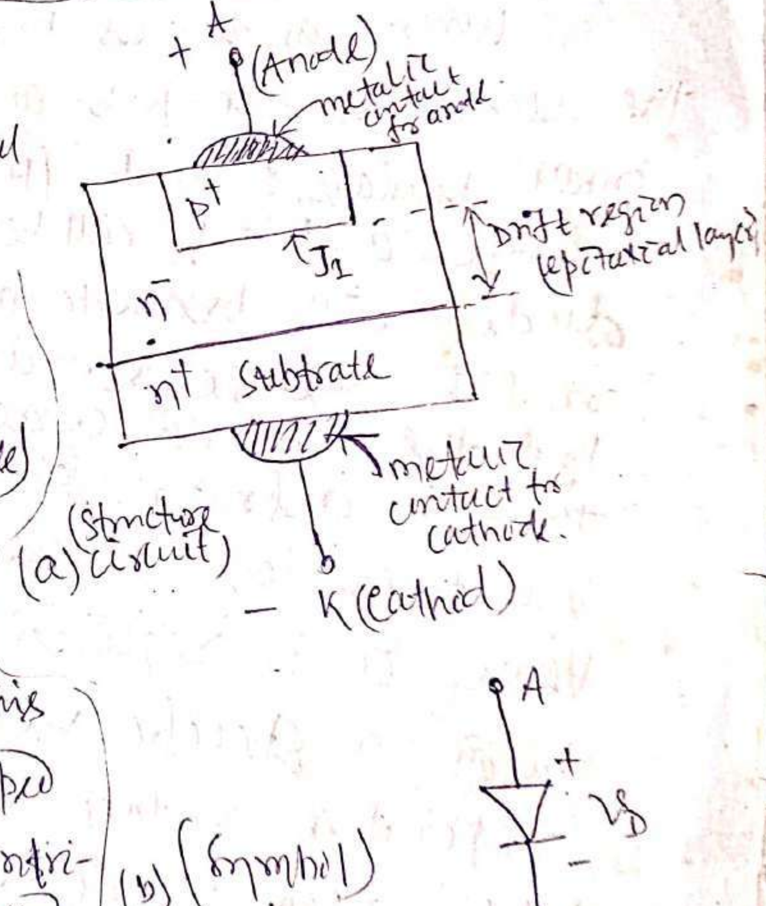
Ch-1 Power Semiconductor Devices

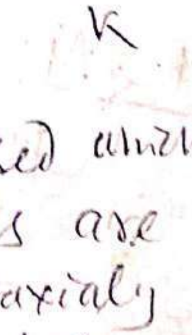
1.1. power diode: power diode is a two terminal p-n semiconductor device capable of handling very large current (the order of kilo Amps) in the forword and block large voltages (of the order of kilowatts) in reverse direction, with very low power loss.

1.1.1. operation and construction & applications

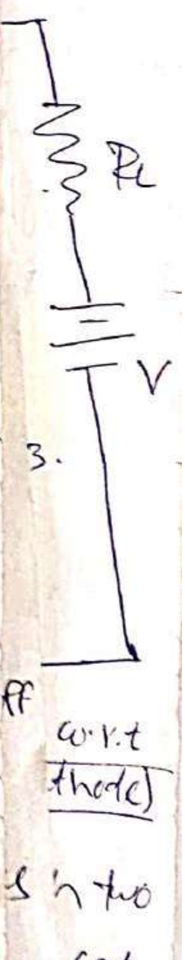
In the fig@ is shown the basic constructional features of a power diode.

A heavily doped n+ substrate (act as cathode) over which a lightly doped n- layer is epitaxially grown. This layer is so lightly doped that it nears an intrinsic layer and so called i-layer. To this layer





Symbol

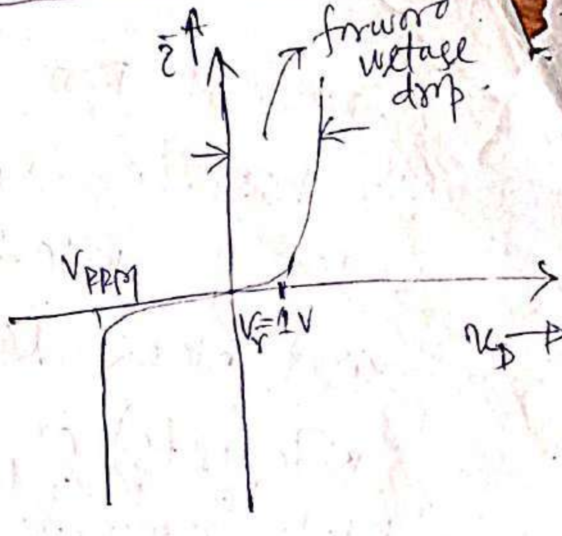


a heavily doped p+ region is diffused which forms the anode. Metallic contacts are taken from anode & cathode. The epitaxially grown n- layer is also called the drift region which provides the required power handling capability to the diode (High forward current & High reverse voltage)

In fig (b) is shown ... circuit symbol

operation and V-I characteristics

When anode is made +ve w.r.t. cathode, the diode is F.B and ON and increasing F.B. voltage above cutin or threshold value forward current flows.



When anode is made -ve w.r.t. cathode, the diode is R.B. and it is OFF. But a very small leakage current flows. Increasing reverse voltage a point will be reached at which the diode will breakdown. After breakdown the reverse voltage remains almost constant but the reverse current increases rapidly towards infinity. Due to very high current high power loss causes destruction of the dio. Hence it is required to operate the diode below a specific voltage called peak reverse repetitive voltage VRRM which is also call the peak inverse voltage (PIV).

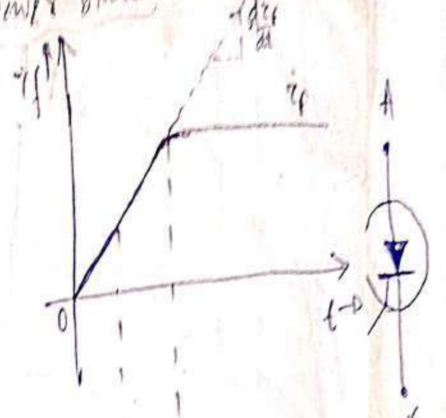
1.1.2 Applications of Power Diodes

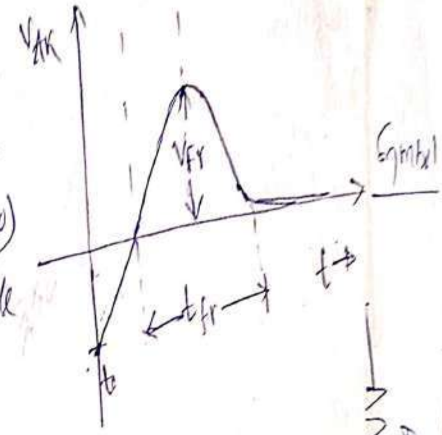
Power diodes are used in—

1) SMPS circuits.
2) Snubber circuits.
3) choppers.
4) as a Freewheeling diode.

1.2.1

Turn-on behaviour of power diode:





when the diode is turned on, the voltage and current characteristics of a power diode can be as shown in figure.

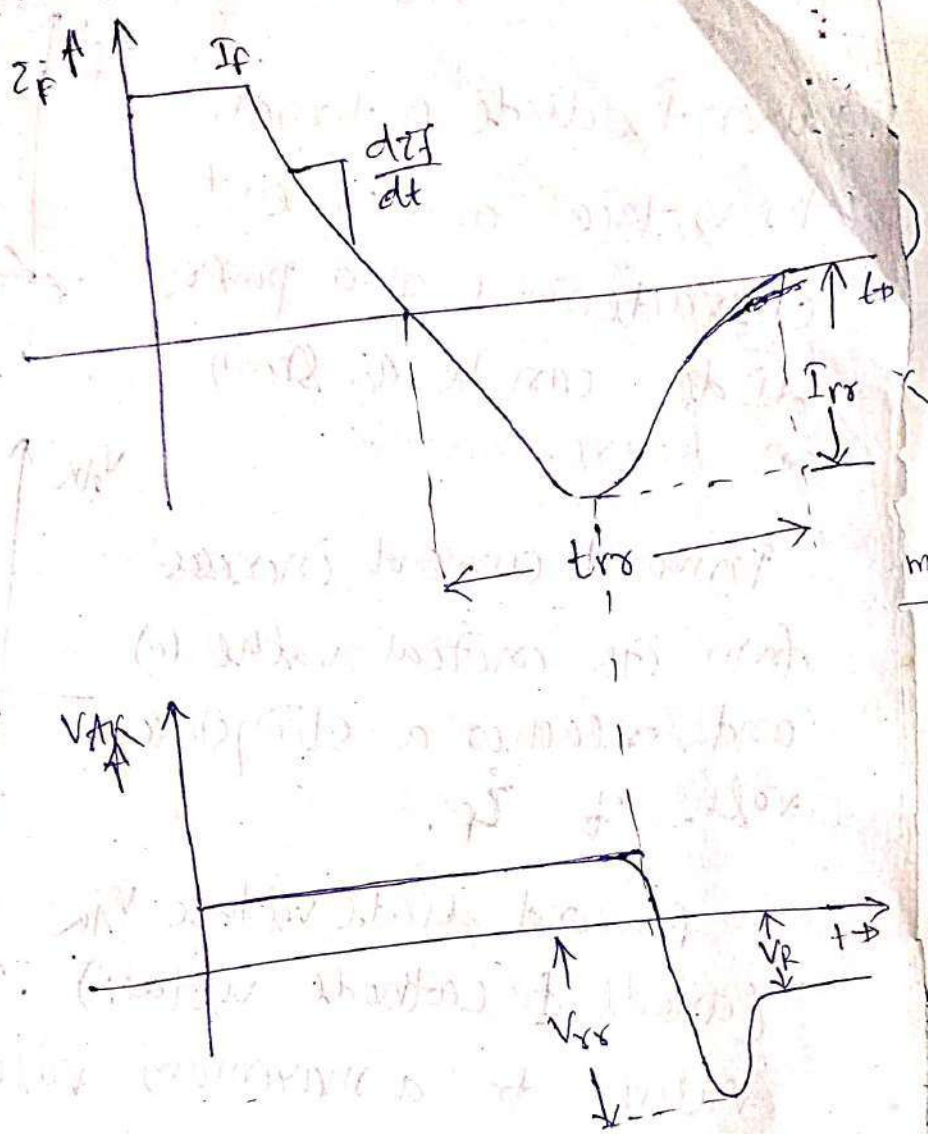
Forward current increases from its initial value (0) and reaches a steady state value of i_f.

Forward diode voltage V_{AK} (anode to cathode voltage) rises from a -ve value to a maximum value V_{fr} called forward recovery voltage and is given as a function of rate of change of forward current i.e, $\frac{di_f}{dt}$.

Turn off behaviour of power Diode:

In the fig. is shown the typical turnoff characteristics of a power diode. The voltage and current waveforms are as shown in fig.

Assuming the power diode, under controlled rate of decrease of forward current, it does not stops at zero

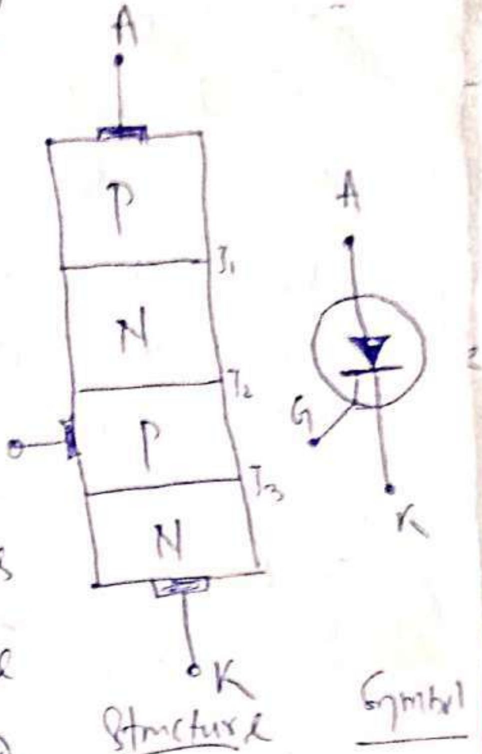


rather decreases to a -ve peak value of Irr (peak reverse recovery current) and after some times (transients), it again increases to zero value. During reverse recovery the voltage across the diode decreases to the lowest possible value called Vrr (reverse recovery voltage) and again increases to remain steady at VR (reverse bias voltage).

1.2 Silicon Controlled Rectifier (SCR)

1.2.1 Layer diagram & construction

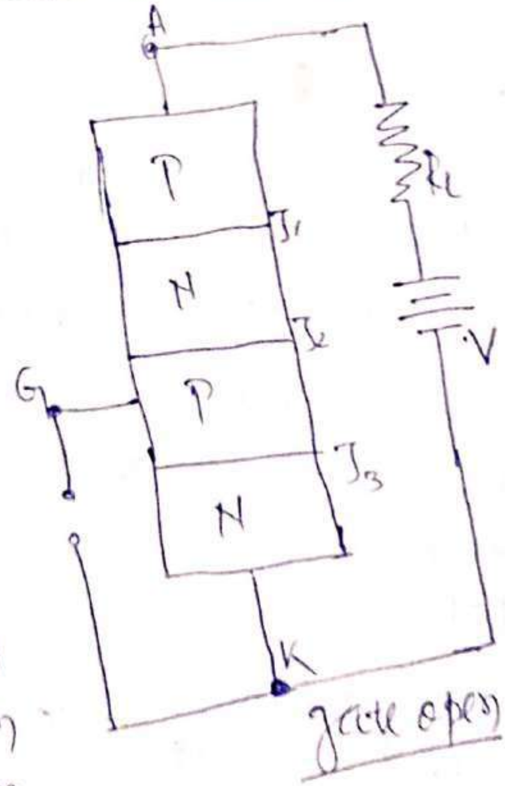
It is a 4 layer alternate PNPN device having 3 terminals, Anode (A), Cathode (K) and Gate (G). There are 3 junctions J_1, J_2, J_3. It conducts only in one direction from anode to cathode and hence is called an unidirectional device.



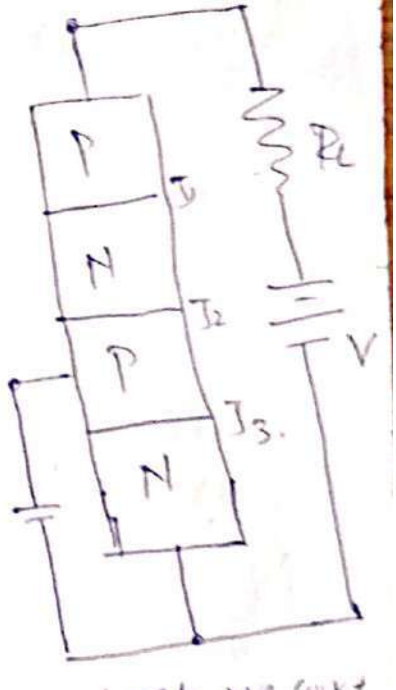
Structure   Symbol

Operation

A load to the SCR is applied between anode and cathode and the anode is kept at +ve potential w.r.t the cathode by using a battery.



gate open



(gate +ve w.r.t Cathode)

The operation of SCR can be explained with two conditions a) gate open b) gate is +ve w.r.t. cathode

when gate is open — as anode is at higher potential than cathode junctions J_1 & J_3 are F.B. and J_2 is reverse biased. So the SCR is OFF or non-conducting. But increasing the anode voltage, at some point it will overcome the reverse bias at J_2 (J_2 will breakdown) and the device will be ON and a current will flow through the load resistance R_L. This anode voltage (+ve or forward voltage) at which the SCR turns ON is called breakover voltage. The SCR offers a very low forward resistance (Of the order of 0.01Ω to 1.0 Ω) so that voltage across it drops to a low value (of the order 1V). The forward current flowing in the circuit is controlled by the power supply and the load resistance and keep on flowing till gate is open.

<u>when gate voltage is applied (+ve w.r.t. cathode).</u>

when gate is applied with a +ve voltage w.r.t cathode junction J_3 is F.B. and J_2 is reverse biased. A gate current flows from gate to cathode leaving the cathode via external load and adds to anode current. Now anode current increses. In a very short time this increased current breaks down the junction J_2 and the SCR conducts heavily. (i.e, breakover takes place earlier) and the current flowing through the load resistance can be controlled by the gate potential.

<u>Following points may be summarised</u>

① If anode is made -ve w.r.t. cathode then J_1 & J_3 are R.B. and J_2 only F.B. Now increasing the -ve anode potential, a stage will be reached when zener breakdown occurs and device will be destroyed. Thus SCR is

(3) an unidirectional device.

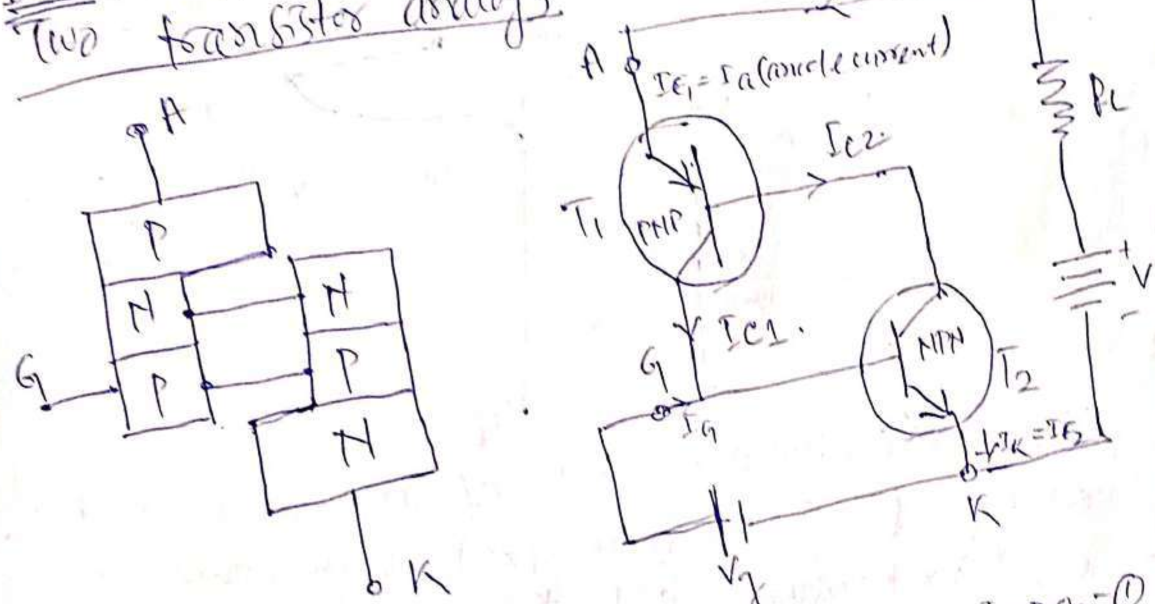
(2) Either SCR does not conduct (OFF state) or conducts heavily (fully ON). Thus it behaves like a switch (or even as a diode)

(3) To make SCR, OFF from ON state, the supply voltage is reduced to zero.

(4) To close the SCR, normally a small +ve voltage is applied at the gate because the gate breakover voltage is usually much greater than breakover voltage.

(5) SCR can be turned ON by keeping the gate open and making supply voltage equal to breakover voltage or making the supply voltage less than breakover voltage and applying a small voltage to (1.5v) the gate.

1.2.2. Two transistor analogy.



for the transistor T_1, $I_{C1} = \alpha_1 I_a + I_{CBO_1}$ — (1)

where α_1 = common base (small signal) current gain for T_1

Similarly for T_2, $I_{C2} = \alpha_2 I_K + I_{CBO_2}$. — (2)

Sum of the two collector currents is equal to the external circuit current I_a, entering the anode terminal A.

$$I_a = I_{C1} + I_{C2} = \alpha_1 I_a + I_{CBO1} + \alpha_2 I_K + I_{CBO2} \quad \text{--- (3)}$$

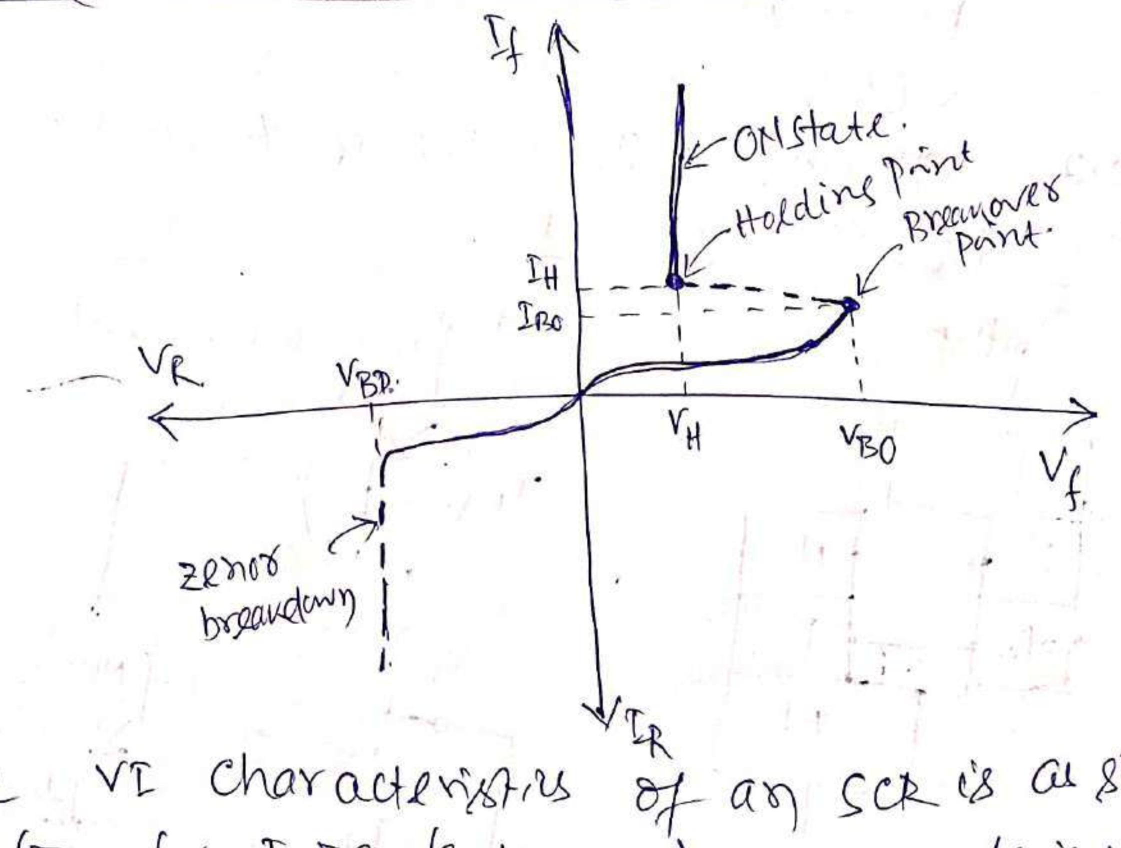
This above eqn. is for gate current $I_g = 0$, when the gate potential is applied (and so I_g, then $I_K = I_a + I_g$), putting $I_K = I_a + I_g$ in (3)

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

$$\text{Or,} \quad I_a [1 - (\alpha_1 + \alpha_2)] = \alpha_2 I_g + I_{CBO1} + I_{CBO2}$$

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

1.2.3 SCR (Static) VI-characteristics



The VI characteristics of an SCR is as shown in fig for $I_G = 0$, (gate open). When anode is made +ve w.r.t cathode and the applied anode voltage increases slowly, the characteristics is called forward characteristics.

Break over voltage (V_{BO}): it is the minimum value

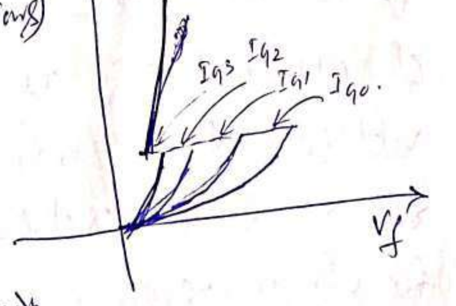
SCR conducts heavily. Current at this point is the breakover ~~point~~ current (I_{BO}).

Holding voltage: As soon as the device turns on (by breakdown of the R.B. junction J_2) after breakover the voltage across the devices drops to a minimum value and remains almost hold (or const) there where as the current increses suddenly. This point is the holding point and the corresponding voltages & current are holding voltage and holding current.

Forword current rating: There is a maximum value of forword (anode) current which the SCR is capable of passing without destruction. This is called the forword current rating (I_F). Typical values are 30A to 100A.

when anode is made -ve w.r.t. the cathode, the characteristic is called reverse characteristic and increasing reverse current, avalanch break down takes place and the SCR starts conducting heavily in reverse direction.

Now appling a gate potential (and hence gate current I_g (large) and increasing it, the breakover will takes place earlier as the applied +ve gate voltage along with applied anode voltage, makes the RB junction J_2 to breakdown. This is shown in the forword characteristics.

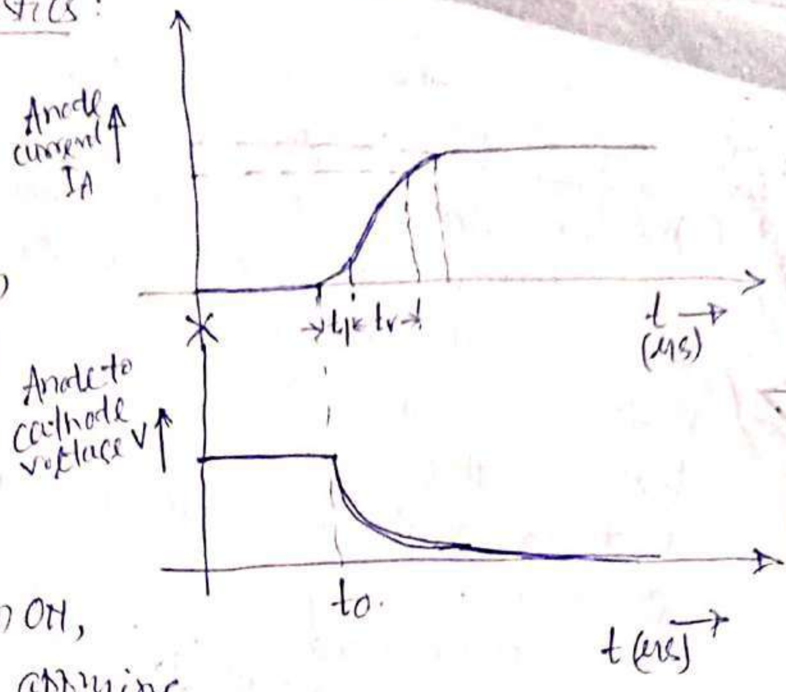


Dynamic characteristics of SCR.

Dynamic characteristics of SCR can be explained in two parts a) turn on characteristics b) Turn off characteristics

a) Turn ON characteristics:

Turn ON characteristics shows the form of current rising during transition from OFF (Non conducting) to ON (conducting) state.



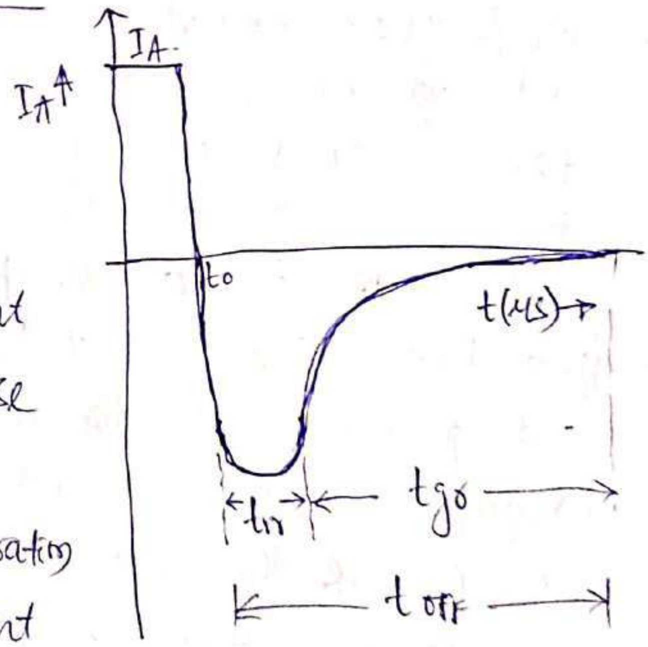
time t_0, indicates the initiation of turn ON, which is caused by applying a step voltage to the gate.

t_d is the delay time and t_r is the rise time.

The total ON time $\boxed{t_{on} = t_d + t_r}$

b) Turn OFF characteristics

This characteristics shows the form of current transition from ON to OFF state.



t_0 indicates the instant of application of reverse voltage. t_{rr} (reverse recovery time) is the duration for which recovery current flows after the application of reverse voltage. t_{gr} (recombination time) is the time required for the recombination of all excess carriers in inner two layers of the device.

$$\boxed{t_{OFF} = t_{rr} + t_{gr}}$$

Applications of SCR (1.2.4)

Some of the important applications of SCR are -

1. As a converter (conversion of ac to dc voltages)
2. As inverter (conversion of dc to ac voltages)
3. As chopper (fixed dc voltage converted to variable dc voltage).
4. cycloconverter (ac at one frequency f_1 is converted into ac at other freq. f_2, where $f_1 > f_2$)

Some other common applications are -

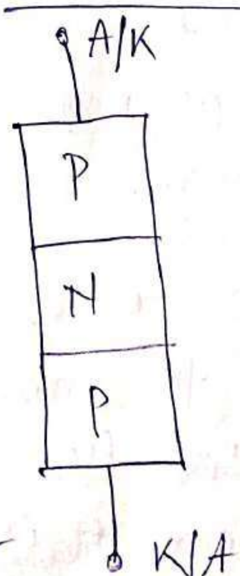
(a). Speed control of ac motors.
(b). Speed control of dc motors.
(c). voltage regulator (d). Heater control.
(e). phase control. (f) regulated power supply.
(g) Ac ckt breaker (h) dc circuit breaker.

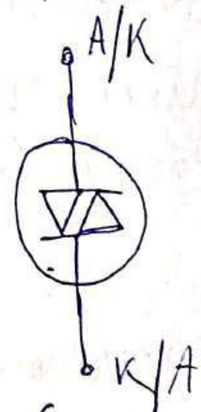
1.3. DIAC

Di means two and ac means alternating current. Hence DIAC is a two terminal device that can be operated in ac.

1.3.1 Construction, operation & VI characteristics.

It is an alternate PNP, 3 layer, two terminal device. The extreme layers can be alternatively used as anode (A) or cathode (K). It is a bidirectional device so it can conduct in either direction.





Symbol

OFF state. when the applied voltage is

The switching from off to ON state can be achieved diac by simply exceeding the avalanche breakdown voltage in either direction. from structural features and

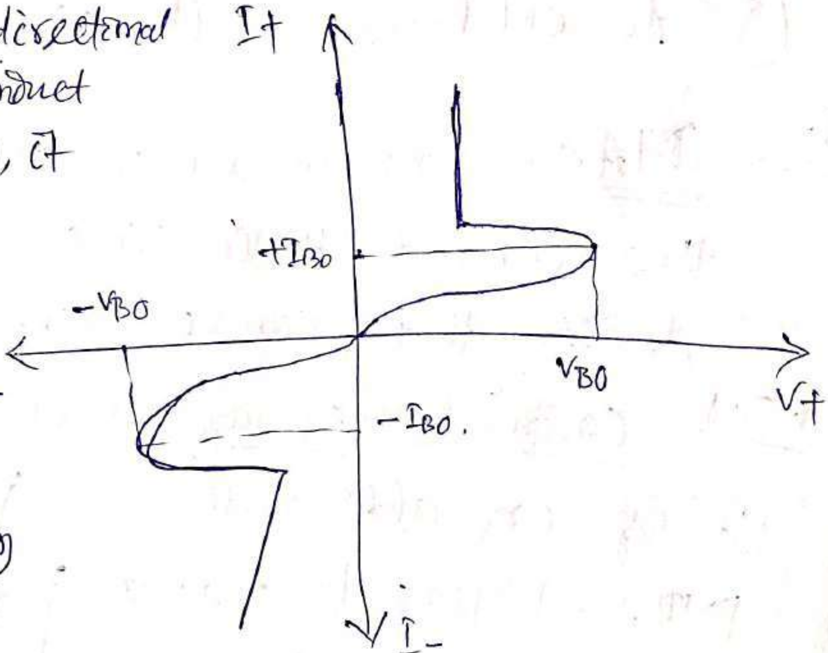
2 logic symbol it is seen that, it can be considered as an inverse parallel connection of two SCRs without control gate.

The structure of DIAC is some what like that of a transistor, except the following factors —

1. No terminal is attached to the base.
2. Unlike a bipolar transistor, the doping concentrations are identical so that the device may give symmetrical properties.

Operation and VI characteristics

As this is a bidirectional device i.e, it can conduct in either direction, it has symmetrical characteristics both in forward and in reverse directions as shown in the figure.



When a voltage (+ve or −ve) is applied less than the breakover voltage VBO, a leakage current IBO flows through the device. This leakage current is due to drift of holes & electrons in the depletion region. This current is not sufficient to cause conduction and device

remains in OFF state. When the applied voltage is (8)
equal to or greater than the breakover voltage, the diac begins to conduct due to avalanche breakdown of the reverse biased junction. The diac current rises sharply as shown in the figure. In the ON condition, the voltage across the Diac decreases with increase in current. Thus the Diac offers a -ve differential resistance.

1.3.2. Diac Applications

a. As a trigger device in triac power control systems.

b. As a lamp dimmer.

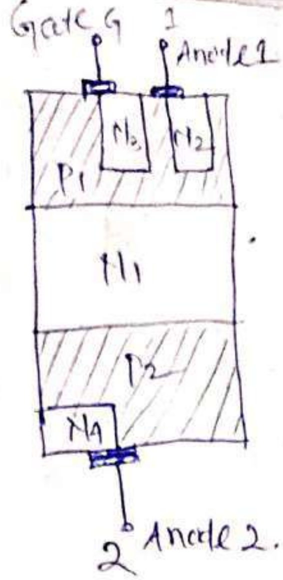
1.4 TRIAC

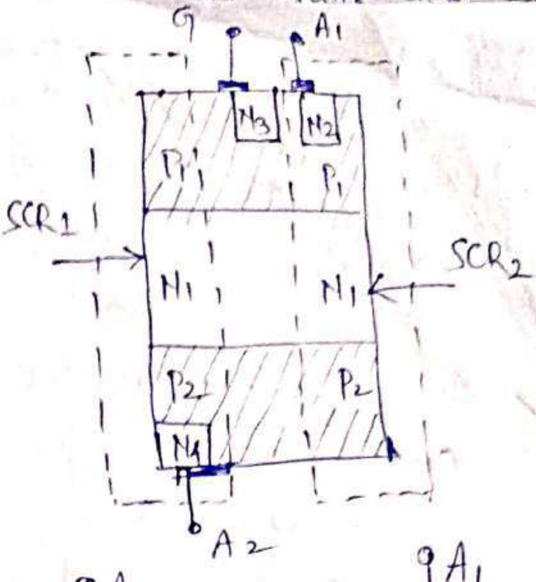
SCR can conduct current only in one direction. So it can control D.C. power or only the forward half-cycle of an ac in a load. In ac systems it is necessary to control both +ve & -ve half cycles for which a triac is used. It is a 3 terminal 4 layer alternate pnp device which can conduct in both directions.

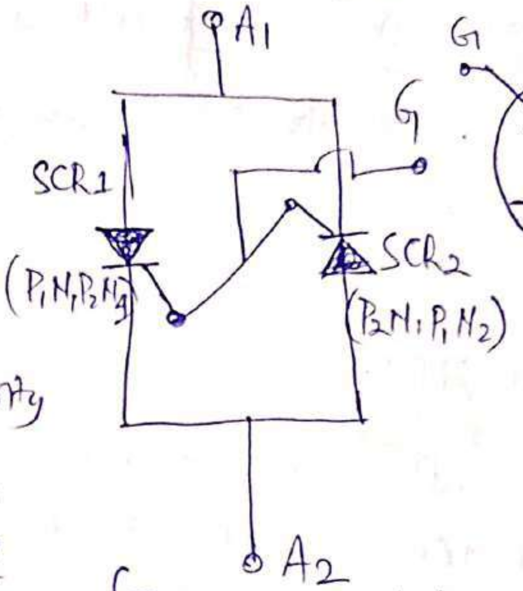
1.4.1 Construction, operation & VI characteristics

In the fig (a) & (b) are shown the basic structural details of Triac. It has 3 terminals anode 1, (A1), anode 2 (A2) and a gate G. Since triac responds to both +ve & -ve voltages at the anode, the concept of cathode as in case of SCR is dropped and instead electrodes 1 & 2 (or anode 1 & 2) are used.

A pulse of either polarity can make the TRIAC ON. A triac thus can be considered as two SCRs connected in parallel but in opposite direction. Gate terminal makes ohmic contacts with both N & P type material, thus allowing any polarity trigger pulse to switch ON the device in any one direction.



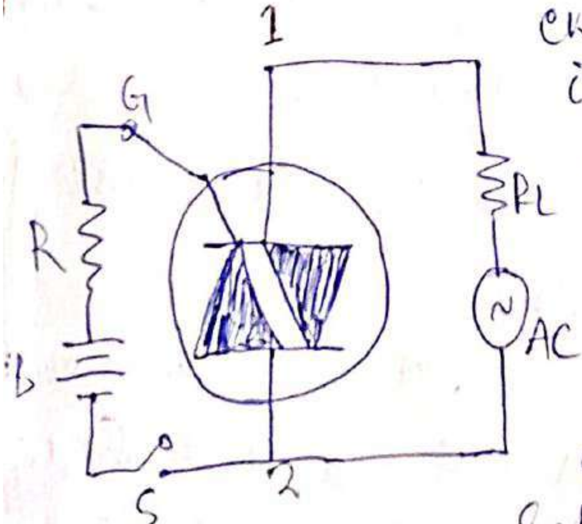




(Two SCR equivalent ckt)

(Symbol)

Operation: In the fig. is shown the simple triac ckt. The ac signal to be controlled is applied between the two anodes through a load resistance RL. The gate ckt consists of a battery B, a current limiting resistor R and a switch S. Without gate supply, the triac can be turned ON



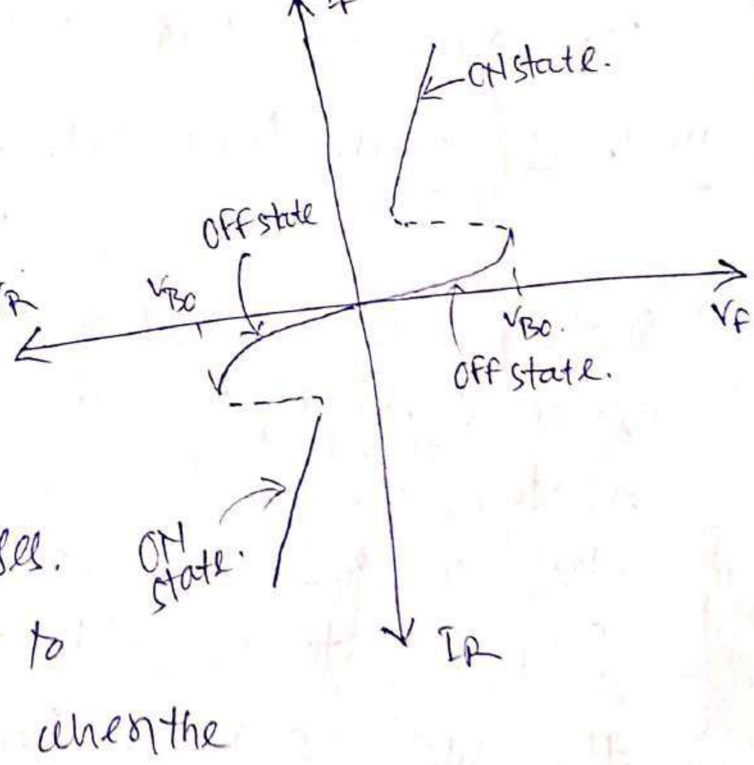
provided the supply voltage is equal to or greater than the breakover voltage. But in practice the normal way of turning ON of a triac is to apply a gate voltage.

1. Let the switch S is open., there is no gate current and the triac is OFF.

2. when switch is closed, and proper gate current flows, then either anode 1 is +ve w.r.t. anode 2 or the reverse, the following two conditions arise —

a. when anode 1 is +ve w.r.t. anode 2. triac is ON and current flows from anode 1 to 2.

b. when anode 1 is -ve w.r.t. anode 2 still triac is ON and current flows from anode 2 to 1.



Characteristics:

As the triac is a bidirectional device, it has same ON and OFF states for +ve as well as -ve applied voltages. The triac is said to be +vely biased when the anode 1. is +ve w.r.t. the anode 2 and negatively biased when anode 1 is -ve w.r.t. anode 2. The triac can be operated with a gate voltage of either polarity.

Modes of operation of TRIAC

Triac can be operated in 4 modes of operation.

mode-1 when terminal A_1 is +ve and gate voltage is +ve.

The flow of current takes place through $P_1N_1P_2N_4$ (SCR1) as A_1 is +ve w.r.t. A_2 and also the gate voltage is +ve w.r.t. A_2, the gate current adds to the anode current, so that the anode current is the sum of load current and gate current. Now increasing +ve gate potential and or anode 1 +ve potential make the device faster. The device operates in 1st quadrant of operation and is highly sensitive in this mode.

mode-2 when terminal A_1 is +ve and gate voltage is -ve w.r.t A_2

In this mode of operation, the main device current is from ~~anode to~~ terminal A_1 to A_2 through SCR1. As the gate is -ve, w.r.t A_2, the reverse gate current flows from A_2 to gate terminal opposing the main current from A_1 to A_2. The device still operates in 1st quadrant through SCR1, but it will be less sensitive than mode 1 operation.

mode-3 when terminal A_1 is -ve & gate potential is +ve w.r.t. A_2

In this case the device operates in 3rd

quadrant through the SCR_2 ($P_2 N_1 P_1 N_2$) and (4)
as the gate current is +ve it ~~adds in early breakover and the SCR_2 operates in its normal way.~~ opposes the main current and thus delaying in breakover. Thus in this mode of operation, the device is less sensitive.

mode-4 Terminal A_1 is -ve & gate voltage is -ve w.r.t A_2

The device operates in 3rd quadrant with the SCR_2 and the -ve gate voltage produces a gate current in the direction of anode current and both gets added up, thus increasing the sensitivity of the device as in case of mode 1. operation.

Hence the preferred modes of operation are mode-1 & mode-4.

1.4.3 Applications of TRIAC

1. As a high power lamp switch.
2. To control ac power to a load.
3. As residential lamp dimmers.
4. Speed control of small single φ series and induction motors.

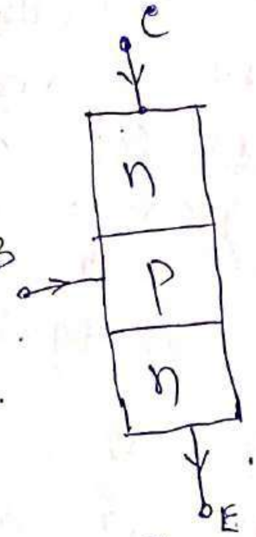
Power transistors are of 4 types
(1) Power Bipolar junction transistor or Power BJT
(2) Power MOSFET.
(3) Power Insulated gate Bipolar Tr (Power IGBT)
(4) power static induction Transistor. or power SITs

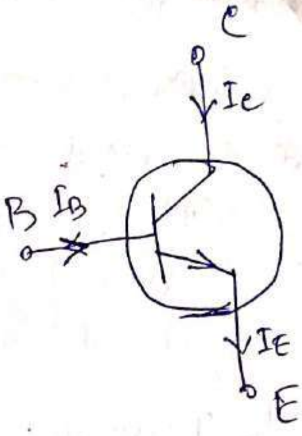
~~1.5 Power BJT.~~

1.5.1 Construction and operation of NPN power BJT:

Power transistors of npn type are easy to manufacture and also cheaper. npn type transistors are also suitable for high voltage and high current applications. out of the 3 basic configurations of CE, CB & CC, the common emitter configuration is mostly used.

In the figure is shown the basic construction details and also the symbol of an n-p-n, CE transistor configuration.





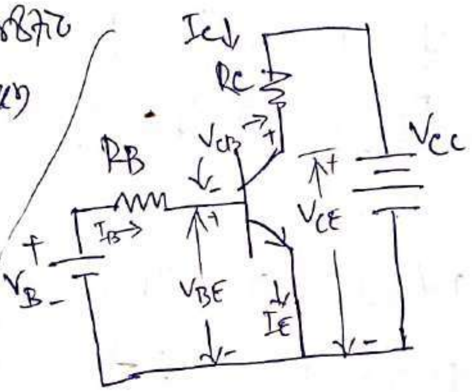
Structure   Symbol

Steady State Characteristics

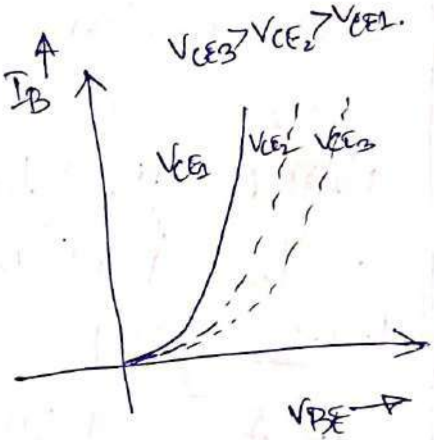
Steady state characteristics of a power n-p-n-BJT in CE configuration consists of two characteristics -

a) Input Characteristics:

Input characteristic is the graph between input current I_B and input voltage V_{BE} for a fixed value of V_{CE} · output voltage.



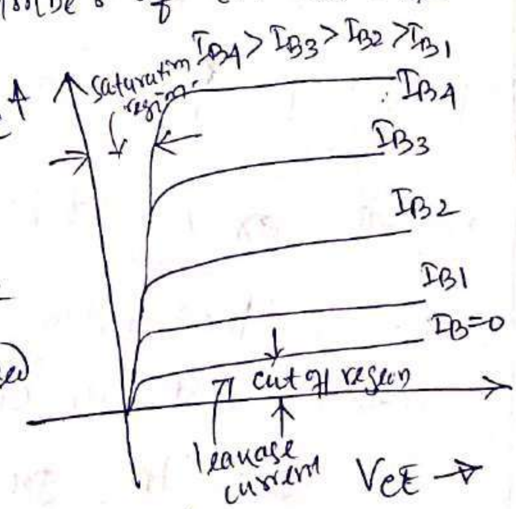
circuit connection



As the input ckt is simply a forward biased PN junction (base to emitter), the input characteristic is the forward biased diode characteristic. Now changing V_{CE} to different values, a number of ch. curves can be drawn.

b) Output Characteristics:

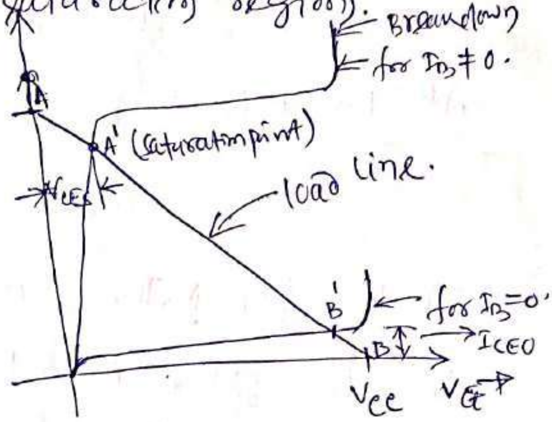
Output characteristics is the graph between output current I_C and output voltage V_{CE} for a fixed value of input current I_B.



For small values of I_B (for $I_B = 0$), the collector current is very small ($\simeq 0$). This small value of

I_C, due to the leakage current. The region till I_B is increased to a certain value, the transistor remains practically off (referred as cut-off region) after which it conducts linearly (active region). Now increasing I_B, more and more, the transistor will conduct heavily (said to be in saturation region).

Load line



In the fig. is shown the output ch. of an npn CE transistor. It consists of two characteristics, one for $I_B = 0$, other for $I_B \neq 0$.

From the o/p ckt, the current eqn. is given by –

$I_C = \frac{V_{CC} - V_{CE}}{R_C}$, at the point when $V_{CE} = 0$, $I_C = \frac{V_{CC}}{R_C}$. this is represented by point A.

Similarly when $V_{CE} = V_{CC}$, $I_C = 0$, This is represented by point B. The line joining the points A & B is called load line. The point of intersection of ch. curve with load line is called the quiscent operating points (A' & B' are operating points for the two curves respectively).

Relation between α, β.

α is called the forward current gain and is given by the ratio of output (collector) current to emitter current. $\boxed{\alpha = I_C / I_E}$

β is called the current gain and is the ratio of collector current I_C to base current I_B. $\boxed{\beta = I_C / I_B}$

From the transistor circuit, $I_E = I_C + I_B$.

or, $\frac{I_E}{I_C} = 1 + \frac{I_B}{I_C}$ or, $\frac{1}{\alpha} = 1 + \frac{1}{\beta}$.

or $\boxed{\alpha = \frac{\beta}{1+\beta}}$ or, $\boxed{\beta = \frac{\alpha}{1-\alpha}}$

almost zero, and collector current $I_C = V_{CC}/R_C$. (5)
with base current more than I_{BS}, hard drive of transistor is obtained. with hard saturation, on state losses of transistor increases.
The ratio of I_B to I_{BS} is called the overdrive factor (ODF). As practical design of the transistor is made such that I_B is much larger than I_{BS} the ODF is ~~also~~ high about 4 or 5.
The ratio of I_{CS} to I_B is called forward current gain β_f. so, $\beta_f = \frac{I_{CS}}{I_B}$ < natural current gain β or h_{FE}

The total power loss in the two junctions of the transistor is $P_T = V_{BE}I_B + V_{CE} \cdot I_C$.
under saturated condition V_{BES} is greater than V_{CES} that is B-E junction is FB. Also V_{CB} is -ve under saturated condition, that is C-B junction is also F.B. Hence under saturated condition both junctions in a power transistor are F.B..

1.5.2 Application of BJT in power switching applications

power BJT have two basic applications.

1) power switching: when the transistor is operated beyond active region (in cut off & saturation) it acts as a switch. in cutoff - it is OFF and in saturation it is ON. Hence it acts as a switch.
2) power Amplification: when operated in active region of operation, the transistor can be used as an amplifier.

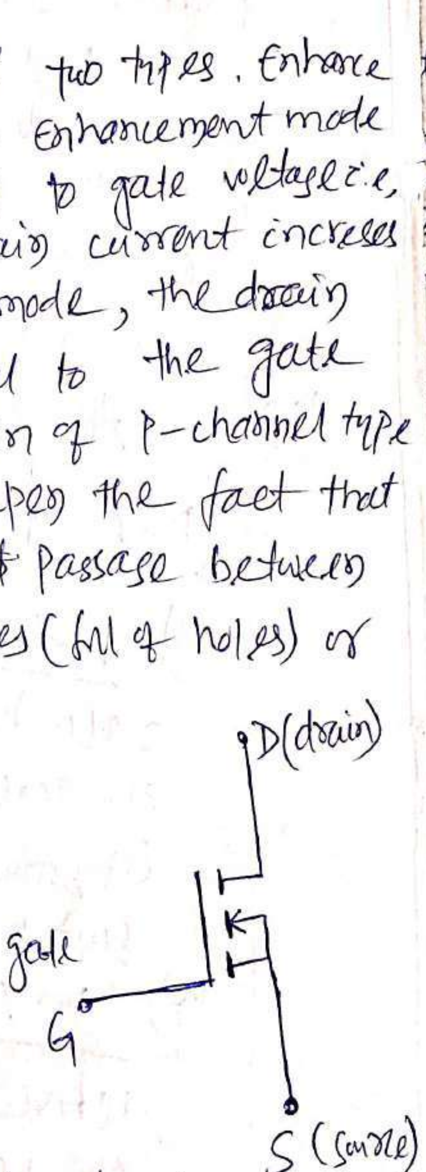
1.6 Power MOSFET. A power MOSFET (metal oxide semiconductor field effect transistor) is a 3 terminal unidirectional device. The terminals are drain (D), source (S) and gate (G). corresponding to collector, emitter and base of a BJT. In MOSFET, the current conduction is only due to majority carriers (holes in case of Pchannel and electrons in case of n channel). As the current conduction is due to the electric field (majority carriers present) of the channel, the device is called a field effect transistor FET and due to its manufacturing is done by MOS Technology it is called MOSFET.

construction and operation:

Power MOSFETs can be of two types. Enhancement mode or depletion mode. In enhancement mode the drain current is proportional to gate voltage i.e, when gate voltage increases drain current increases and vice versa. In depletion mode, the drain current is inversely proportional to the gate voltage. Each type can be again of P-channel type or n-channel type, depending upon the fact that electric field of the channel (passage between source and drain) is +ve types (full of holes) or -ve type (full of electrons).

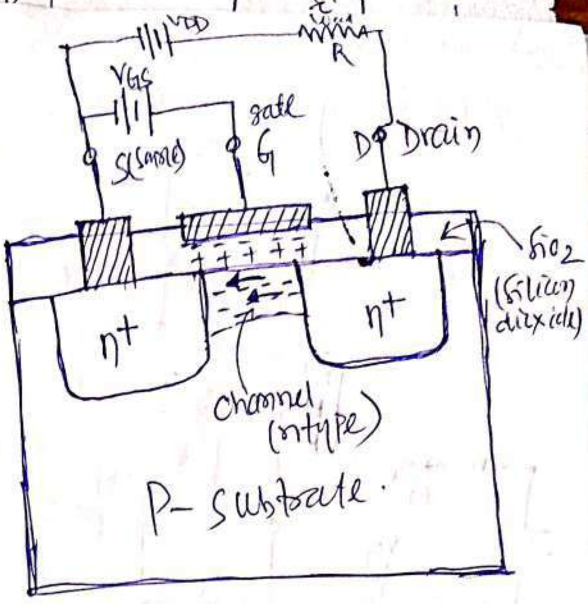
Construction:

In the fig. is shown the symbol of an n-channel enhancement mode PMOSFET in common source configuration. In the subsequent fig. is shown its basic construction details.



(n-channel enchancement mode pmosfet in CS configuration) 7

On a P-substrate, two heavily doped n+ regions are defused. An insulating layer of silicon dioxide SiO_2 is grown on the substrate. This insulating layer is etched to embed metalic source (S) and drain (D) terminals, connected to internal n^+



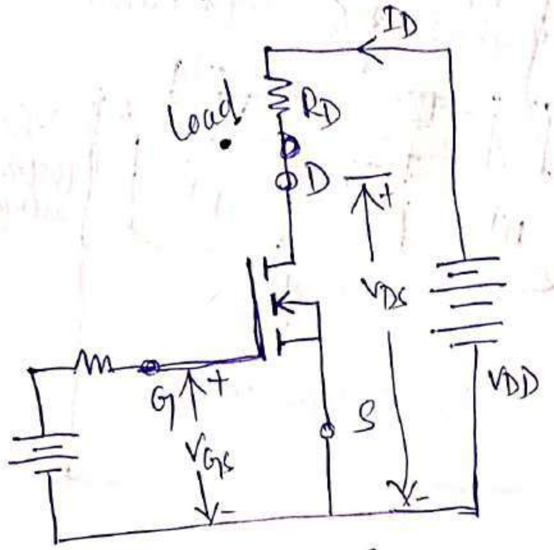
regions. The gate terminal is taken out, by depositing a layer of p type meterial above the SiO_2 layer in between source and drain.

<u>Operation</u>: when gate ckt is open, junction between n^+ regions and p substrate is reversebiased by input voltage VDD. Therefore no current flows from drain to source and through load. when gate is maid +ve w.r.t. source, an electric field is establised in the SiO_2 layer below the gate as shown by (- & +) signs. This will induce -ve charge carriers between the two n^+ regions serving as source and drain. This induced layer in the p substrate between source and drain is called the channel, as it is fully of electrons (-ve charge carriers here), this is the n-channel and the width of the channel and so the corresponding drain current I_D increses if the +ve gate to source voltage increses. Hence the name is enhancement MOSFET.

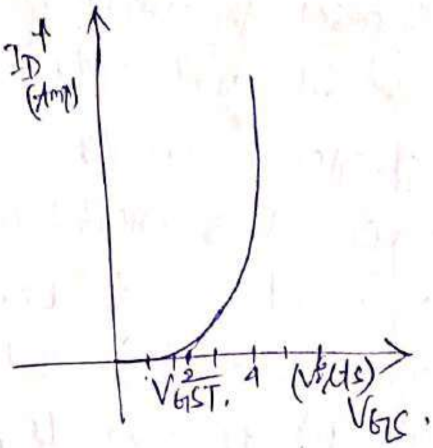
<u>PMOSFET characteristics:</u>

In order to obtain the characteristics of Power MOSFET i.e, a) Transfer ch. b) o/p ch. and

c) Switching ch., the circuit connection as shown in the fig. is taken.



(circuit connection)
n-channel enchancement
PMOSFET.

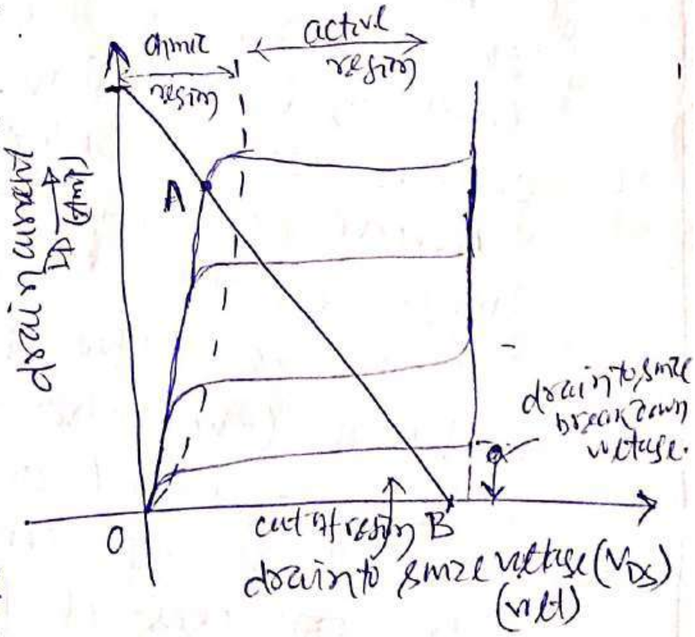


a) Transfer characteristic

a) Transfer characteristics: It is the graph between drain current I_D to gate to source voltage V_{GS} as shown in fig@. V_{GST} is called the threshold voltage which is the minimum voltage required to induce the n-channe. The chacteristic, resembles that of a forward bias diode. for gate to source voltage V_{GS} below V_{GST}, the device is OFF.

b) out put characteristics

It is the graph between drain current I_D and drain to source voltage V_{DS} with const. V_{GS}.



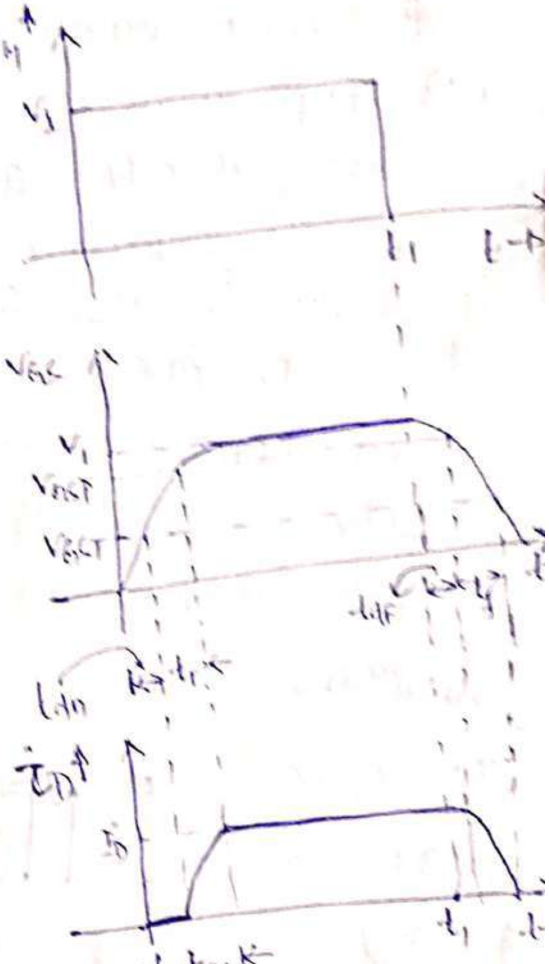
For low values of V_{DS}, the graph of $I_D \sim V_{DS}$ is almost linear producing the ohmic resistance $R_{DS} = V_{DS}/I_D$. For a fixed V_{GS}, if V_{DS} incres, the curve remains flat showing that I_D is almost const. (independant of V_{DS}).

A load line can be drawn as shown by line AB

MOSFET operates as ...
at B

When gate to source voltage is made still larger the device turned fully ON, and it acts as a closed switch (goes into ohmic region). So when the device turns ON, power MOSFET moves the characteristics traverses through cut off to active region and then to ohmic region.

c) Switching characteristics



Switching characteristic of power MOSFET is influenced by internal capacitance of the device and internal impedance of gate drive ckt.

When the device turn-ON —
the initial delay time is t_{dn}, during which the capacitor charges to threshold voltage V_{GST}. t_{dn} is called turn-ON delay time.

A further delay t_r is called rise time, during which, the gate voltage rises to V_{GSP} which is sufficient to turn ON the device, during this time drain current I_D increases from 0 to fully ON current I_D.

Thus the total turn ON time $t_{ON} = t_{dn} + t_r$

Similarly the device can be made OFF by removing the gate voltage at time $t = t_1$.

t_{df} is the turn-off delay time during which the input capacitance decreases from overdrive gate voltage V_1 to V_{GSP}. The t_f is the fall time during which input capacitance decreases from V_{GSP} to V_{GST} value.

So total Off time $t_{OFF} = t_{df} + t_f$

1.6.2 MOSFET applications:

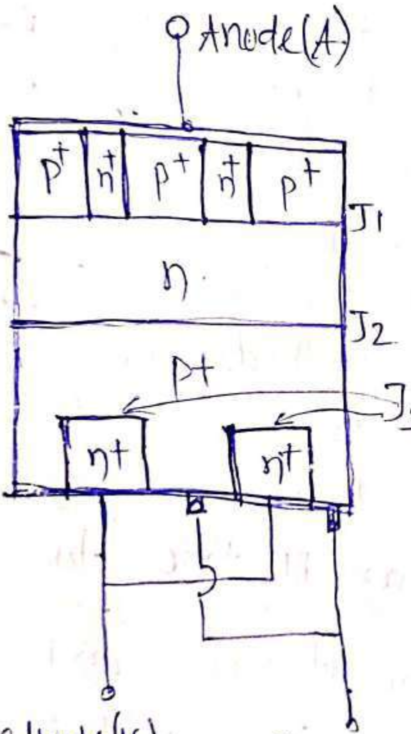
1. It is used in very high freq. switching operations.
2. It is used in SMPS.
3. It is used in convertors.

1.7. GTO (Gate turn-off Thyristor)

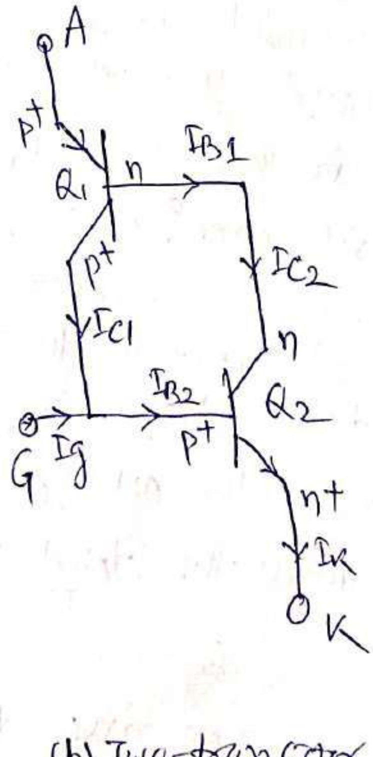
A conventional thyristor can be turned ON by applying a +ve voltage to the gate terminal but to make it off, a complex commutation circuit is used. To overcome this difficulty, a special type of thyristor is manufactured which can be turned ON by applying a +ve gate voltage and can be turned off by applying a -ve voltage to the cathode gate terminal. This device is called a gate turnoff thyristor (GTO).

Structure:

GTO is a 3-terminal 4 layer alternate PnPn device whose basic structure is as shown in fig (a).



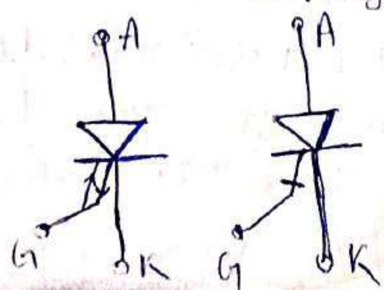
(a) Structure.



(b) Two-transistor analogy.

The four layers are p^+, n, p^+ and n^+.

Anode terminal consists of p+ material onto which

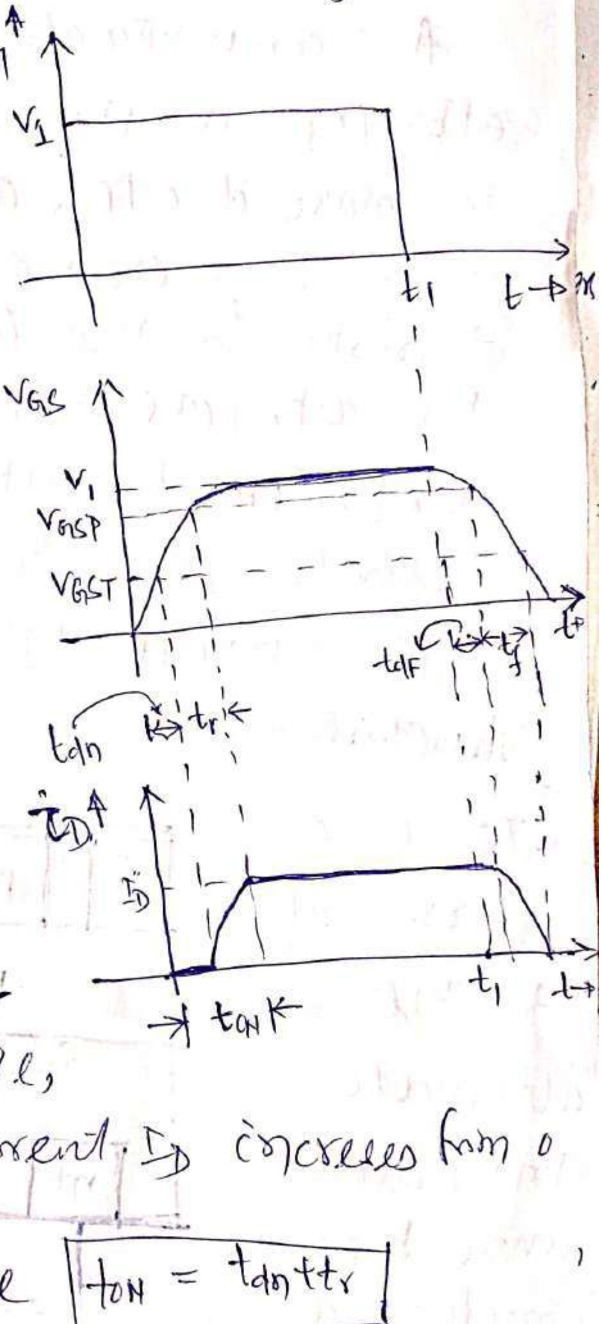


(c) Symbols

at B.

when gate to source voltage is made still larger the device is turned fully ON, and it acts as a closed switch (goes into ohmic region). So when the device turns ON, power MOSFET characteristics traverses through cut off to active region and then to ohmic region.

c) Switching characteristics



Switching characteristic of Power MOSFET is influenced by internal capacitance of the device and internal impedance of gate drive ckt.

when the device turn-ON —

the initial delay time is t_{dn}, during which the capacitor charges to threshold voltage V_{GST}. t_{dn} is called turn-ON delay time.

A further delay t_r is called rise time, during which, the gate voltage rises to V_{GSP} which is sufficient to turn ON the device, during this time drain current I_D increases from 0 to fully ON current I_D.

Thus the total turn-ON time $t_{ON} = t_{dn} + t_r$

Similarly the device can be made off by removing the gate voltage at time $t = t_1$.

t_{df} is the turn-off delay time during which the input capacitance decreases from overdrive gate voltage V_1 to V_{GSP}. The t_f is the fall time during which input capacitance decreases from V_{GSP} to V_{GST} value.

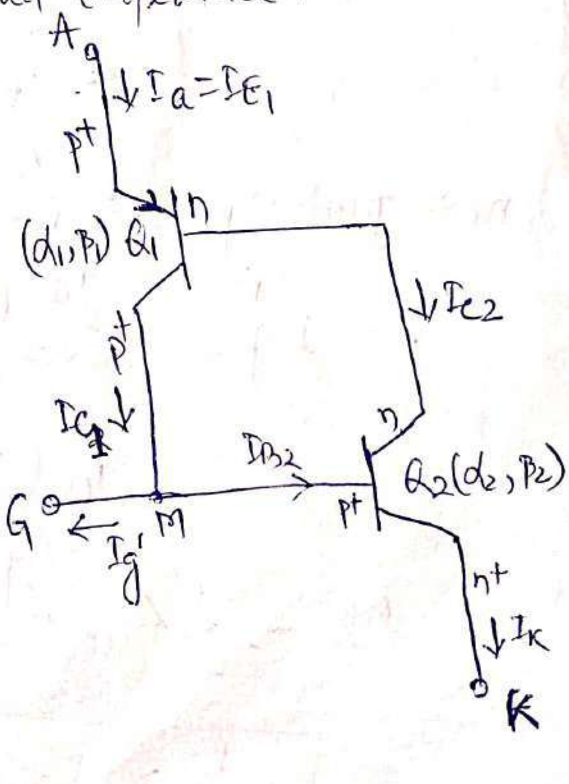
n+ type fingers are diffused ... form two n+ materials diffused into the p+ material and the two islands are shorted. Gate terminal is taken from the, 3rd p+ layer nearing the cathode and so called cathode gate. The two transistor equivalent ckt. is shown in (b), Transistor Q_1 is a pnp type consisting p+, n & p+ layers whose collector is the base to transistor Q_2 and also provides the gate terminal of GTO. Q_2 consists of n, p+ & n+ layers. In fig (c) is shown two alternate symbols of GTO.

Operation

a) Turn ON process: Referring to fig (b), the GTO is made turn-ON by applying a gate current (+ve) I_g as per the direction shown in fig (b). The GTO get forward biased and regeneration starts. Current gains α_1 & α_2 of the transistors Q_1 & Q_2 begin to rise and when $\alpha_1 + \alpha_2 = 1$, saturation level is reached and GTO is turned ON. The anode current I_a is then limited by load impedance.

b) Turn off process:

Let consider the two transistor eq. ckt as shown in fig. The transistors Q_1 & Q_2 have current gains (α_1, β_1) and (α_2, β_2) respectively. To initiate turn off process, the gate current I_g' as per direction shown in fig. is applied.



For transistor Q_1, $I_{C1} = \alpha_1 \cdot I_{E1} = \beta_1 \cdot I_{B1}$

and for Q_2, $I_{C2} = \alpha_2 I_{E2} = \beta_2 I_{B2}$.

applying KCL, at node M, $I_{C1} - I_g' - I_{B2} = 0$

$$\text{or } I_{B2} = I_{C1} - I_g' = \alpha_1 I_a - I_g' \quad \text{—} (1)$$

now, $I_a = I_{C1} + I_{C2}$, or $I_{C2} = I_a - I_{C1}$

$$\text{or } I_{C2} = I_a - \alpha_1 I_{E1} = I_a - \alpha_1 I_a = I_a(1-\alpha_1) \quad \text{—} (2)$$

when saturation in Q_2 occured, $I_{B2} = I_{C2}/\beta_2$. for initiating turn off process, Q_2 must brought out of saturation. This can be acomplished only if I_{B2} is made less than I_{C2}/β_2. So when $I_{B2} < I_{C2}/\beta_2$, Q_2 will shift to active region and regenerative action will take place, to turn off the GTO.

$\therefore$ for turning off Q_2 (or GTO), $I_{B2} < \frac{I_{C2}}{\beta_2}$

putting the values of I_{B2} & I_{C2} from eqns (1) & (2) —

$$\alpha_1 I_a - I_g' < \frac{1}{\beta_2}(1-\alpha_1) I_a.$$

$$\text{or, } -I_g' < \frac{1}{\beta_2}(1-\alpha_1) I_a - \alpha_1 I_a.$$

$$< \frac{I_a}{\beta_2} - I_a \alpha_1 \left(1 + \frac{1}{\beta_2}\right)$$

now putting $\beta_1 = \frac{\alpha_2}{1-\alpha_2}$ gives → ~~$I_g < \frac{I_a}{\alpha_2}(1-\alpha_2)$~~

$$- I_g' < \frac{I_a}{\alpha_2}(1-\alpha_2) - I_a \cdot \alpha_1 \left[1 + \frac{1-\alpha_2}{\alpha_2}\right]$$

$$< I_a\left(\frac{1}{\alpha_2} - 1\right) - I_a\left(\frac{\alpha_1}{\alpha_2}\right)$$

$$\text{or } -I_g' < I_a\left[\frac{1-\alpha_1-\alpha_2}{\alpha_2}\right]$$

$$\text{or } \boxed{I_g' > I_a\left(\frac{\alpha_1+\alpha_2-1}{\alpha_2}\right)}$$

In order that I_g' for turning off V_{AK} of GTO is low,
α_2 is made high nearly equal to 1, and α_1 is made low. (7)

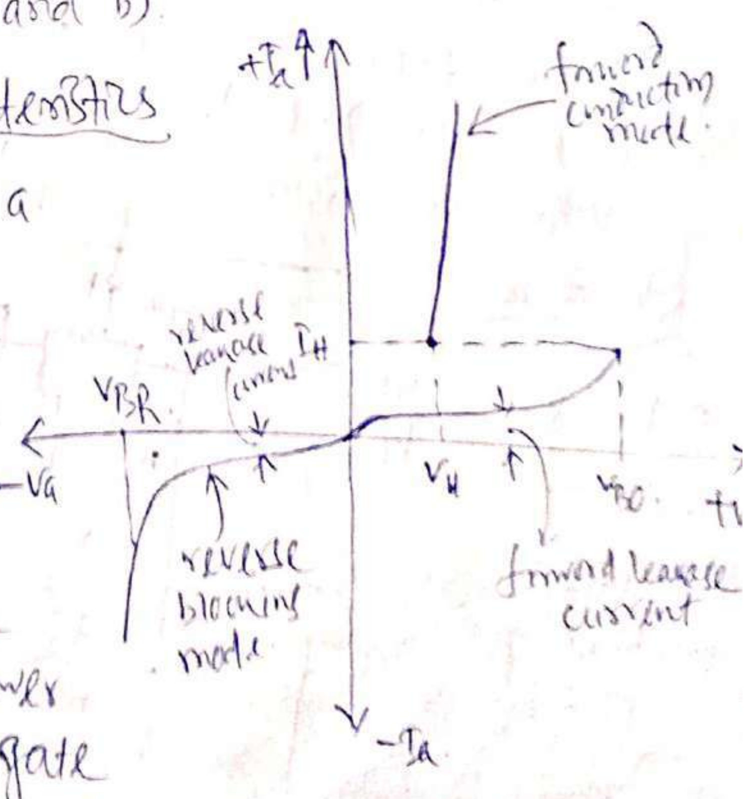
The turnoff gain of the GTO is defined as the ratio of anode current I_a to gate current I_g' needed to turnoff the device. Turnoff gain

$$\beta_{off} = \frac{I_a}{I_g'} = \frac{\alpha_2}{\alpha_1 + \alpha_2 - 1}$$

Hence to turnoff the GTO, a low value of -ve gate current is required, which requires a low value of α_1 and high value of α_2.

This low value for α_1 of transistor Q_1 can be achieved by —
a) diffusing gold or other heavy metals in n base of Q_1 transistor. The GTO is then called gold doped GTO.
b) introducing short circuited n^+ fingers in the anode p^+ layer as shown in fig (1). The GTO is then called anode shorted GTO.
c) or by employing both techniques as in a) and b).

1.7.3. V-I Characteristics



VI characteristics of a GTO is exactly identical to that of an SCR. When gate terminal is open, by increasing anode potential, the device turns ON. However by applying a -ve gate signal, breakover takes place earlier.

1.7.2. Applications of GTO.

GTOs are used in a) High frequency drive systems such as field control scheme used in rolling mills, robotics and machine tools.

b) traction purposes.

c) Adjustable frequency inverter drives.

1.8. IGBT (Insulated Gate Bipolar Transistor)

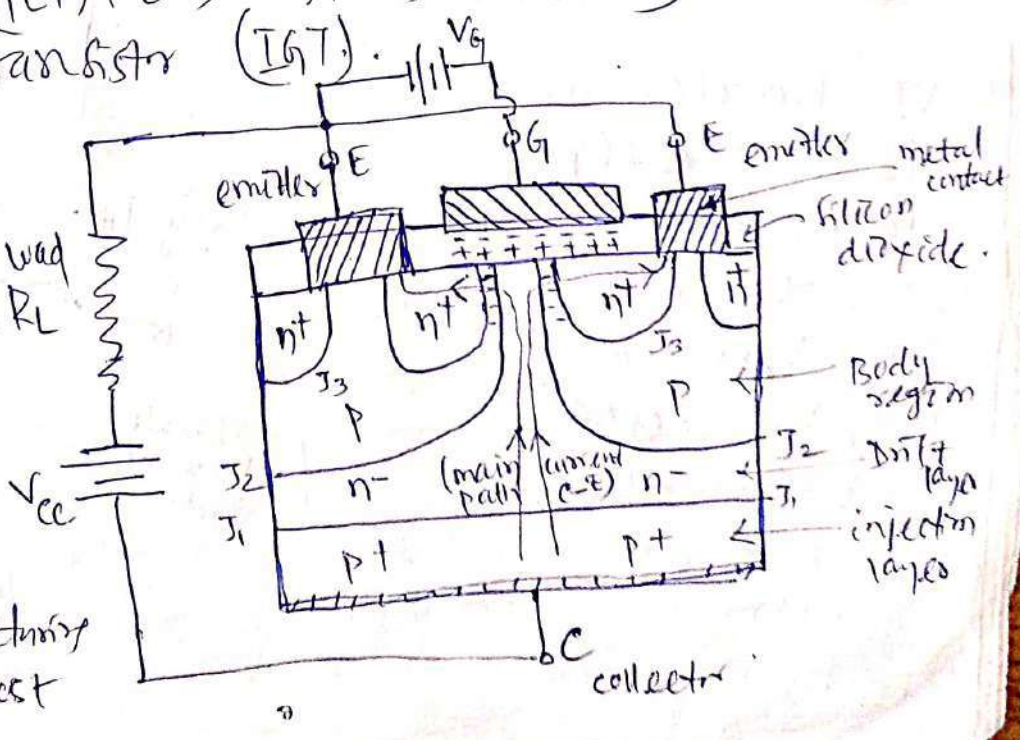
Insulated Gate Bipolar transistor IGBT is developed by combining the best qualities of BJT and MOSFET. Thus IGBT have high input impedance like MOSFET and low ON-state power loss as in case of BJT. The 2nd Breakdown problem of BJT is not their in IGBT.

IGBT is also called Metal oxide insulated gate terminal (MOSIGT), conductively modulated field effect transistor (COMFET) or gain modulated FET (GEMFET). It was initially called insulated gate transistor (IGT).

Structure.

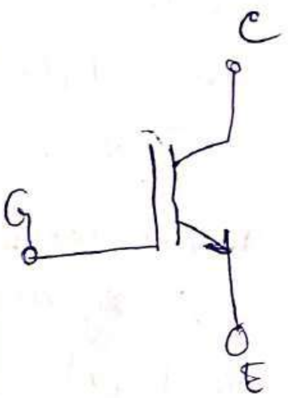
In the fig. is shown the basic structure of an IGBT.

The manufacturing process is almost

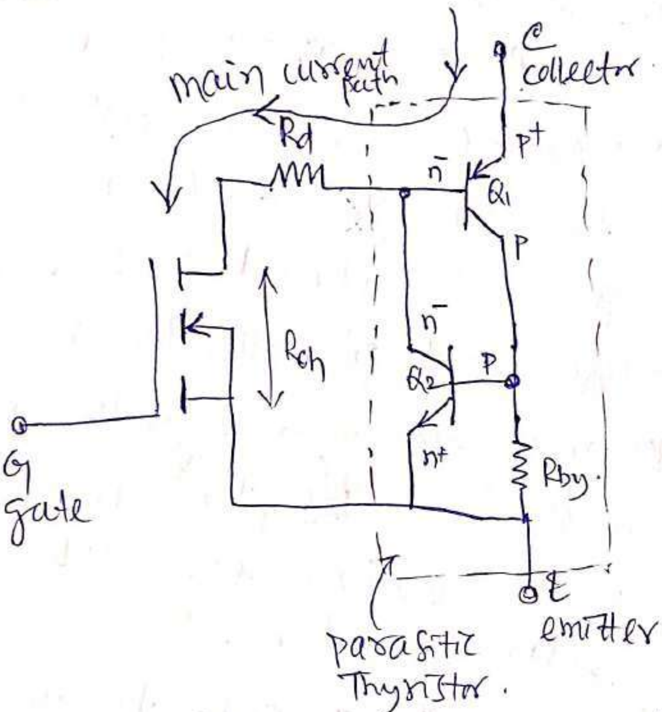


similar to that of a PMOSFET. The base is a p^+ layer substrate, acting as collector. This p^+ layer is called the <u>injection layer</u> as it injects holes into next n^--layer called <u>drift layer</u>. The thickness of the n^- drift layer determines the voltage blocking capability of the device. The p layer is called the body region. The n^- layer inbetween p and p^+ layers serves to accomodate the depletion layer of pn^- junction that is junction J_2.

<u>Equivalent ckt.</u>



(Symbol)



(Equivalent circuit)

The equivalent ckt is as shown in figure. It consists of an MOSFET along with a parasitic thyristor consisting two transistors Q_1 & Q_2. Q_1 is the p^+n^-p transistor and Q_2 is the n^-pn^+ transistor. Rch is the n-channel resistance. Rd is the resistance offered by the n^- drift region. Rby is the p type body resistance. The main current path is as shown. The next fig. shows the circuit symbol of IGBT.

Working: when collector is made +ve w.r.t. e... IGBT is said to be F.B., but junction J_2 (two J_2 junctions are there) is R.B. so the device cannot conduct.

When gate is made +ve w.r.t. emitter by the gate voltage V_G, with gate-emitter voltage (V_{GE}) more than the threshold value V_{GET}, an n-channel is formed on the upper part of p layer just below the gate contact (shown by - signs), as in case of a PMOSFET. This channel shorts the n^- region with n^+ emitter region.

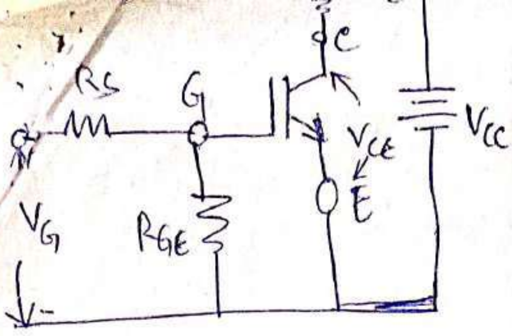
As the IGBT is FB with collector +ve and emitter -ve, p^+ collector region injects holes into n^- drift region. So the n^- drift region is flooded with electrons from P-body region and p^+ collector region. So injection carrier density of the n^- drift region increases which increases (enhances) the conductivity of n^- region with increasing +ve collector to emitter ($+V_{CE}$) supply voltage.

The IGBT gets turned ON and collector current I_C flows ON.

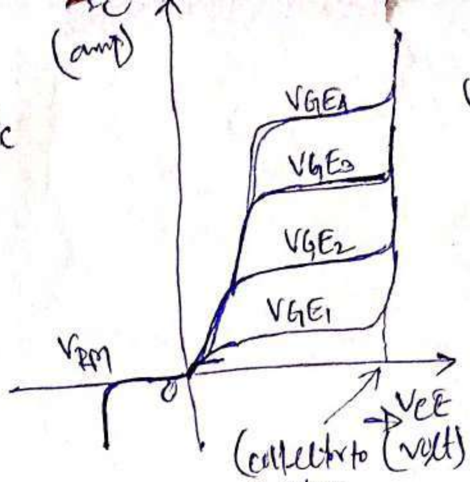
IGBT characteristics:

In the fig (a) is shown the basic circuit connection for obtaining static VI characteristic as in fig (b) and transfer characteristics as in fig (c)

The VI characteristic is obtained as the graph between collector current I_C versus collector to emitter voltage V_{CE}, keeping

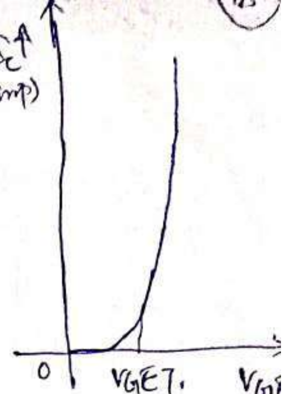


(Ckt connection)
(a)



(collector to emitter breakdown voltage)

(b) (static VI characteristics)



(c) (Transfer characteristics)

gate to emitter voltage constant. In forward direction, the characteristics resembles to that of a BJT, but the controlling parameter is the gate-to-emitter voltage V_{GE}. In reverse direction V_{RM} is the maximum reverse breakdown voltage.

Transfer characteristics is the graph between collector current I_C and gate-emitter voltage V_{GE}. It resembles to that of an n-channel enhancement mode power MOSFET.

1.8.2 Applications of IGBT.

IGBTs are used in —

1) dc & ac motor drives.
2) UPS systems.
3) Power supplies & drives for solenoid
4) Relays & contactors etc.
5) In induction motor drives.

Ch-2 SCR control Circuits.

2.1 Turn ON Methods:

Turning an SCR from its forward blocking state to forward conduction state is called turn-ON or triggering of SCR.

2.1.1. Different Methods of turn-ON.

i) Forward voltage triggering: when the SCR is forward biased i.e, anode is made +ve w.r.t cathode, junctions J_1 and J_3 are forward biased but junction J_2 is reverse biased, so the device did not conduct. But increasing the forward voltage (more than break over voltage), the junction J_2 breaksdown and the SCR, conducts. This type of triggering is called forward voltage triggering

ii) Thermal (temperature) triggering:

The width of the depletion layer of an SCR decreses with increse in junction temperature. So applying a small forward voltage and then incresing junction temperature of the reverse biased junction J_2, it will collapse and SCR will be triggered. This is called thermal triggering.

iii) Radiation (light) Triggering:

This method is only for a special type of SCR called light triggered SCRs in which a special terminal niche is made inside the inner p layer (instead of gate terminal). When light of appropriate intensity strikes this terminal, free charge carriers are generated which breaks the reverse bias junction and the device starts conducting.

iv) $\frac{dv}{dt}$ triggering: When an SCR is forward biased, junctions J_1 & J_3 are F.B. and junction J_2 is RB. This reverse biased junction acts as a capacitor.

If voltage across the capacitor is V, charge-Q and capacitance-C, then

$$i_C = \frac{dQ}{dt} = \frac{d}{dt}(CV) = C\cdot\frac{dV}{dt}.$$

So, when rate of change of voltage (dv/dt) is very large i.e., i_C is large, then the device may turn ON, even if the voltage across the device is small.

v) Gate triggering: This is the most widely used triggering process in which a small +ve voltage is applied to the (cathode) gate terminal, so that it lowers the depletion layer of the r.b. junction J_2 by injecting more charge carriers.

increasing the applied the gate voltage, the device can turn on.

2.1.2 Two general functions to be fullfilled by gate control circuit

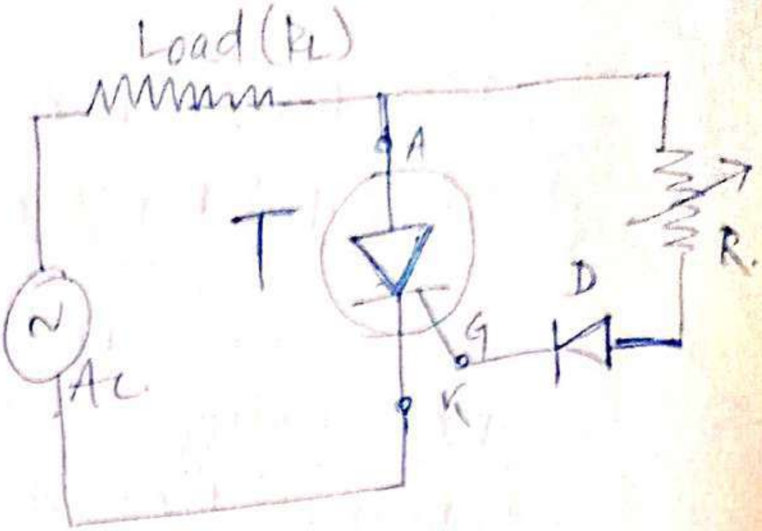
The gate control circuit also called the firing circuit must fullfill the following two functions —

1. If the power circuit has more than one SCRs, the firing ckt should produce gate pulses for each SCR at desired instant of time for proper operation of the power circuit.
   The pulses must be periodic and sequence of firing must correspond to the thyristorised power controller.
2. Before giving the voltage pulses to the firing circuit, the voltage pulses should be fed to a driver circuit, to increase its strength.

2.2. Firing circuits.

2.2.2 Resistance (R) firing circuit

In the fig. is shown the R-firing ckt. The variable resistance is used to control the gate current.

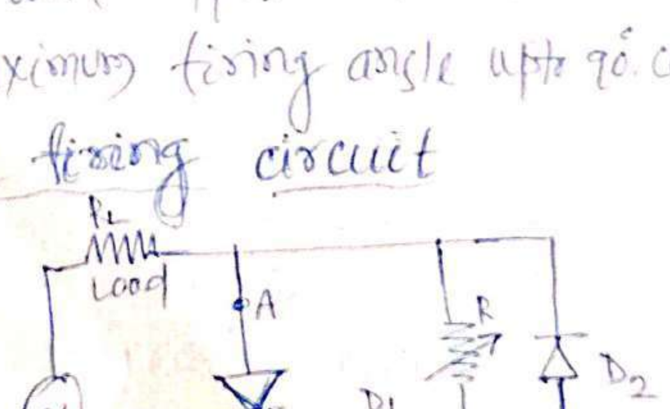


when magnitude of gate current reaches certain value (latching current of SCR, the SCR starts conducting. The blocking diode D. prevents the gate cathode junction from getting damaged in the -ve half cycle.

If the gate ckt is assumed to be purely resistive, then gate current is in phase with applied voltage. In this method maximum firing angle upto 90° can be achie

2.2.3 RC firing circuit

In the fig. is shown the RC firing circuit. During +ve half cycle of the applied ac voltage, capacitor C charges through the



variable resistance R upto the +ve peak of applied voltage. R controls the charging time. Whe

Cont... ... of +ve cu

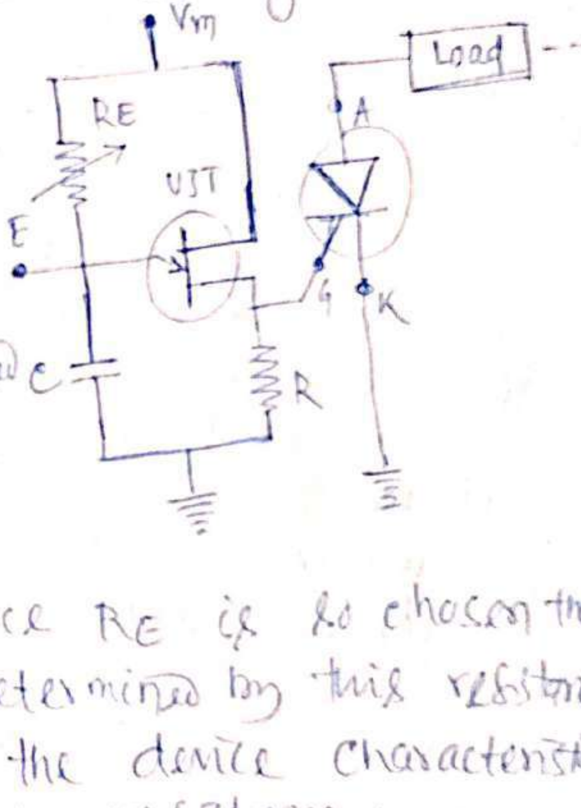
(2)

voltage across the capacitor becomes to provide sufficient gate current through diode D_1, the SCR starts conducting.

During -ve half cycle, the capacitor charges reversely through diode D_2 upto -ve peak value. Diode D_1 prevents the reverse breakdown of the gate-cathode junction of SCR, during -ve half cycle.

2.2.4. UJT-pulse triggering

In the fig. is shown the UJT-pulse triggering ckt. The unijunction transistor (UJT) produces triggering pulses which is applied to the gate of the SCR to turn it ON.

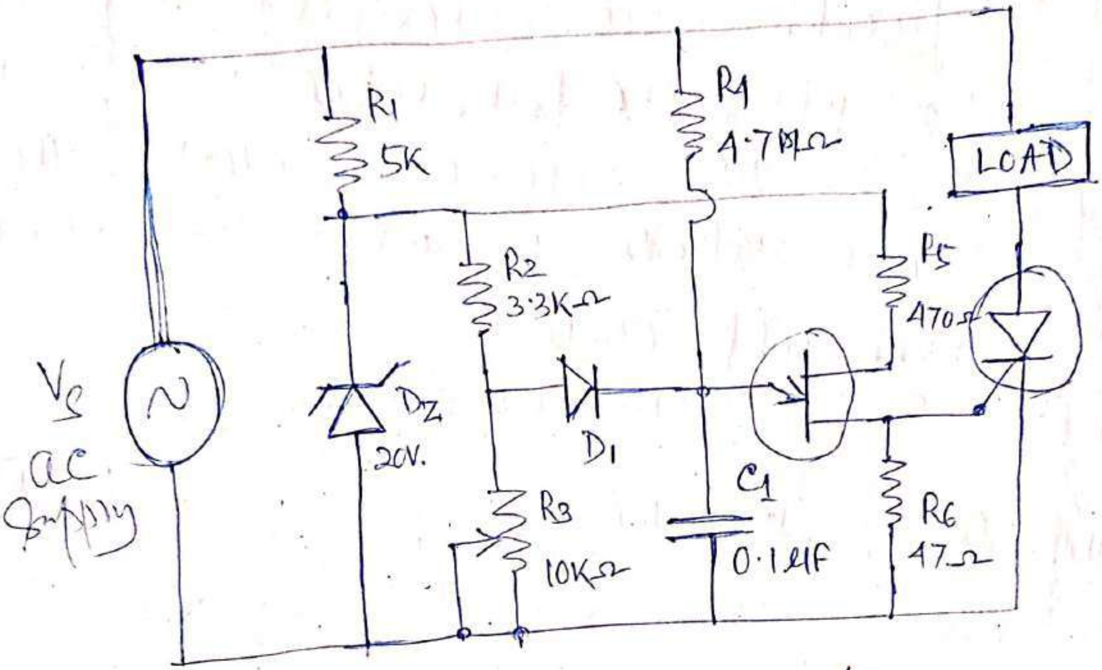


The resistance R_E is so chosen that the load line determined by this resistance R_E passes through the device characteristic curve in the -ve resistance region, between peak point (P_P) and valley point (P_V).

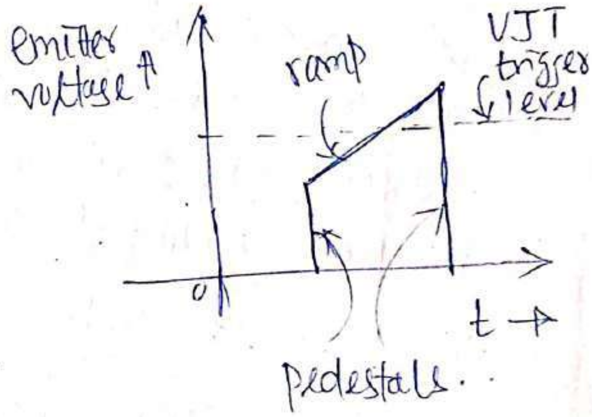
The resistance R is chosen small enough so as to ensure that SCR is not turned on by the voltage V_R (across R) when emitter terminal is open (or $I_E = 0$).

Capacitor C determines the time interval between triggering pulses and the time duration of each pulse. R_E determines the to constant ($R_E \cdot C$) and alter the points at which UJT fires.

2.2.5 Ramp-Pedestal UJT SCR control c



On the fig. is shown the UJT-SCR control circuit in which the ramp-pedestal structure of emitter voltage is utilised to produce triggering pulses.



When the supply voltage exceeds 20V. the zener diode conducts, providing a dc voltage across the base connection of UJT. At the same time diode D_1 is forward biased and capacitor C_1 charges quickly through R_1 & R_3. This represents the left hand pedestal portion of the emitter voltage once the capacitor charges to the voltage across R_3, D_1 will become reverse bia...

by origin...

the capacitor still charges but slowly through R_4. This represents the ramp portion. The capacitor will continue to charge until the UJT fires and after firing the capacitor discharges quickly through R_6. This represents the right hand pedestal. when UJT fires and capacitor discharges, the SCR turns ON. By varying the POT R_3, UJT firing angle can be adjusted.

2.3 Turn-OFF Methods.

2.3.1: Turning off an SCR is also called commutation. An SCR can not be made off, by withdrawing the forward bias voltage to zero, rather a -ve voltage is required to be applied to the anode. to overcome the reverse blocking state and can be made off.

Different, commutating methods are —

2.3.2. a) natural commutation:

By utilising the alternating, reversing nature of ac. voltage, i.e, when the applied ac voltage changes from +ve half cycle to -ve half cycle, naturaly a reverse voltage is applied to the SCR anode, to make it off. This type of commutation is called natural commutation

b) Forced commutation:

In case of dc circuits, for commutating the thyristor, the forward current is forced to become zero and then -ve) by some external circuit. This process is called forced commutation.

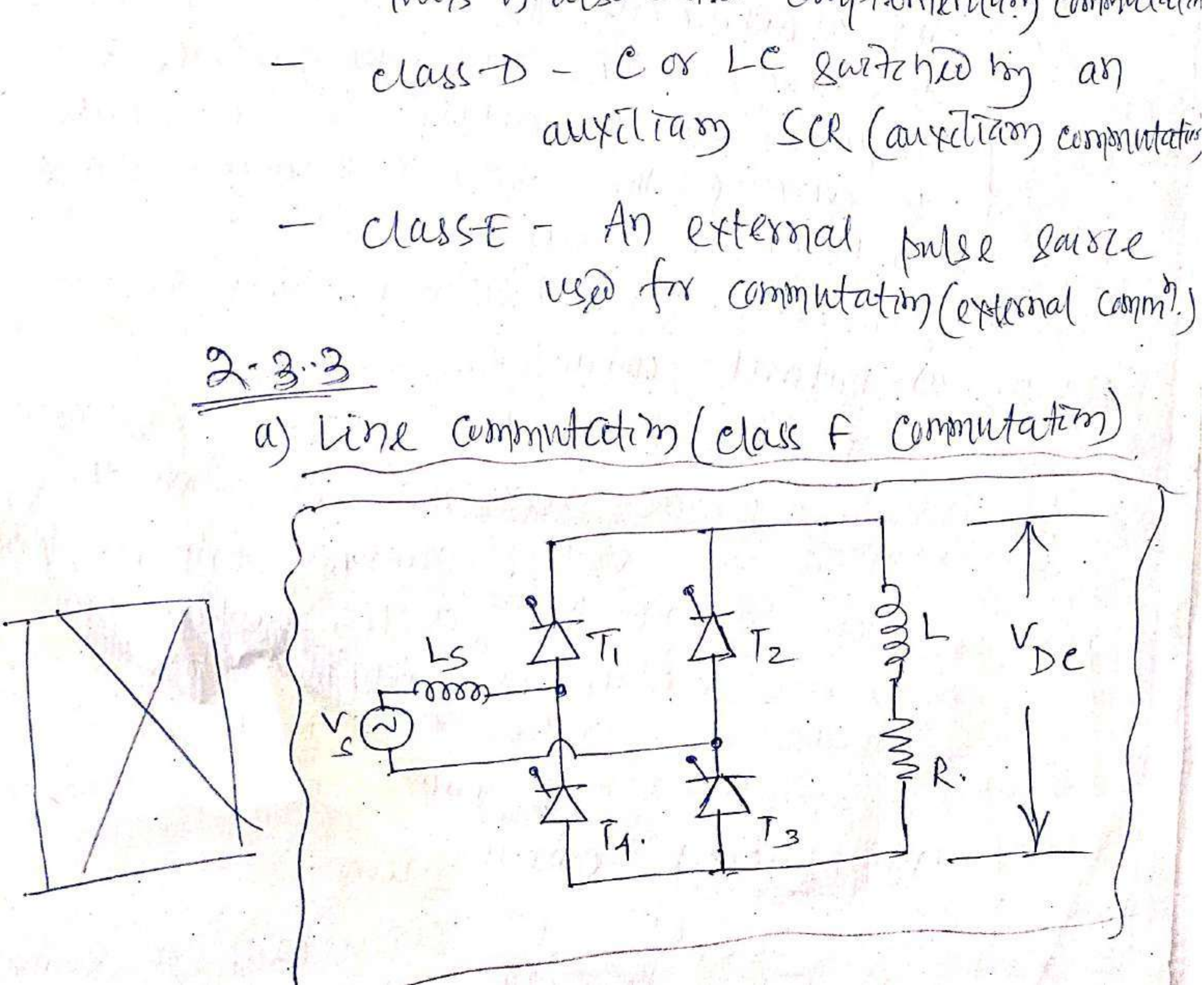
Classification of forced commutation techniques

Classification is based on the arrangement of commutating components and the manner in which '0' current is obtained in the SCR.

- Class-A - self commutated by resonating load
- Class-B - self commutated by LC ckt.
- Class-C - C or LC switched by another load carrying SCR. This is also called complementary commutation
- Class-D - C or LC switched by an auxiliary SCR (auxiliary commutation)
- Class-E - An external pulse source used for commutation (external comm.)

2.3.3

a) Line commutation (class F commutation)



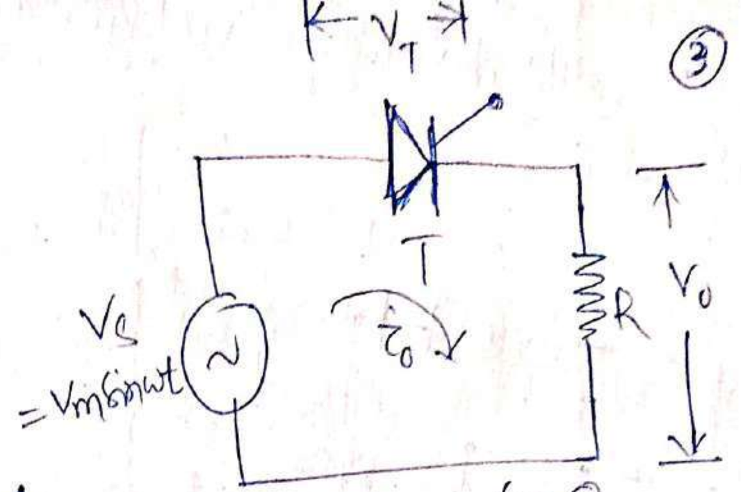


fig (a)

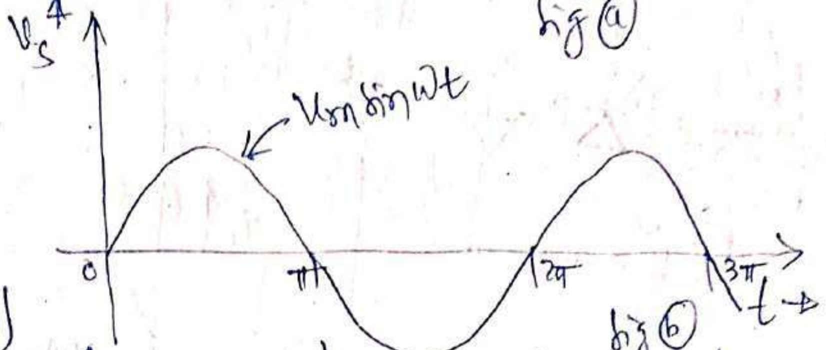


fig (b)

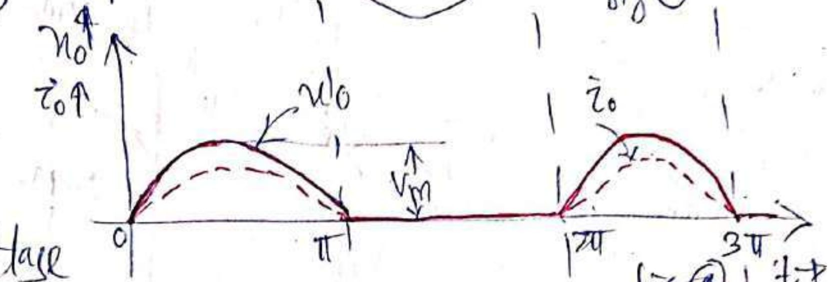


fig (c)

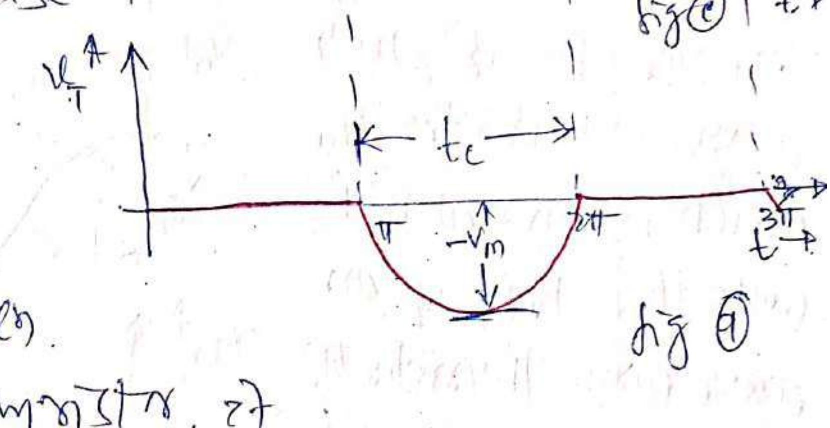
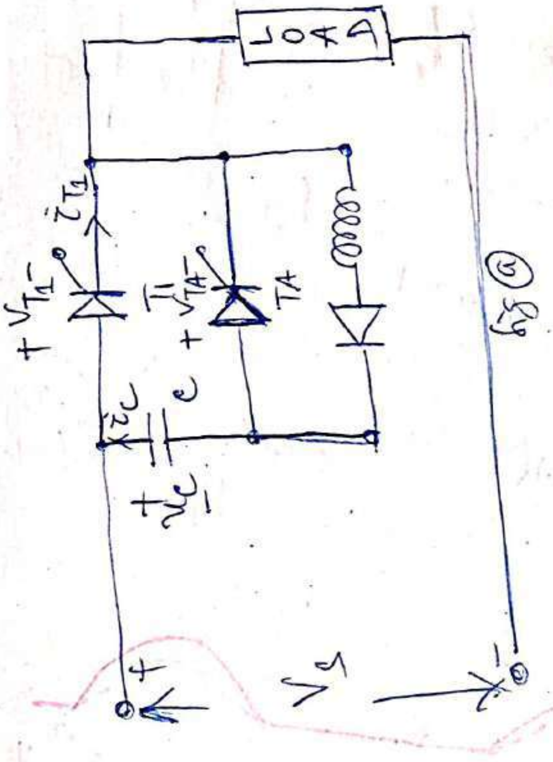


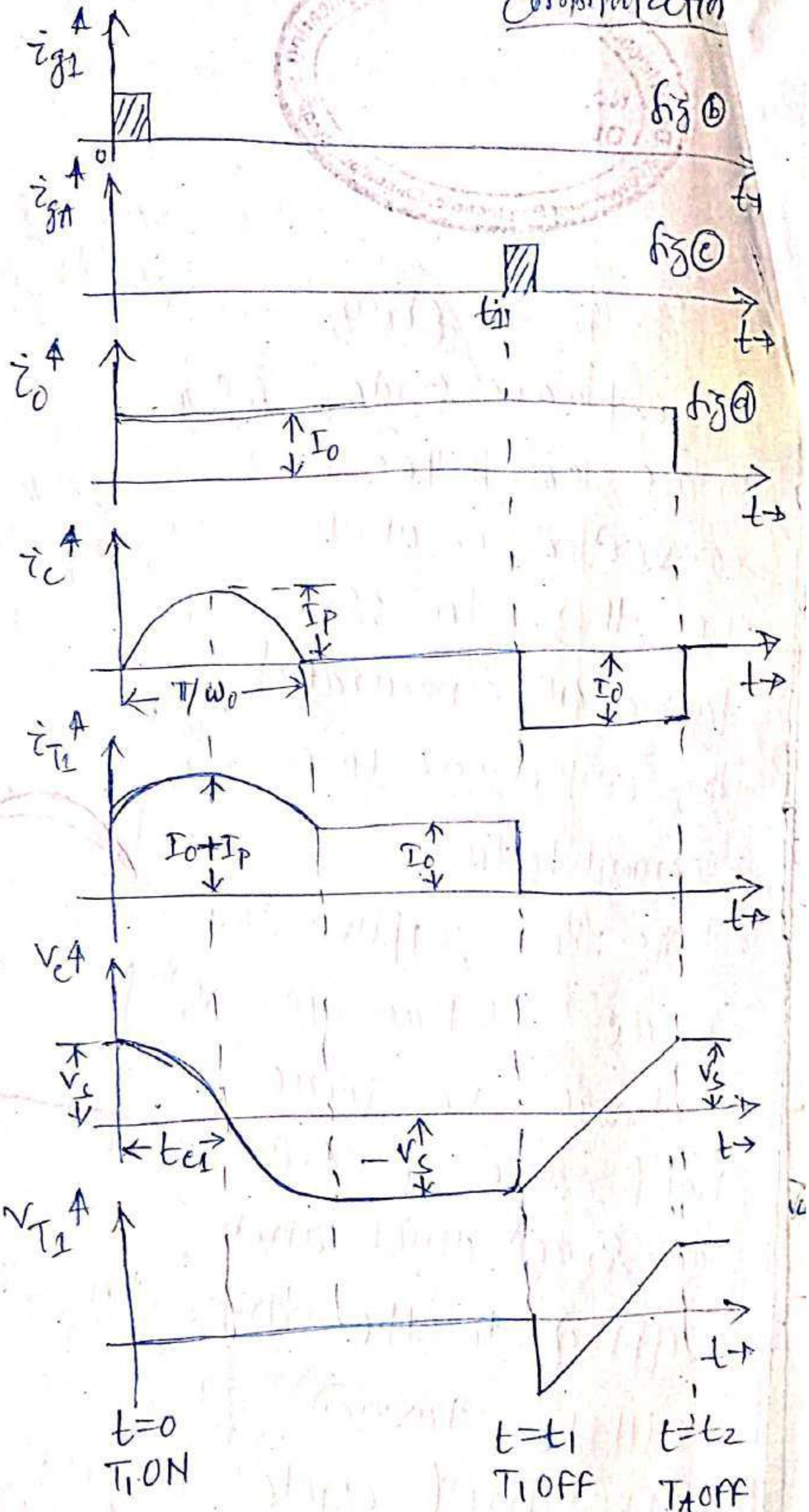
fig (d)

In fig (a) is shown a half-wave single phase controlled converter in which the thyristor is turned off (commutated) by employing line commutation.

As the supply voltage is ac, it has its natural -ve going half cycle (zero crossing) which when applied to the thyristor, it will be turned off or commutated. During the +ve half cycle it was ON assuming the firing angle to be '0'. The commutation time $t_c = \pi/\omega$ sec. When T is ON, voltage across it is zero and when OFF (during -ve half cycle of ac input), the total voltage appears across it as shown in fig (d).

(b) Auxiliary voltage commutation or class D commutation





In the fig. is shown a main thyristor T_1, which is turned off with the help of an auxiliary thyristor T_A, by applying a sudden -ve voltage at its anode. Therefore it is called Auxiliary commutation or voltage commutation.

Initialy – both T_1 & T_A are off and capacitor is assumed charged to V_s with upper plate +ve.

at time $t=0$, T_1 is triggered by applying a trigger pulse i_{g1}. Source voltage V_s applied across the load and load current I_0 flows which remains constant for a long time. when T_1 is ON an oscillatory circuit is formed with C, T_1, L & D and the capacitor current $i_c = V_s\sqrt{C/L}\sin\omega_0 t = I_p \sin\omega_0 t$ when $\omega_0 t = \pi$ (or at $t = \pi/\omega_0$), $i_c = 0$, capacitor voltage changes from $+V_s$ to $-V_s$

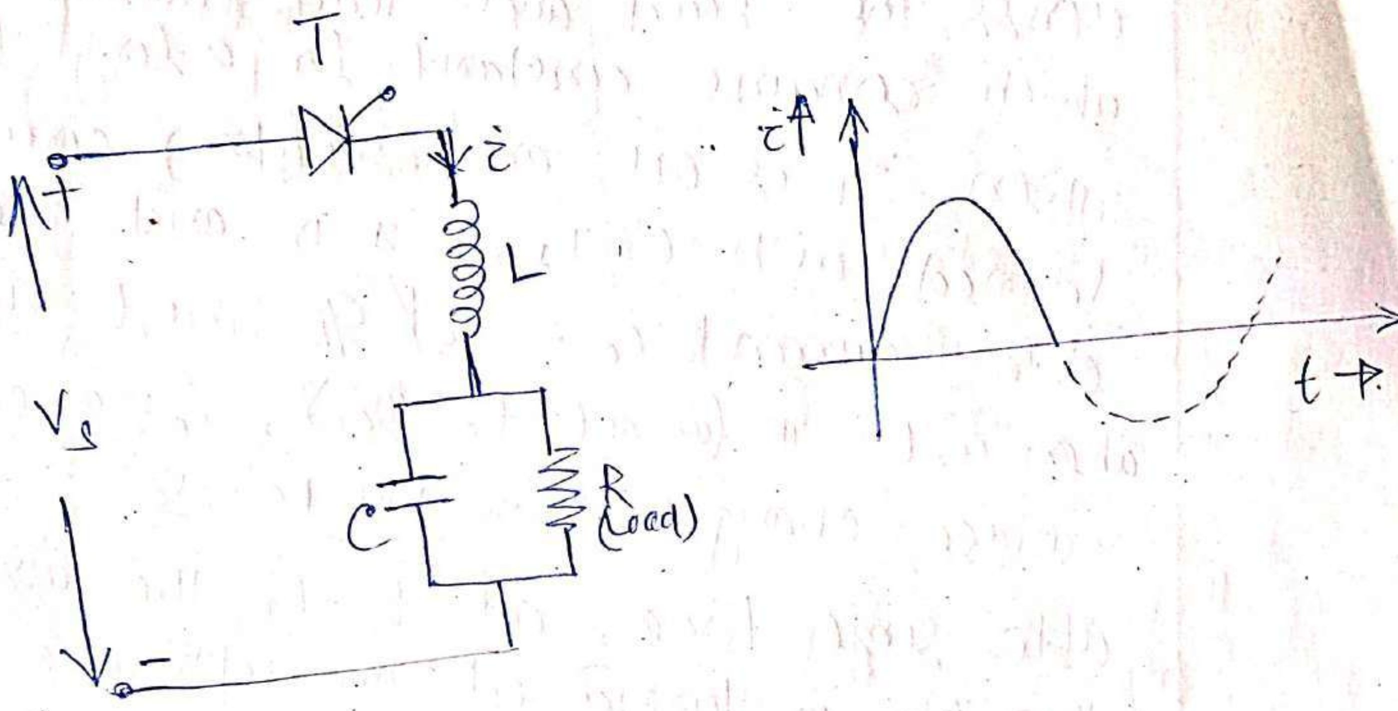
after some time, at $t = t_1$, the auxiliary thyristor is turned ON by applying a gate trigger pulse i_{gA}. The capacitor voltage $V_c = -V_s$ applied across the anode of thyristor T_1 and commutate it (OFF). so voltage across main thyristor which was $V_{T1} = 0$ from $t = 0$ to $t = t_1$, now becomes $V_{T1} = -V_s$ at $t = t_1$,

Now the load current is carried by C & T_A capacitor get charged from $-V_s$ to $+V_s$. at time $t = t_2$, when $V_c = +V_s$, the aux. thyristor TA is turned OFF.

(e) Class A or Resonant commutation:

class A or resonant commutation is also called self commutation.

In the fig. is shown the self commutated circuit with a dc voltage source and load is a resistance in parallel with a capacitance and then in series with an inductance.



The commutating components are L, R & C. The shunt capacitor shown in the fig can also be placed in series with R & L. The overall circuit is underdamped in nature.

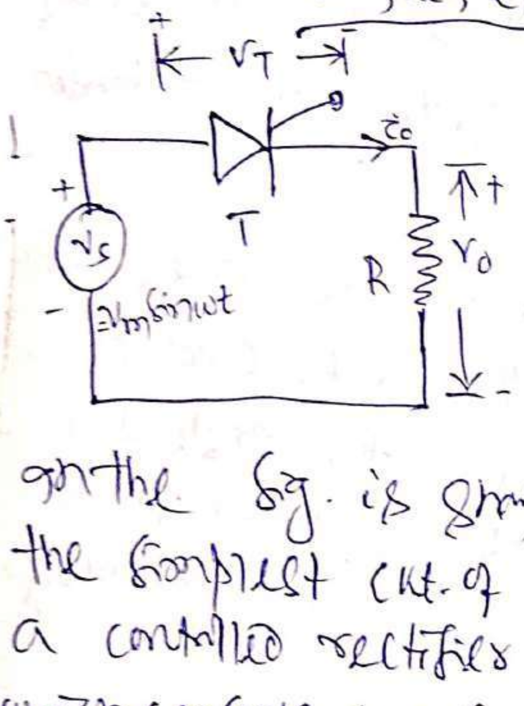
output voltage v_o is +ve when the (4)

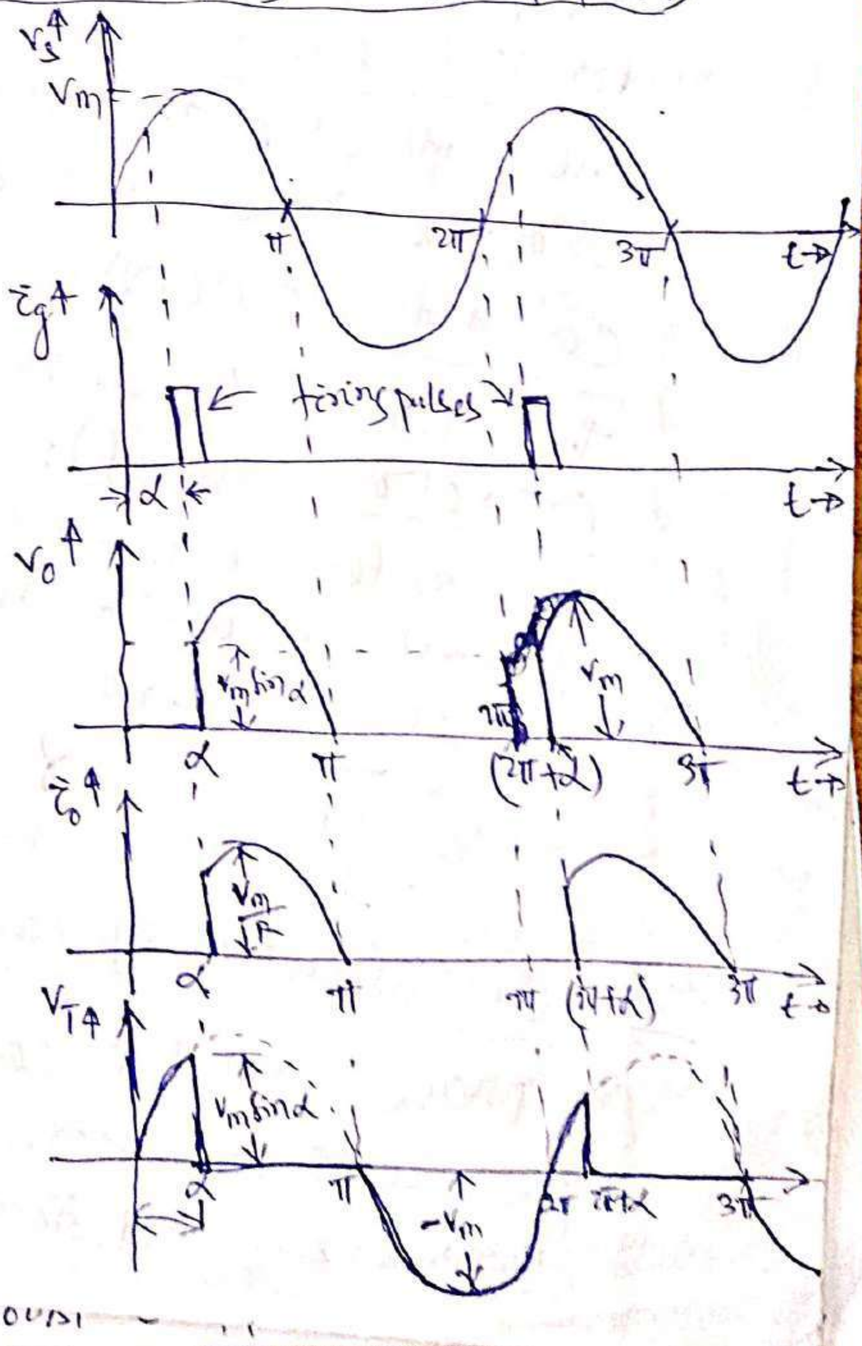
Ch-3

Controlled Rectifiers (1)

Controlled rectifiers are converters which converters ac to dc power. The ON and Off periods of the unidirectional (dc) current or voltage can be controlled by using thyristors (SCRs) as controlling circuits.

3·1 (§3.3) controlled rectifier techniques (phase angle, extinction Angle control & PWM)





In the fig. is shown the simplest ckt. of a controlled rectifier which consists of a single thyristor providing dc power to a resistive load.

During +ve half cycle of the applied voltage $v_s = V_m \sin\omega t$,

c) BUCK-BOOST

the thyristor conducts (as its anode becomes +ve w.r.t. cathode) when a triggering pulse is applied to the gate. During conduction period, the entire input voltage appears across the load. During -ve half cycle, the SCR is OFF and the reverse voltage appears across the thyristor. The waveforms shows, the input signal, gate current pulses, output voltage V_0, output current i_0 and voltage across the thyristor V_T.

<u>Firing angle (α)</u>: It is the instant between the time, the thyristor gets forward biased and the time it fires.

<u>Conduction angle (γ)</u>: It is the angle during the period for which the SCR conducts.

<u>Extinction angle (β)</u>: It is the angle, from the reference point (SCR gets F.B.) to the instant at which the SCR current extinguishes to zero.

$$\boxed{\beta = \alpha + \gamma}$$

3.2 Classification of converters:

Phase controlled converters can be classified as semi converter, full converter and dual converter. Depending upon the ac input signal, it can be either single phase or 3-phase type.

Semi converter: It is also called half wave controlled converter. It is a one quadrant converter and it has only one polarity of output voltage and current. The circuit contains thyristors and diodes. It permits power flow from ac systems to dc load.

Full converter: Full converter is a two quadrant converter. Its output voltage polarity can be either +ve or -ve but output current has only one polarity. Here power flow can takes place from Ac system to dc load (conversion) or from dc system to ac load (inversion). The rectifying elements here are only thyristors.

Dual converter: If two full converters are connected back to back, they form a dual converter. It can operate in four quadrants and both the output voltage and its current will have +ve and -ve polarities.

3.4. Integral cycle control (ICC)

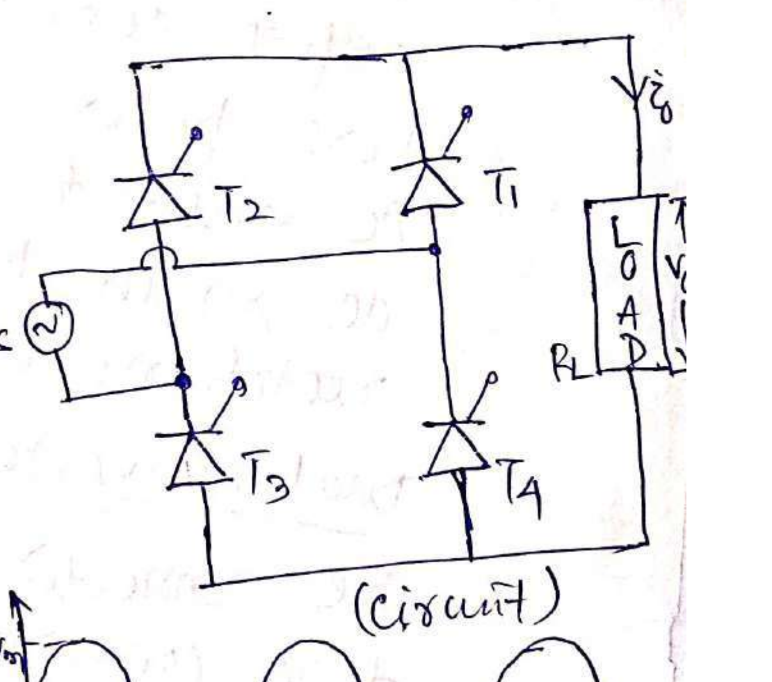
For transfer of power from source to load, two types of controls are normally used. One is ON-OFF control or integral cycle control and other is phase angle control.

In integral cycle control, thyristor acts as a switch and connects the load to ac source for a few cycles of the input voltage and disconnects it for another few cycles.

The ICC is also called burst firing or zero voltage switching or cycle selection.

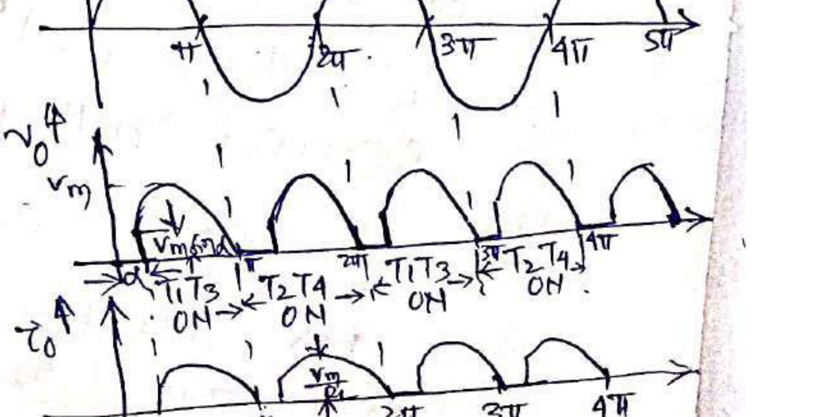
3.5. Single phase full wave controlled bridge ~~rectifier~~ converter with resistive load.

In the fig. is shown the single phase full wave controlled bridge converter with a resistive load.



(circuit)

In the below fig. are shown the input ac voltage waveform, output (load) dc voltage waveform and output (load) dc current waveform.



Operation: For +ve half cycle of the input signal, thyristors

T_1 & T_3 are fired (conducting) and thyristor (2)
T_2 & T_4 are in reverse blocking state
and so OFF. The thyristors T_1 & T_3 are
fired at angle (say α) after the reference time ($t=0$) when their anode voltage
increases from '0' to +ve values.

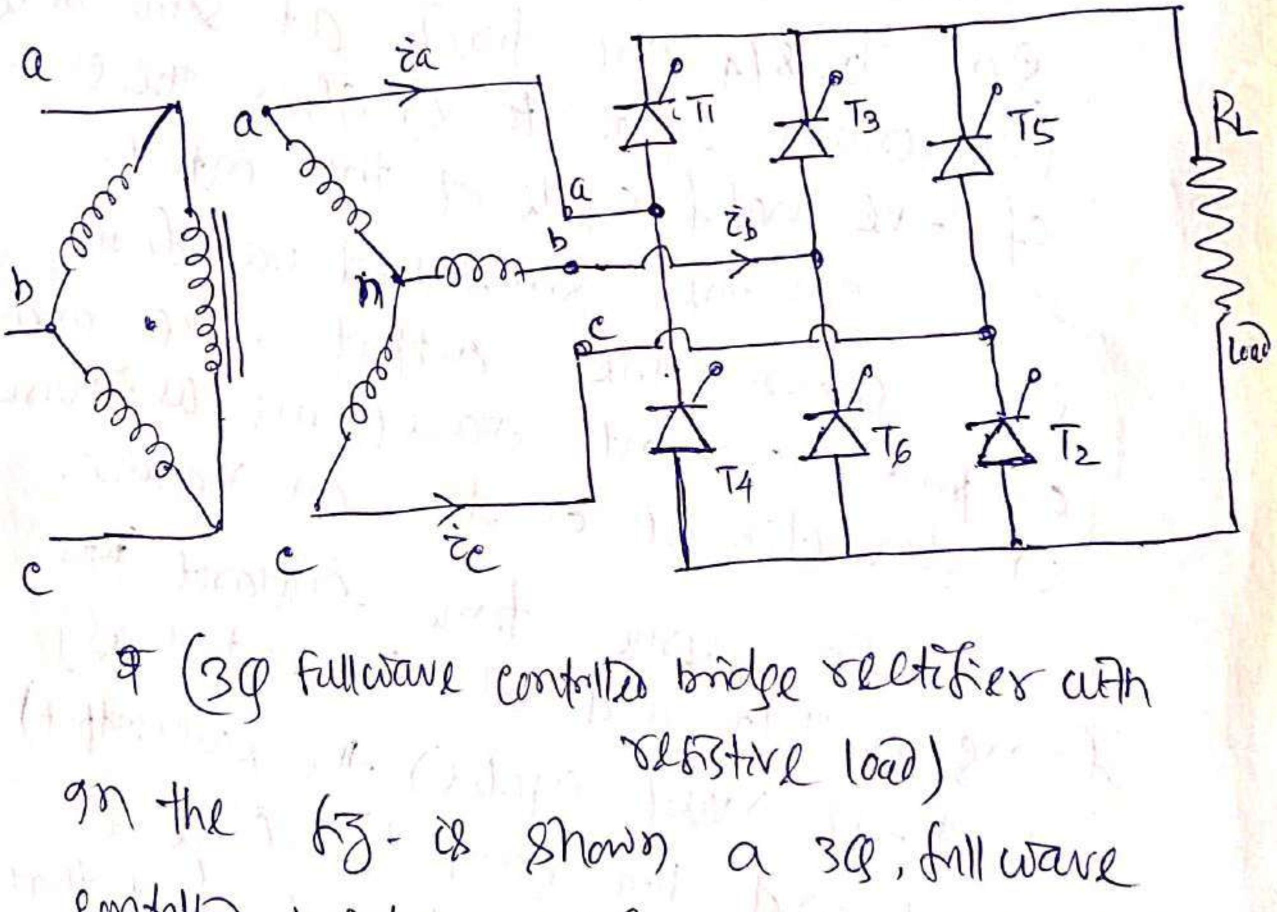
Similarly during -ve half cycle of
the input signal, the thyristors T_2 & T_4
are conducting and $T_1 T_3$ are in ~~forward~~
reverse blocking state, so OFF. The Thyristors T_2 & T_4 are fired at some angle
(preferably equal to α) after the start
of -ve half cycle of the input.

In the subsequent wave forms
are shown the output voltage and
output current waveforms, which are
unidirectional or dc in nature.

For some time instant (upto
firing of $T_1 T_3$ and $T_2 T_4$ in respectively
+ve & -ve half cycles) the load (output)
current and load (output) voltage is
zero. This is due to the fact that
during this instant both pairs of
thyristors $T_1 T_3$ & $T_2 T_4$ are all OFF.
This type of ~~conduction~~ operation is called
the discontinuous mode of operation.

In normal mode of operation, the firing angle is so controlled that the load (output) current never becomes zero (always +ve), this type of operation is called the continuous mode of operation.

3.6 Threephase (3-φ) Full wave controlled bridge converter with resistive load.



(3φ fullwave controlled bridge rectifier with resistive load)

In the fig. is shown a 3φ, full wave controlled bridge rectifier with resistive load.
The 3φ power supply can be connected to the FW bridge rectifier ckt, in
a) star connection (or in) b) delta connection.
In the fig. is shown a delta to star input system, connection of input 3φ supply.

Line to neutral voltages

Let $V_{an} = V_m \sin\omega t$

$V_{bn} = V_m \sin(\omega t - 2\pi/3)$

$V_{cn} = V_m \sin(\omega t + 2\pi/3)$

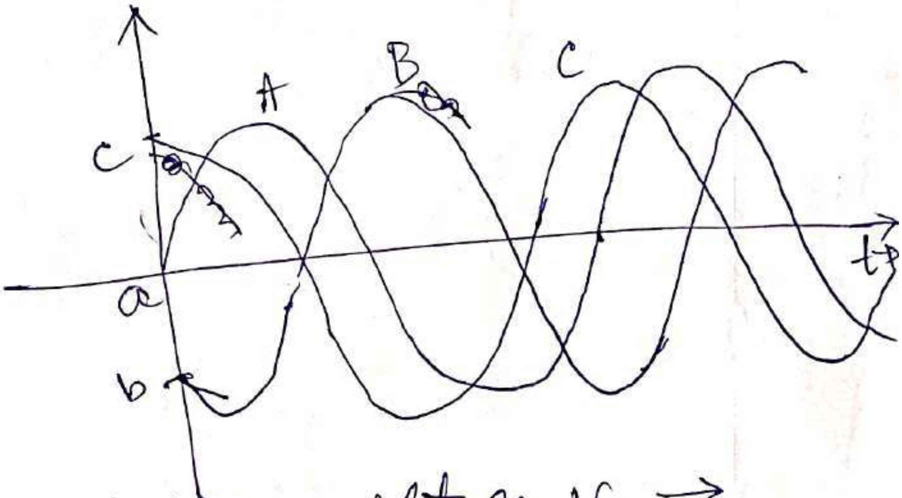
Line to line voltage is –

$V_{ab} = V_{an} - V_{bn} = \sqrt{3} V_m \sin(\omega t + \pi/6)$

$V_{bc} = V_{bn} - V_{cn} = \sqrt{3} V_m \sin(\omega t - \pi/2)$

$V_{ca} = V_{cn} - V_{an} = \sqrt{3} V_m \sin(\omega t + \pi/2)$

waveforms



During line to line voltage V_{ab} →

T_1 & T_6 are ON.

During line to line voltage V_{bc} →

T_3 T_2 are ON.

During line to line voltage V_{ca} →

T_5 T_4 are ON.

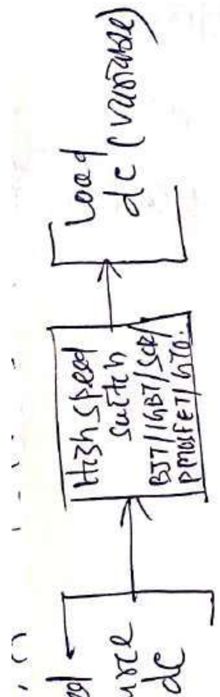
... output voltage V_0 is +ve when ...

... is greate...

CH:4 CHOPPERS

4.1. Chopper and Its applications

Chopper is a power electronic device that converts power from a fixed dc value to variable dc value. Thus chopper is a dc to dc converter



The fixed dc voltage of a dc source can be converted to a variable dc voltage on a load by putting a high speed switch between the source and the load. The high speed switch can be a thyristor or BJT or IGBT or power MOSFET or a GTO depending upon the types of applications.

Types of choppers: choppers (dc-dc convertor) are of 3 types.

a) Buck converter – is a step down chopper. which converts a fixed dc voltage to lower variable dc values.

b) Boost converter: is a step up chopper which converts a fixed dc voltage to a higher variable dc voltage.

c) Buck-Boost chopper: Mix of buck & boost types.

Applications of choppers:

- In traction motors.
- trolley cars.
- variable speed ac & dc drives.
- Battery operated vehicles.

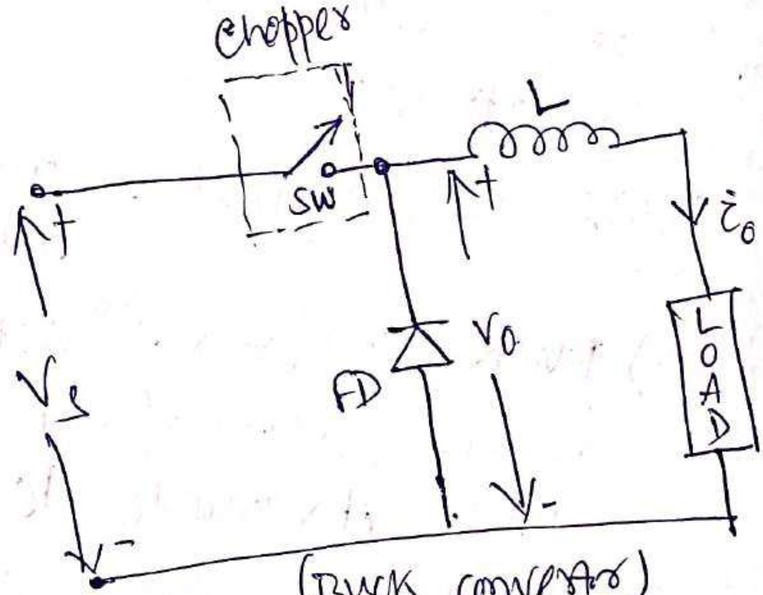
Advantages of Chopper:

It provides
- smooth speed control
- low losses
- High efficiency
- fast dynamic response
- regeneration capabilities when applied in drive control.

4.2 Principle of operation.

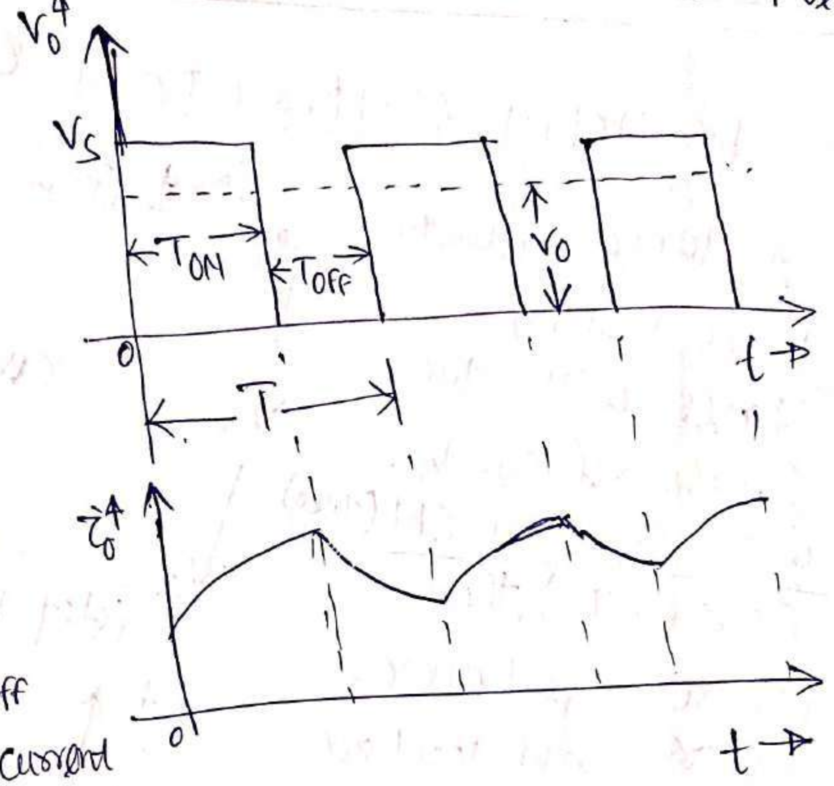
a) Step Down chopper/ Buck converter)

Basic ckt of a step down chopper is as shown in figure. It consists of a high speed switch (called the chopper) in series with an inductor and a resistive load (so to say the load is inductive ; R-L)



(Buck converter)

ltage V_0 is +ve



when switch SW remains ON, (from 0 to T_{ON} time period called ON time T_{ON}), the entire source voltage is applied to the load. So load voltage is equal to source voltage.

During OFF time T_{OFF} (from T_{ON} to T), current through the ~~inductive~~ load decreses due to the fact that high emf is induced in the inductor and the freewheeling diode (FD) ~~acts as~~ conducts and it acts as a short circuit across the load. So the load voltage is $V_0 = 0$.

So during ON time, load current increses and during OFF time load current decreses. The average load voltage is given by –

$$V_0 = \frac{T_{ON}}{T} \cdot V_s = \frac{T_{ON}}{T_{ON}+T_{OFF}} \cdot V_s = f \cdot T_{ON} \cdot V_s. \quad \text{where } f = \frac{1}{T}.$$

or $\boxed{V_0 = \alpha \cdot V_s}$ where $\alpha = \frac{T_{ON}}{T_{ON}+T_{OFF}} = \frac{T_{ON}}{T}$

called duty cycle.

value of α lies in the range $0 \le \alpha \le 1$

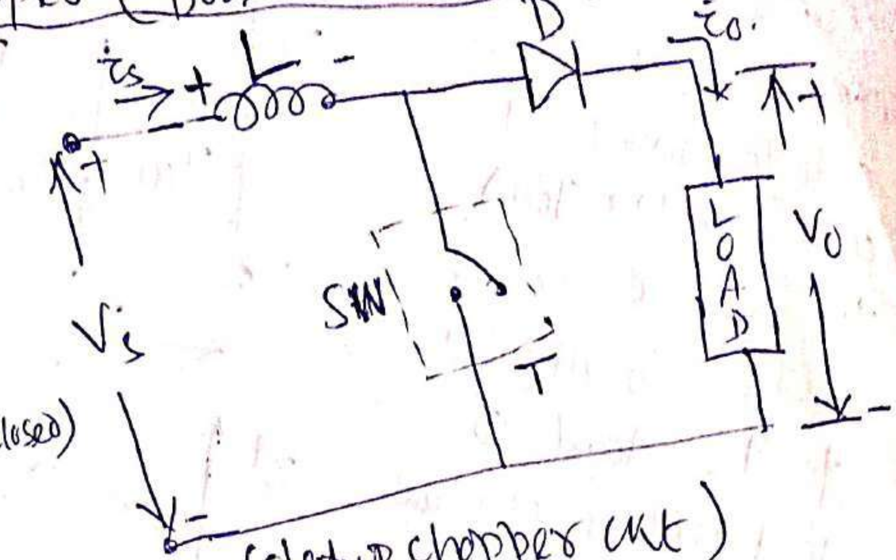
and, $T_{ON} \rightarrow$ ON time

$T_{OFF} \rightarrow$ OFF time

$T = T_{ON} + T_{OFF} \rightarrow$ chopping period.

$f = \frac{1}{T} \rightarrow$ chopping frequency.

b) Stepup chopper (Boost converter)

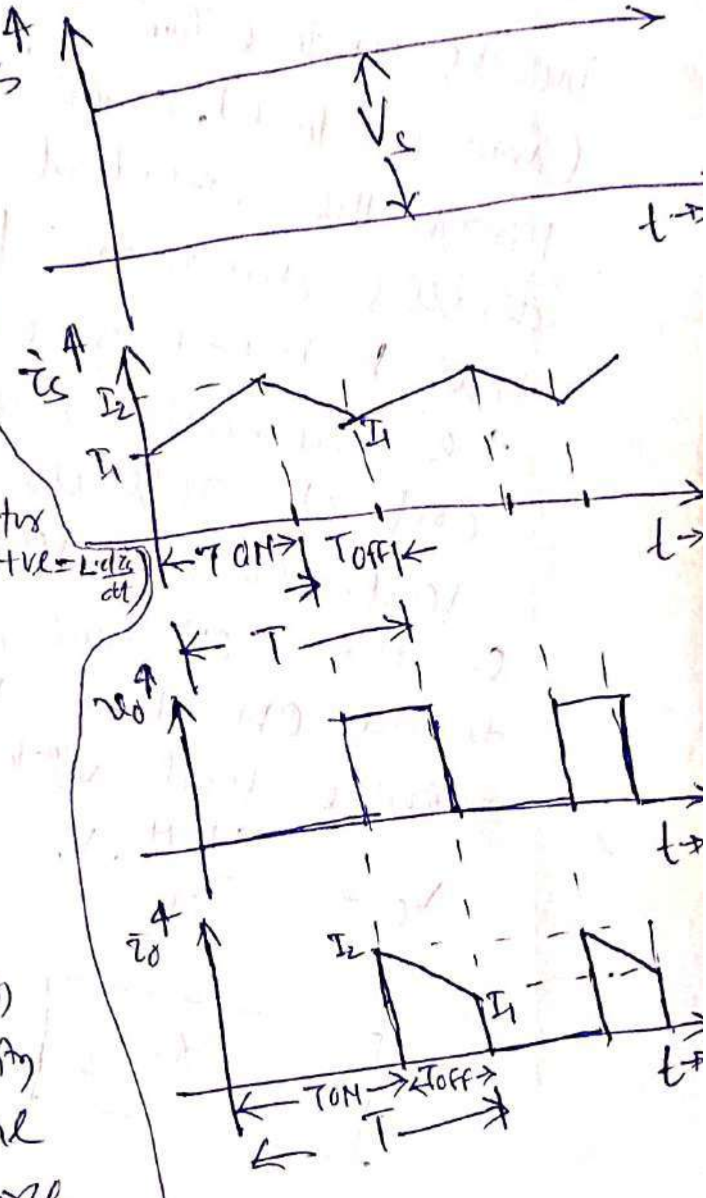


(stepup chopper ckt)

A large inductor L is put in series with the source voltage V_s.

when switch is ON (closed)

$(0 \le t \le T_{ON})$, the inductor get charged by V_s and load ckt is cut off from the supply. So the output $v_0 = 0$. During this period the inductor current (supply current) increases from a value say I_1 to I_2 (inductor get charged to store the emf with LHS +ve $= L\frac{di_s}{dt}$). load current $i_0 = 0$.



when switch is off (open)

$T_{ON} \le t \le T_{off}$; the source current is tend to flow through diode D and load. As the current in the inductor can not die down instantaneously, the polarity of the emf stored in the inductor reverses (as source current decreases from I_2 to I_1) with left hand side being -ve. Now the voltage across the load i.e, $v_0 = V_s + L\cdot\frac{di_s}{dt} > V_s$.

So the avg. value of the output voltage

The average output voltage V_0 is +ve when the (4)

is greater than V_S. and the chopper (2) (3)
is a Boost converter or stepup chopper.
The input output relationship can be given as

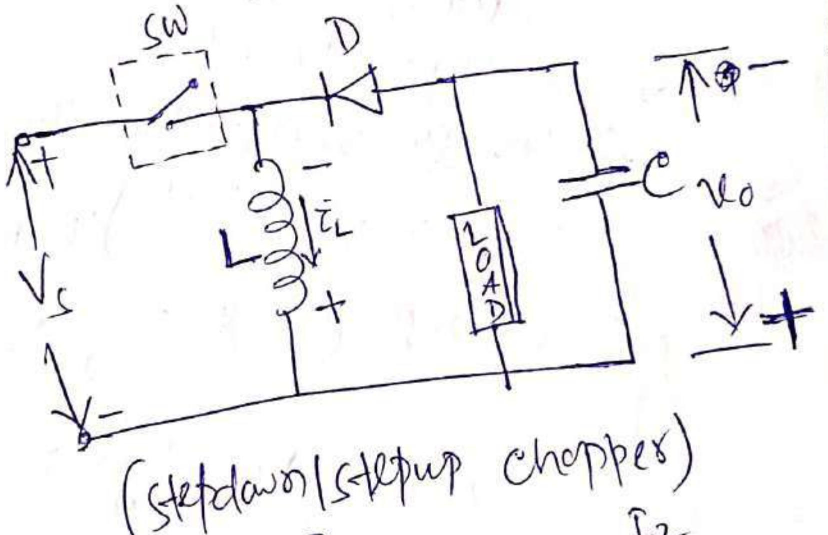
$$V_S \cdot T_{ON} = V_0 T_{OFF} - V_S \cdot T_{OFF}$$

or, $V_0 T_{OFF} = V_S (T_{ON} + T_{OFF}) = V_S \cdot T.$

$$\text{or, } V_0 = V_S \cdot \frac{T_{ON} + T_{OFF}}{T_{OFF}} = V_S \cdot \frac{T}{T_{OFF}}$$

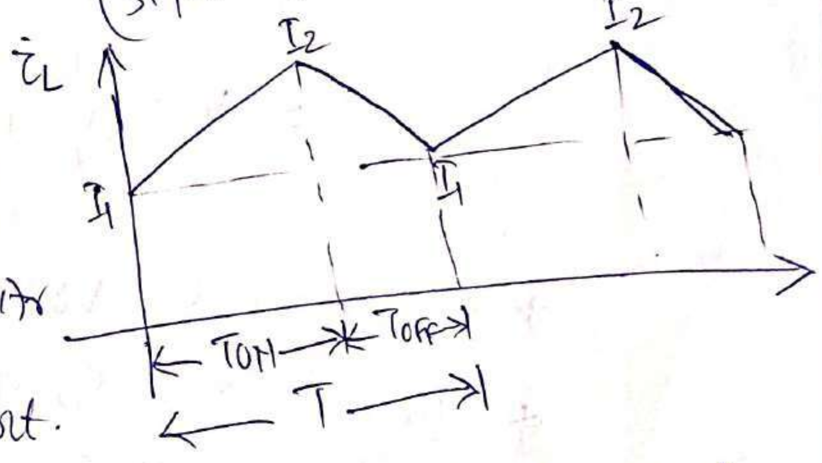
$$\text{or } V_0 = V_S \cdot \frac{1}{1-\alpha}.$$ α being the duty cycle

(c) Step-up/stepdown (Buck-Boost) chopper



In the fig. is shown a Buck-Boost converter (Step-down & Step-up chopper).
The ckt. consists of a chopper switch SW, inductor L, diode D, capacitor C and load. Inductor stores energy and release it when discharged. The capacitor tends to maintain load voltage constant.

(stepdown/stepup chopper)



The load voltage polarity is opposite to the source voltage polarity.

When switch is ON. ($0 \le t \le T_{ON}$), current flows from source V_s to SW and inductor L and back to V_s. During this period (T_{ON}), current through L rises from I_1 to I_2 and V_s appears across L.

$\therefore$ Energy stored in the inductor during T_{ON},

$$W_{on} = V_s \left(\frac{I_1 + I_2}{2} \right) T_{ON} \quad \text{—— (1)}$$

When switch SW is OFF; inductor current tends to decrease and so the polarity of the induced emf across L gets reverse (as shown in the figure with upper part $-ve$). Thus the diode gets forward biased and energy stored in the inductor discharges through load, diode D and inductor L, during the OFF period.

$\therefore$ Energy released by the inductor during T_{OFF}

$$W_{OFF} = V_0 \left(\frac{I_1 + I_2}{2} \right) T_{OFF} \quad \text{—— (2)}$$

Equating (1) & (2); $V_s \left(\frac{I_1 + I_2}{2} \right) T_{ON} = V_0 \left(\frac{I_1 + I_2}{2} \right) T_{OFF}$

$$\text{or, } V_0 = V_s \cdot \frac{T_{ON}}{T_{OFF}} = V_s \cdot \frac{T_{ON}}{T - T_{ON}} = V_s \frac{1}{\frac{T}{T_{ON}} - 1}$$

$$= V_s \cdot \frac{1}{\frac{1}{\alpha} - 1} \quad \text{or,} \quad \boxed{V_0 = V_s \cdot \frac{\alpha}{1 - \alpha}}$$

* for $\alpha = 0.5$, $V_0 = V_s$.
* for $0 < \alpha < 0.5$, $V_0 < V_s$ and the chopper acts as a stepdown (Buck) chopper.
* for $0.5 < \alpha < 1$, $V_0 > V_s$, and the chopper acts as step up (Boost) chopper.

4.3 control strategies of chopper:

The average value of the output voltage V_0 can be controlled by controlling the duty cycle (α), by opening and closing of the semiconductor switch periodically. The verious control strategies used to vary duty cycle α are as follows —

1. Time ratio control (TRC)
2. current limit control.

1. Time ratio control:

The time ratio (T_{ON}/T) or the duty ratio or dutycycle is varied in two ways —

i) constant frequency system: The ON time T_{ON} is varied but the chopping frequency f (or chopping period $T = \frac{1}{f}$) is kept constant. variation of T_{ON} means ~~adjustment of~~ pulse width. so this scheme is also called pulse width modulation (PWM) scheme.

In fig (a) is shown the output voltage a diagram for $T_{ON} = \frac{1}{4}T$ i.e, $\alpha = 0.25$ or 25% duty cycle. chopping freq. $f = \frac{1}{T}$ is kept const.

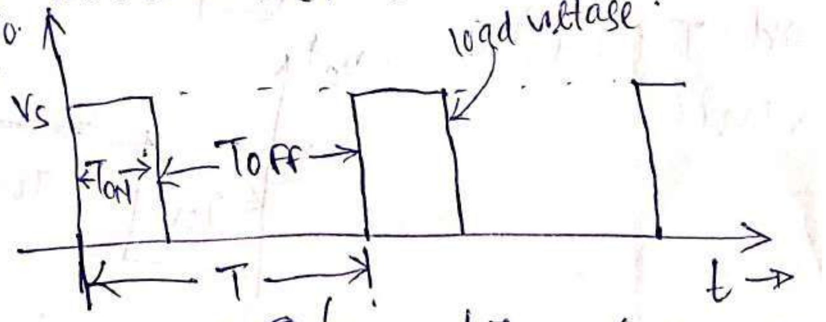


fig (a) ($T_{ON} = \frac{1}{4}T$ or $\alpha = 0.25$ or 25%)

fig (b) is for $T_{ON} = \frac{3}{4}T$ i.e, $\alpha = 0.75$ or 75% duty cycle.

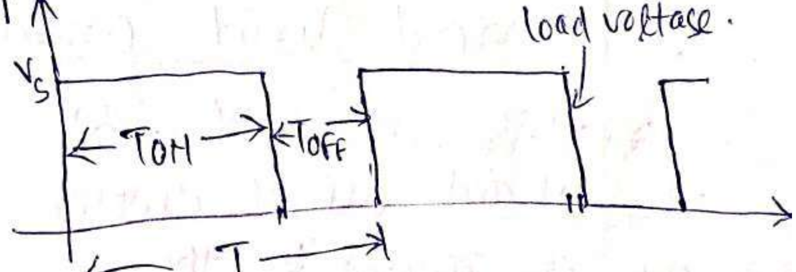


fig (b) ($T_{ON} = \frac{3}{4}T$, or $\alpha = 0.75$ or 75%)

ii) <u>variable freq. system</u>; here the chopping frequency f (or chopping period T) is varied and either 1) ON time is kept constant or 2) OFF time T_{OFF} is kept constant. This method of controlling α is also called frequency modulation (FM) scheme.

In fig (a) $T_{ON} = \frac{1}{4}T$
so $\alpha = 25\% = 0.25$

In fig (b) $T_{ON} = \frac{1}{2}T$
so, $\alpha = 50\% = 0.5$

In both cases T_{ON} duration is kept constant, but T_{OFF} is varied so that freq. is varied by varying $T = T_{ON} + T_{OFF}$

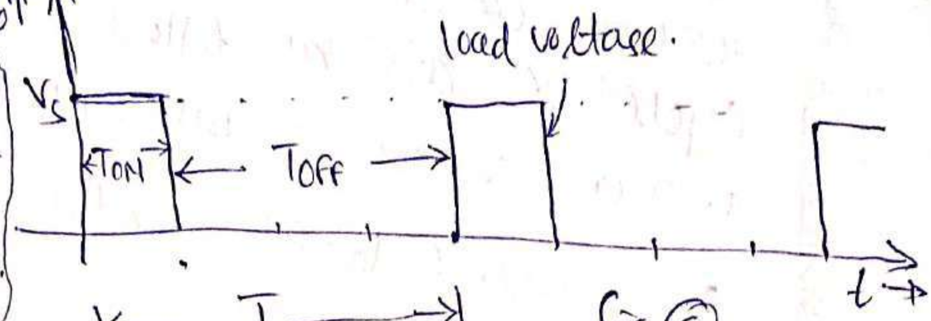


fig (a)

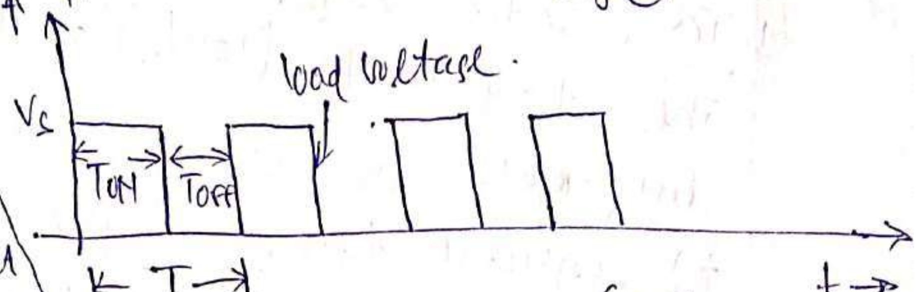


fig (b)

In fig (c) & fig (d) T_{OFF} is kept const. and T (so f) is varied.

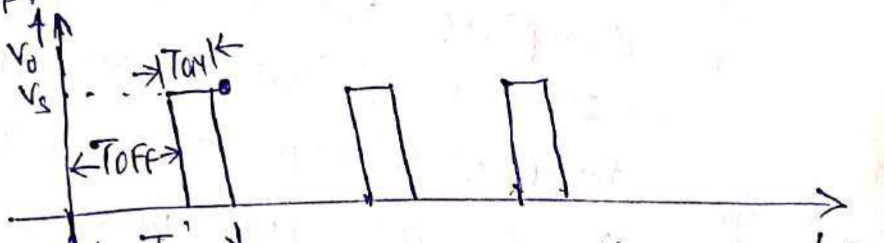


fig (c)

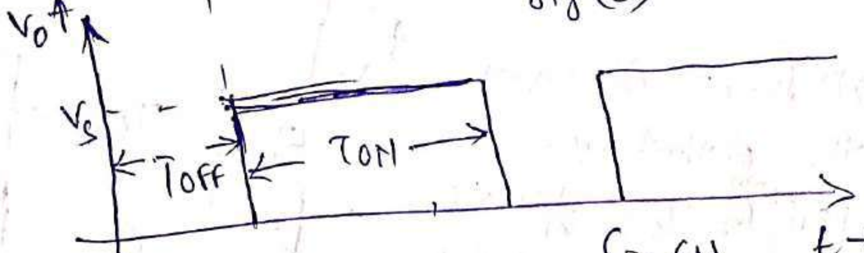
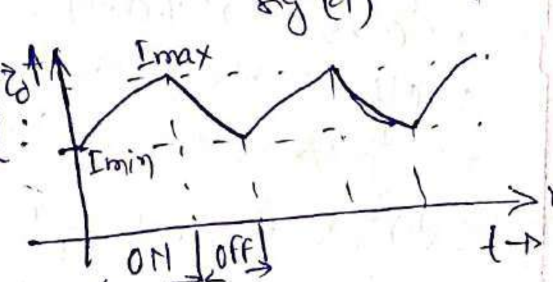
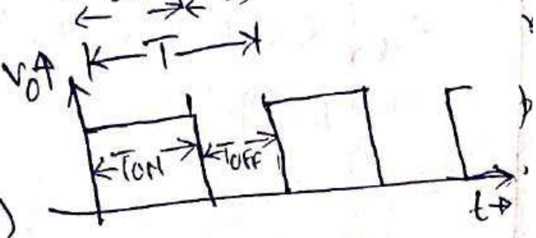


fig (d)

2. <u>Current limit control</u>:



In this scheme of control, the ON and OFF of chopper ckt. is guided by the previous sets of values of load current (i.e., I_{max} & I_{min})



switching freq. of the chopper can be controlled by setting Imax and Imin. The ripple is given by $(I_{max} - I_{min})$ which can be lowered by increasing the switching frequency

4.4. Different chopper configurations

Depending upon the operation, the choppers can be classified as —

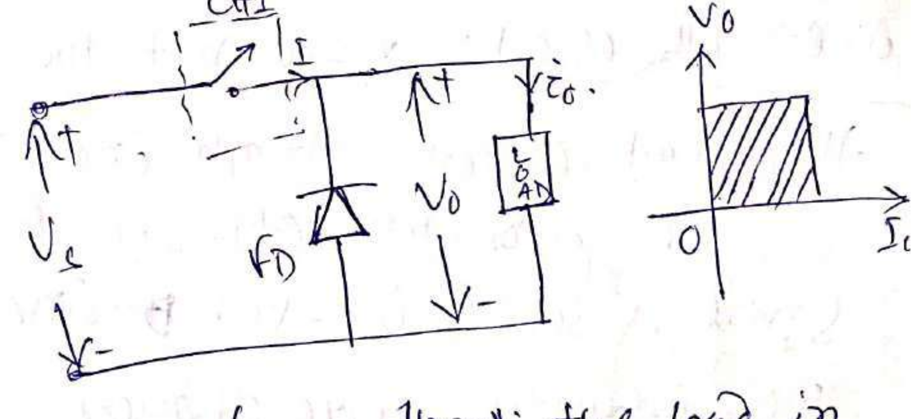
1. Single quadrant choppers; These are of two types –(i) 1st quadrant or class-A.
   –(ii) 2nd quadrant or class-B.

2. Two quadrant choppers: These are of two types –(iii) Two quadrant (1st & 2nd) Class C chopper
   –(iv) Two quadrant (1st & 4th) class D chopper

3. Four quadrant or (v) class E chopper.

i) 1st quadrant or class-A chopper:

In the fig. is shown a step-down or class-A chopper.



when CH1 is ON

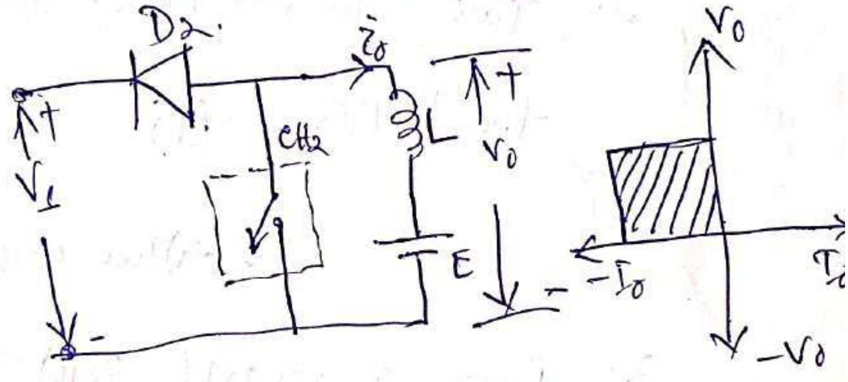
$V_0 = V_s$, and current flows through the load in the direction shown in fig.

when CH1 is OFF : $v_0 = 0$, but current is still flowing through the load and diode FD in the same direction. Hence it is evident that average value of load voltage (V_0) and load current (I_0) are always +ve (both in 1st quadrant of $V_0 \sim I_0$ plane)

power flow in a class A chopper is always from source to load and as it is a step down chopper average value of output voltage V_0 is always less than V_s.

ii) Second quadrant or class B chopper.

A second quadrant or class B chopper is as shown in figure. The load is an inductor along with a dc source (may be a dc motor).



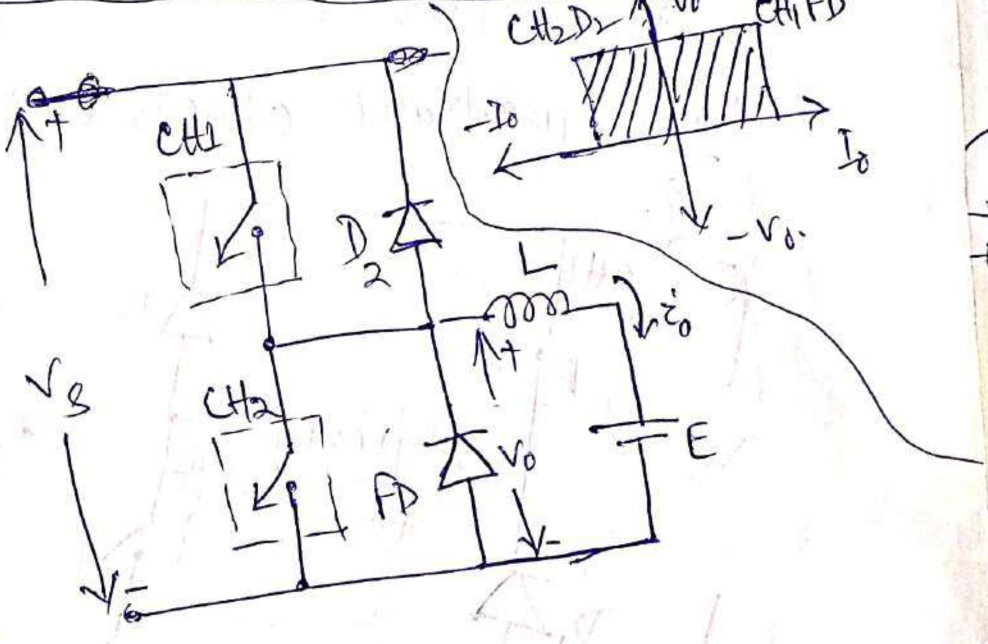
when CH2 is ON : $v_0 = 0$, but the load voltage E drives the load current through inductor L and CH2 in the direction opposite to that shown in figure, so i_0 is -ve. During this ON period (Ton) the inductor gets charged.

when CH2 is OFF : $v_0 = E + L \cdot \frac{di}{dt}$ exceeds the source voltage V_s. It makes diode D_2 forward (4) biased and current flows through load and D_2 in the same direction as during ON period (−ve). So during both the periods T_{ON} & T_{OFF}, the load current is −ve and flows from load to source.

As load voltage V_0 is always greater than source voltage V_s, class B choppers are also called stepup (Boost) choppers.

iii) Two quadrant- class A or class-C chopper

In the fig. is shown a two quadrant class-A chopper or class C chopper which can be obtained by parallel combination of class A and class B choppers.



The output voltage V_0 is always +ve because of the presence of the freewheeling diode FD across the load.

when chopper CH_2 is ON or freewheeling diode FD conducts: output voltage $V_0 = 0$, and load current is −ve

(its direction is opposite to that shown in fig.)

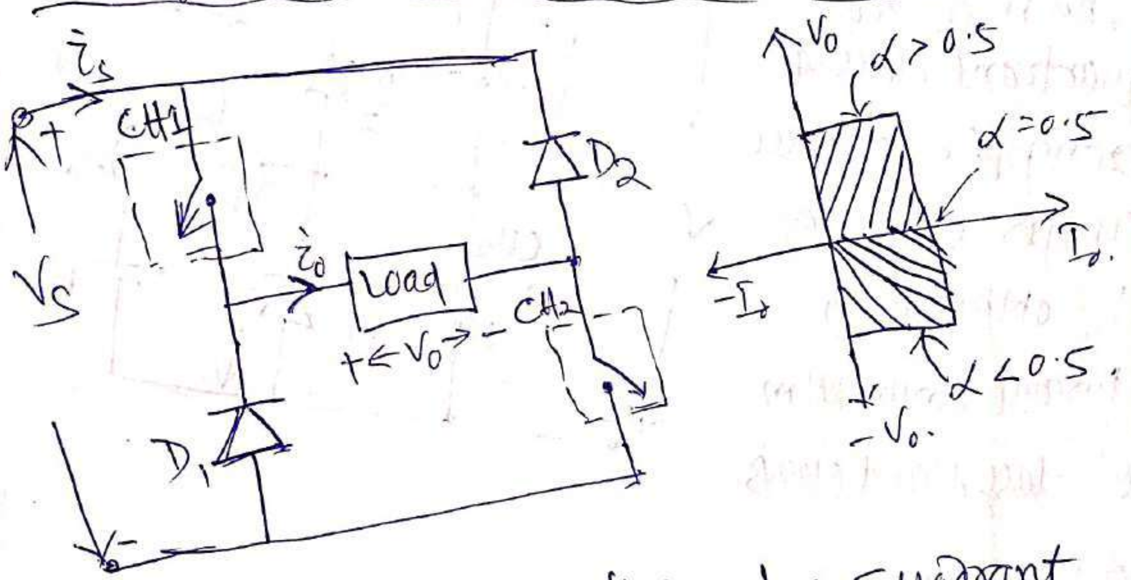
when CH1 is OFF or diode D_2 conducts:

$v_0 = V_s$ and the load current i_0 is +ve and flows in the direction as shown in fig.

Hence output voltage V_0 is always +ve but output current i_0 changes its direction.

So, CH_1 & FD operate together as class A chopper in first quadrant and CH_2 & D_2 operate together as class B chopper in 2nd quadrant.

(iv) Two quadrant class B chopper or Class-D chopper



In the fig. is shown the two quadrant class B chopper or class D chopper.

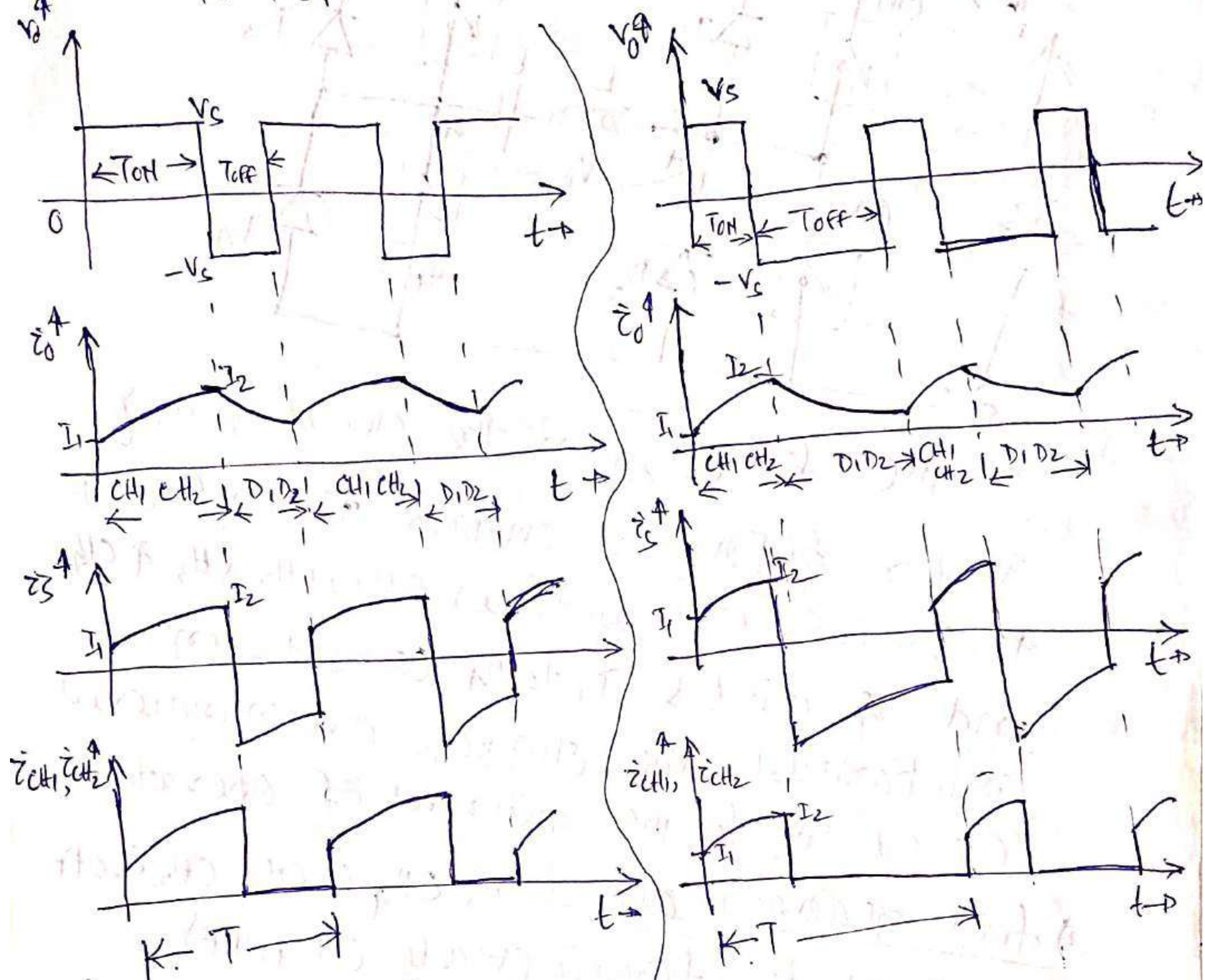
when both CH1 & CH_2 are ON: $V_0 = V_s$.

when both CH1 & CH_2 are off; but both diodes D_1 & D_2 are conducting $V_0 = -V_s$

ad current (i.e, Imax & Imin)

④

∴ The average output voltage v_0 is +ve when the choppers turn on time T_{ON} is more than their turn off time.



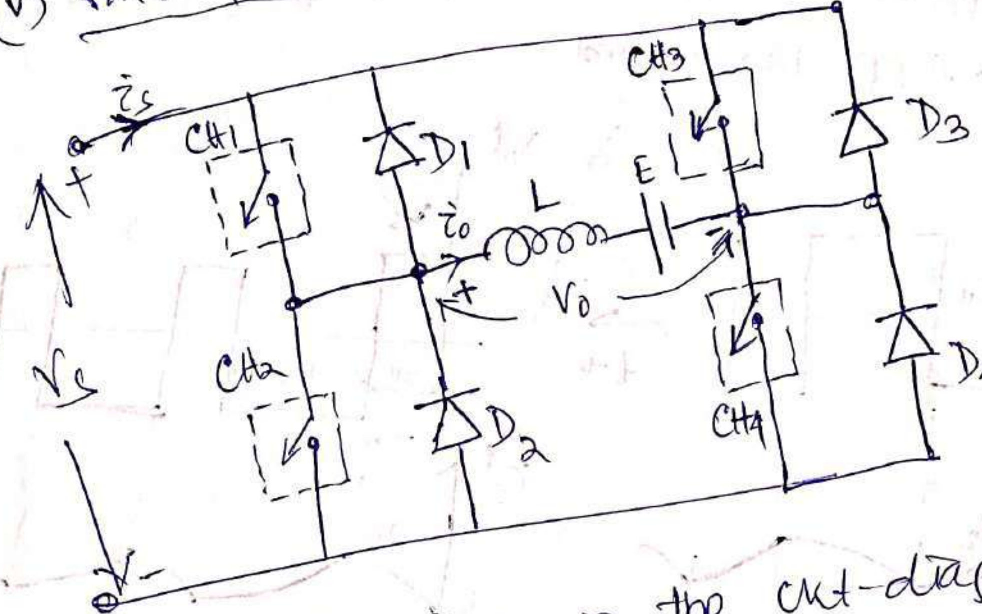
(For $T_{ON} > T_{OFF}$) fig ⓐ

(for $T_{ON} < T_{OFF}$) fig (b)

for $T_{ON} > T_{OFF}$, the various waveforms are plotted in fig ⓐ; average values of both v_0, i_0 (that is V_0 & I_0) are both +ve and chopper operates in 1st quadrant power flow takes place from source to load.

for $T_{ON} < T_{OFF}$, the waveforms are shown in fig ⓑ. Here average value of v_0 is -ve but avg. value of i_0 is +ve. Therefore the chopper operates in 4th quadrant and power flows from load to source

(v) Four quadrant chopper or Type-E chopper



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In the fig. is shown the ckt-diagram of a four quadrant chopper. It consists of 4 semiconductor switches CH1, CH2, CH3 & CH4 and 4 diodes D1 to D4 connected in antiparallel. The choppers are numbered according to the quadrant of operation.

i) First quadrant operation: CH_4 is ON, CH_3 is OFF. and CH_1 is operated (made ON & OFF). with CH_1 & CH_4 both ON, load voltage $V_0 = V_s$ and load current i_0 flows. when CH_1 is made OFF, the +ve current i_0 freewheels through CH_4 & D_2. Hence both V_0 & i_0 are +ve giving 1st quadrant operation.

ii) 2nd Quadrant operation: CH_1, CH_3 & CH_4 are OFF only CH_2 is operated. when CH_2 is ON, reverse current flows through L, CH_2, D_4 and E. Inductance get

when CH_2 turned OFF, current is fedback to source through diodes D_1 & D_4.
Here v_0 is +ve and i_0 is -ve, giving 2nd quadrant of operation.

iii) <u>3rd quadrant</u>: CH_1 is OFF, CH_2 is ON and CH_3 is operated. The emf E polarity are to be reversed for operation.
<u>when CH_3 is ON</u>; load gets connected to source
So both v_0 & i_0 are -ve giving rise to 3rd quadrant of operation.
<u>when CH_3 is turned off</u>, -ve current freewheels through CH_2, D_4. The chopper operates as a stepdown chopper

iv) <u>4th quadrant operation</u>:
CH_1, CH_2, CH_3 are all OFF, CH_4 is operated.
when CH_4 is ON, +ve current flows through CH_4, D_2, L & E. Inductance L stores energy during the time CH_4 is ON.
when CH_4 is OFF, current is fed back to source through diodes D_2, D_3. Here load voltage is -ve but load current is +ve giving rise to 4th quadrant of operation. Power flows from load to source. The chopper acts as a stepup chopper.

V_0

Quadrant II: 1 chopper on step up chopper
CH_2 operated
CH_2-D_4 : L stores enersy
CH_2 OFF ; then D_1-D_4 Condut

Quadrant I: 2 choppers on step down chopper
CH_1 operated
CH_1, CH_4 → ON
CH_1-OFF ; then CH_4-D_2 conduct.

I_0

$-I_0$

Quadrant III: 2 choppers on step down
CH_3- operated
CH_3-CH_2 : ON
CH_3-OFF ; then CH_2 D_4 conducts
E reversed

Quadrant IV: 1 chopper on step up chopper
CH_4 operated.
CH_4, D_2 ; L stores enersy
CH_4 OFF ; then D_2 D_3 conducts.
E reversed.

$-V_0$.

— ρ —

Ch 5 Inverters ①

5.1 Inverter and its classification

Inverter is a power conversion (or power conditioning) circuit that converts a dc power (from a dc voltage or current source) to ac power, (produces ac voltage or current).

It does the reverse operation (dc to ac conversion) of converter (ac to dc conversion).

Hence inverter is device that converts dc power to ac power at a desired output voltage and frequency (or at desired output current and frequency).

Classification :- Depending upon the power source, inverters can be classified as-

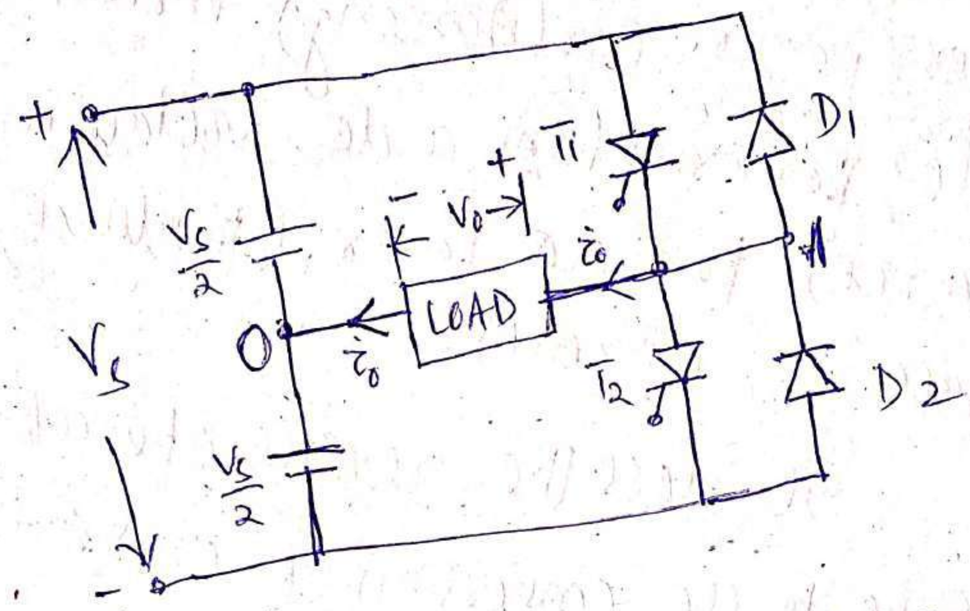
i) voltage source (or fed) inverter (VSI or VFI) and

ii) current source (or fed) inverter (CSI or CFI)

- Depending upon the connection of semiconductor device, inverters can be classified as-

a) Bridge inverter b) Series inverter
c) parallel inverter.

5.2 Single phase Half bridge voltage source inverter (1ϕ HBVSI)



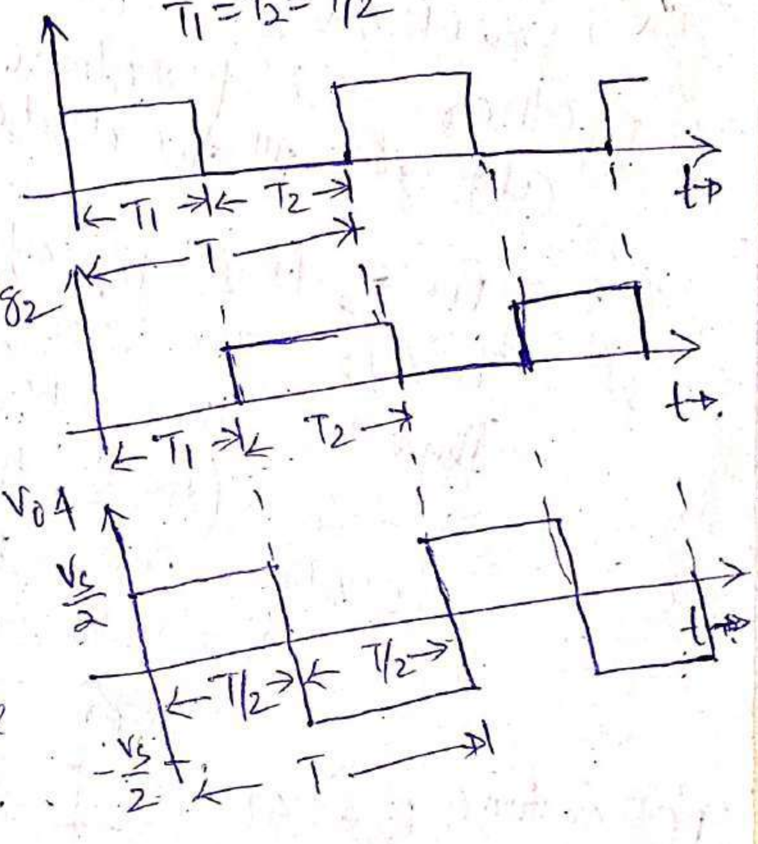
In the fig. is shown the basic circuit diagram of a 1ϕ half bridge voltage source inverter. At the first stage the source voltage V_s is divided into two equal halves of $\frac{V_s}{2}$ each through a potential divider network (may be capacitive). To each half voltage path are connected one power switch (Thyristor or IGBT or GTO) in antiparallel with a diode. Between the junction of the bridge (point A) and junction of the two voltage halves (point O) is connected the load.

The operational waveforms are as shown in fig below. For a period $0 \le t \le T/2$ the thyristor T_1 is on and T_2 is off. So the source voltage half $\frac{V_s}{2}$ appear across the load and the output voltage & current will have the polarity and direction as shown in fig.

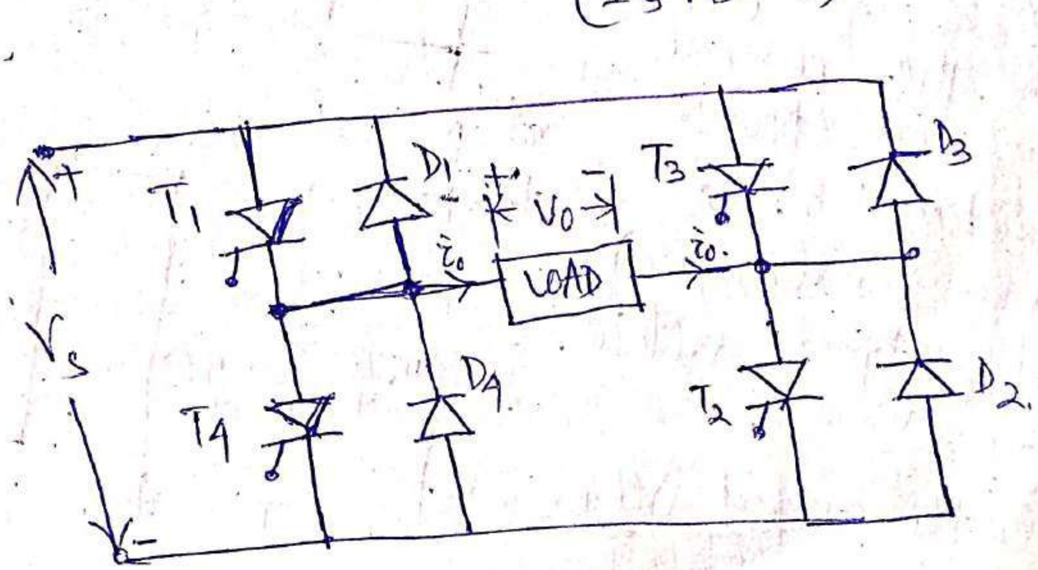
For the next half period $T/2 \le t \le T$, the thyristor T_2 conducts and load voltage and current will have opposite polarity as to its 1st half cycle case.

It is seen that the load voltage is an alternating (ac) voltage of amplitude $\frac{V_s}{2}$ and freq $\frac{1}{T}$, which are independent of the load.

Freq. of the inverter output voltage can be changed by varying T.



5.3 Single phase full bridge voltage source inverter (1Ø FBVSI)

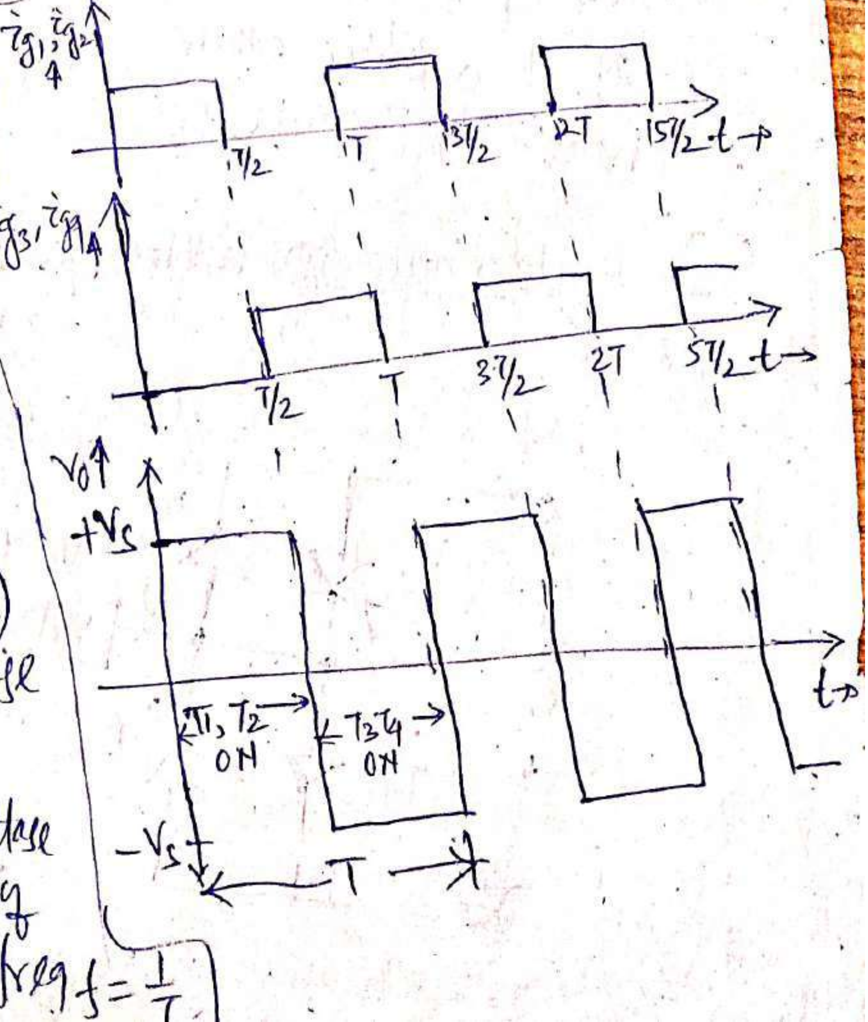


V_0 step down chopper

In the fig. is shown the basic circuit diagram of a single phase full bridge voltage source inverter. The four arms of the full bridge contains one thyristor in antiparallel with a diode ($T_1 D_1$, $T_2 D_2$ ...)

The load is connected between two junctions of the bridge and between the other two junctions the source voltage V_s is applied. All the diodes D_1, D_2, D_3 & D_4 are feedback diodes.

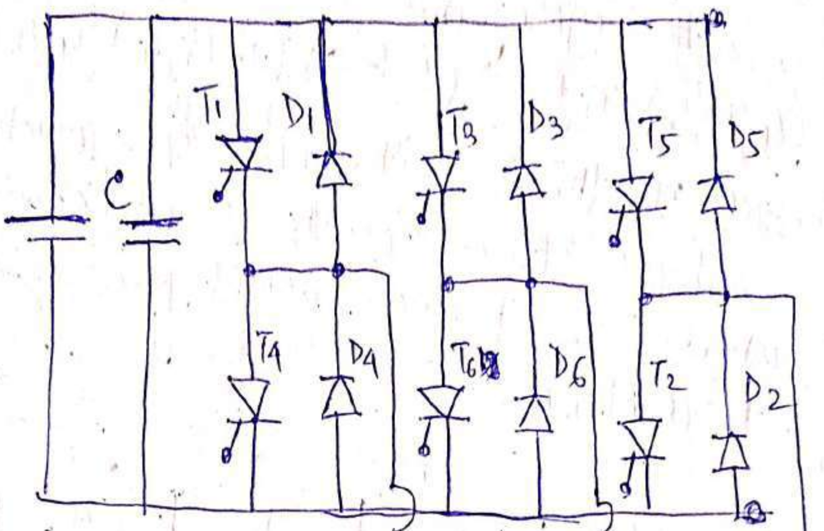
For a time period $0 \le t \le T/2$, thyristors T_1 & T_2 are ON and T_3 & T_4 are OFF. During this period, the source current $i_s = i_0$ flows through T_1, load & T_2 with the direction as shown in fig. with $V_0 = V_s$ with the polarity as shown.



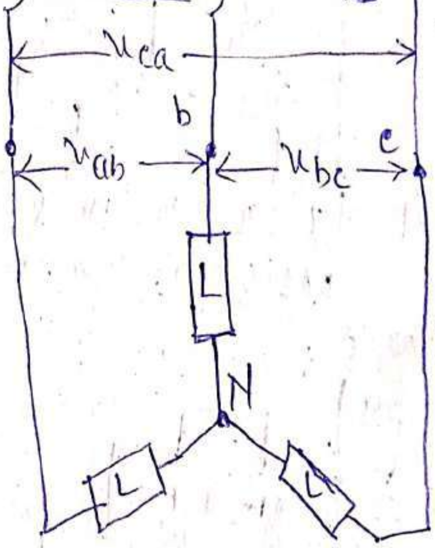
For a time $T/2 \le t \le T$ the thyristors T_3 & T_4 are ON and T_1 & T_2 are OFF. Now the current flows in opposite direction (to its previous half cycle) and output voltage $v_0 = -V_s$.

So the output voltage is an ac voltage of amplitude V_s and freq $f = \frac{1}{T}$

5.4 Three phase bridge inverter



In the fig. is shown a 3φ bridge type VSI which produces square wave pole voltages. The circuit can be assumed to consist of 3 single phase half bridge inverters put across the same dc bus.

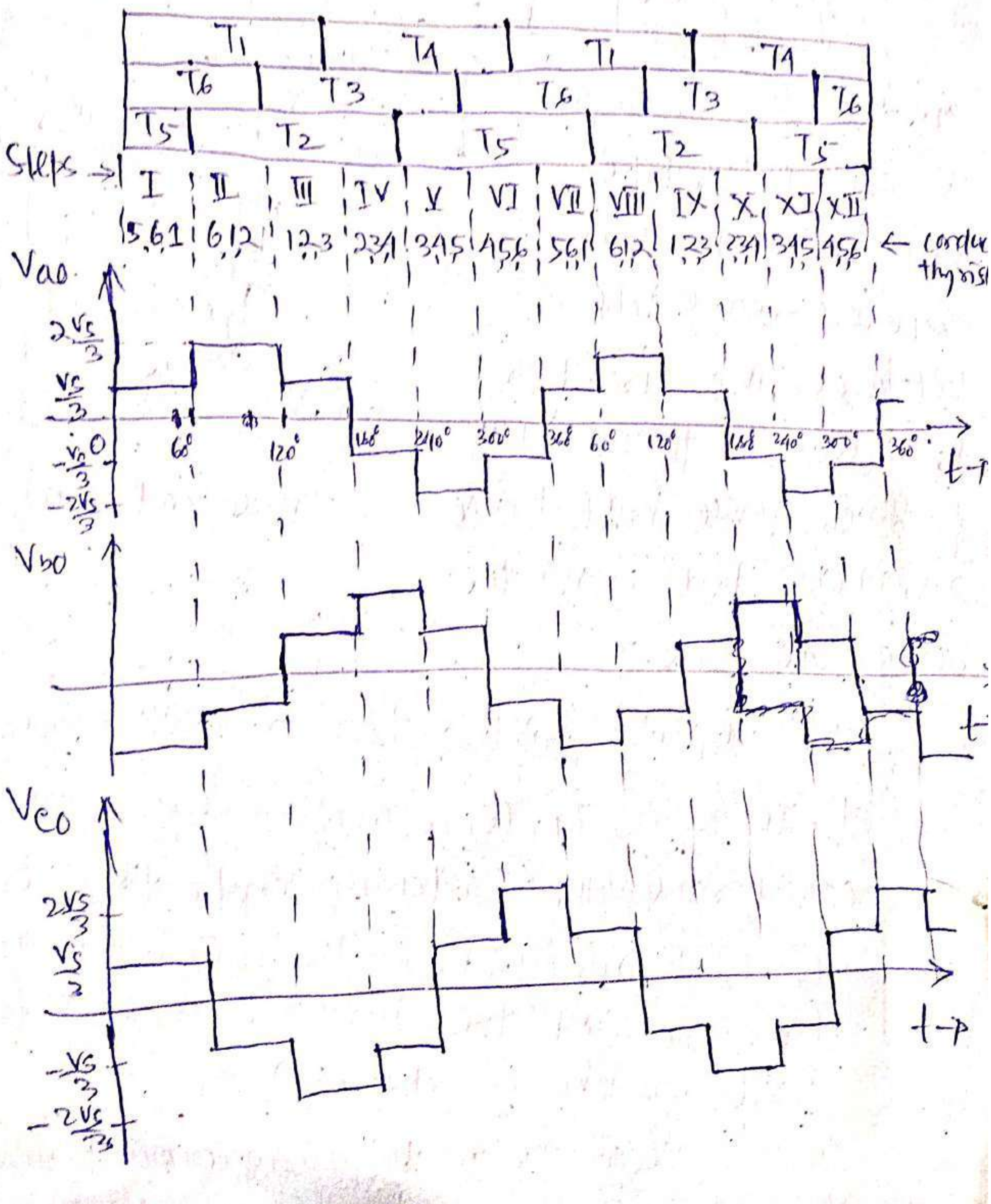


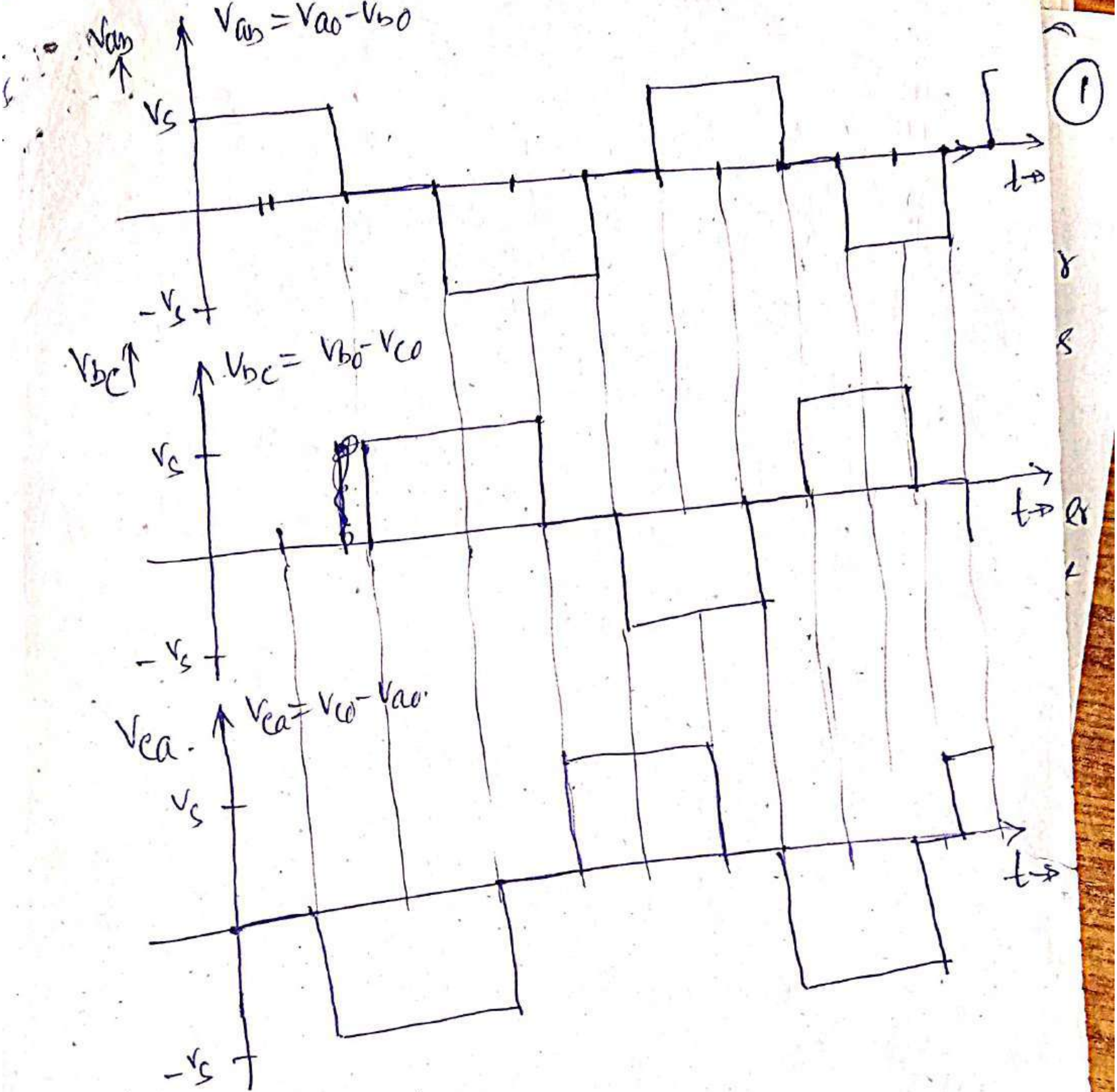
3 phase load (Star)

The thyristor switches turn on in the sequence of $T_1, T_2, T_3, T_4, T_5, T_6, T_1, T_2$ - - - and so on. Considering the switching cycle time as 360^0 (2π radian), each switch conducts for 180^0 and the turning on of the adjacent switch is staggered by 60^0.

According to the conduction pattern

indicated in the waveform diagram, there are six combinations of conducting switches during an output cycle. These are (T5, T6, T1) (T6, T1, T2) (T1, T2, T3) (T2, T3, T4) (T3 T4 T5) (T4 T5 T6). Each of these combination of switches conducts for 60° in the sequence mentioned above to produce output phase sequence of a, b, c.





5.5 Application of inverters:

Inverters are used in –

- variable speed ac motor drives
- Induction heating
- UPS (uninterruptible power supply)
- HVDC transmission lines
- Regulated voltage and frequency power supplies.

are connected in ...

6 CYCLOCONVERTERS (1)

6.1 Definition & Classification

Cycloconverter is a power controller (power controlling device) which converts ac voltage at one frequency (supply frequency f_s) to ac voltage at another frequency (load frequency f_o) without any intermediate dc stage.

A circuit which converts input power at one frequency to output power at a different frequency with one stage conversion is called a cycloconverter.

Classification:

- Depending upon the frequency of conversion cycloconverters are of two types -

a) Step up cycloconverter: The load or output frequency (f_o) is greater than supply or source frequency (f_s) or, $f_o > f_s$ in stepup cycloconverter

b) Step down cycloconverter: The load frequency is less than supply frequency or, $f_o < f_s$ in stepdown cycloconverter

- Depending upon the φ of supply ac voltage
  a) 1-φ to 1-φ, b) 3φ to 3-φ
  c) 3φ to 1-φ.

- Depending upon the type of connections -
  - a) mid point type cycloconverter
  - b) bridge type cycloconverter.

Applications: cycloconverters are used in -
- Speed control of high power ac drives
- Induction heating
- Static VAr compensation.
- for converting variable speed alternator voltage to constant frequency output voltage for use as power supply in aircraft or ship boards

6.2 Advantages & Disadvantages of Cyclo converters.

Advantages:

① In cycloconverter ac power at any frequency can be converted to lower or higher frequencies in one stage conversion.

② cycloconverters functions on phase commutation, not by forced auxiliary commutation. So the power circuit is compact and loss is less.

③ cycloconverter is capable of power transfer between source and load in either direction. It can supply power to load in any power factor. It is also capable of regeneration over the ~~enti~~ complete speed range from maximum speed to zero (stand still).

④ In cycloconverter, if an individual fuse blows it, complete shutdown will not happen and the cycloconverter will function with somewhat distorted waveforms.

⑤ cycloconverter can deliver high quality sinusoidal waveform at low output frequencies, making it preferable for low speed applications.

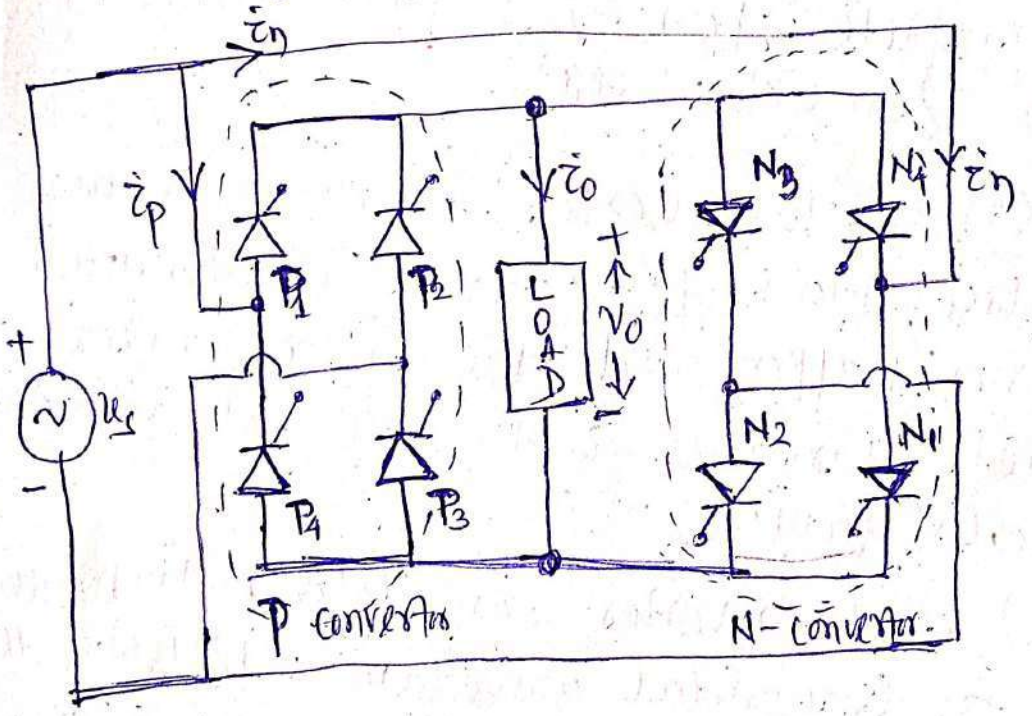
⑥ cycloconverter is extremely useful for large power, low speed drives.

Disadvantages: ① Large no. of thyristors are required and its control circuitry is also complex. Hence cycloconverters are not justified to use it for small installations, but is economical for units above 20 KVA.

2. For reasonable power output and ~~frequency~~ efficiency the output frequency is limited to one third of the input frequency.

3. The power factor is low, particularly at reduced output voltages, as phase control is used with high firing delay angle

<u>6.3 Single φ to 1-φ cycloconverter with resistive load.</u>



The circuit of a ~~1-φ~~ 1-φ to 1-φ cycloconverter is as shown in the figure. It consists of two full wave fully controlled bridge convertor circuits using four thyristors for each bridge,

CH- are connected in opposite direction, (5)
(back to back), with both bridges being fed from an ac source. Bridge-1 (P or positive converter) supplies load current in the +ve half cycle of ~~load~~ output ~~current~~ cycle. and bridge 2 (N or negative converter) supplies load current in the -ve half of output cycle.

Operation for a resistive load: for a resistive load, the load current goes to zero at the end of each half cycle (both +ve & -ve) reaches zero.

Considering the ~~+~~ 1st bridge (P or +ve bridge)

Considering top point of ac source as +ve w.r.t. the bottom point which is -ve, the thyristor pairs ~~diod~~ P_1 & P_3 conducts at some firing angle (say α_1) and load current flows through P_1, load, P_3 to supply for the +ve half cycle. Then as the -ve half cycle starts, P_1 & P_3 goes off and other pairs P_2 & P_4 start conducting at some firing angle (say α_2). Current flows through the load in the same direction and output voltage remains +ve.

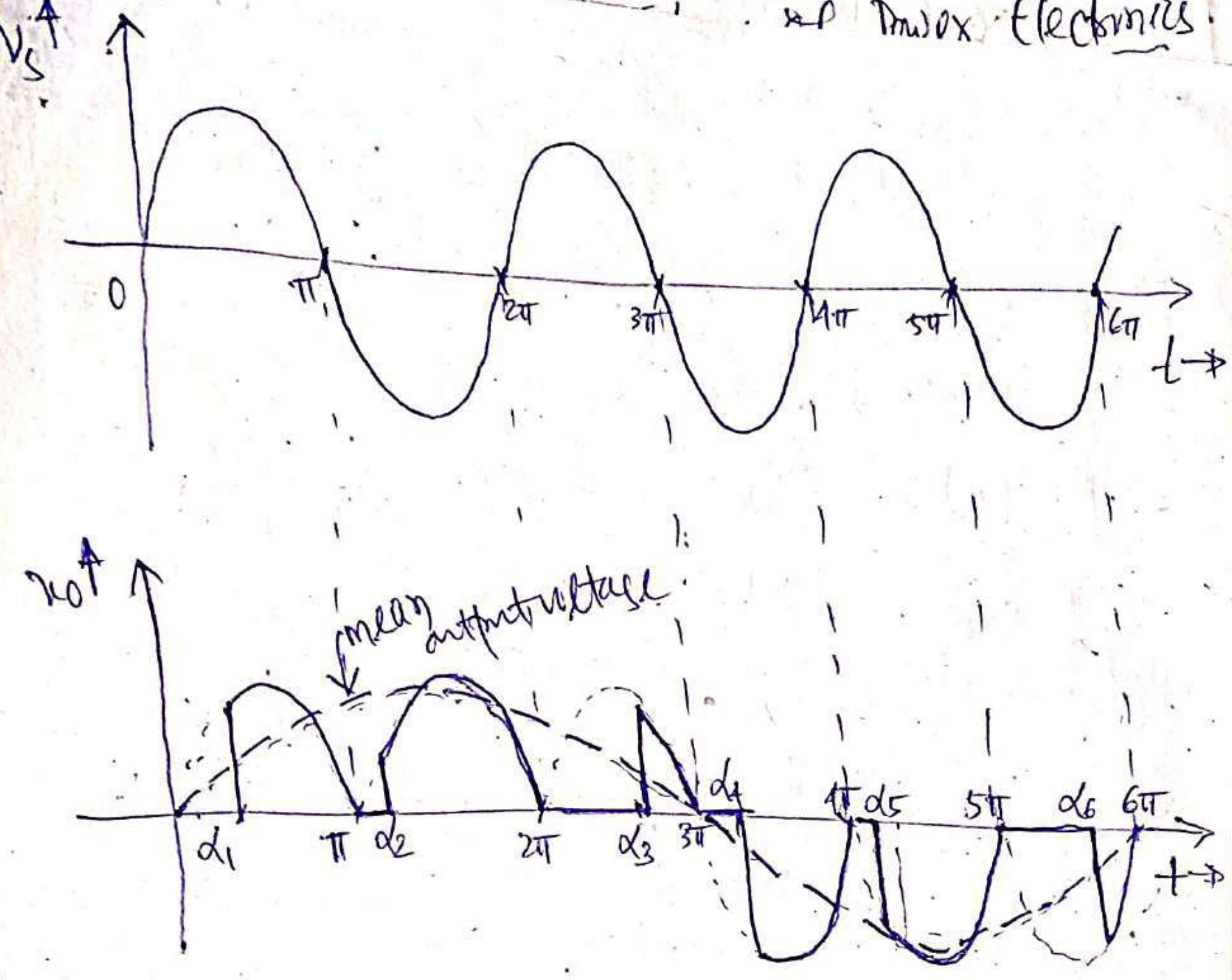
Then for negative half cycle (-ve) of the input signal again P_1 & P_3 gets fixed at same angle (say α_3).

At the start of 7th half cycle w.r.t. top point -ve of the input cycle *considering bottom point +ve of the input (either 3rd), the 2nd bridge 'B' becomes active and thyristor pairs P_2 & N_4 conducts for one half cycle then N_1 & N_3 conducts for the +ve half cycle and then N_1 & N_3 for the next -ve half cycle.

In this way one cycle of the output is obtained for 3 cycles (or 6 half cycles of the input signal) as shown in the waveform diagram.

So the output signal is a discontinuous waveform, having frequency more than that of the input signal.

Dual Converter / Power Electronics (heading partly illegible)



CH-7 Protection, Rating & Failure of Power Electronics Devices. ①

7.1 Specification, rating & Nomenclature of Thyristors

SCR Specifications

a) forward breakover voltage (V_{FBO}): It is the applied forward voltage at which break over takes place with gate open.

b) Reverse breakdown voltage (V_{RBD}): It is the reverse applied voltage at which breakdown of the device takes place.

c) Forward ~~breaking~~ blocking voltage (V_{DRM}): It is the maximum forward voltage that can be applied without causing the SCR to conduct

d) Reverse blocking voltage (V_{RRM}): It is the maximum reverse voltage that can be applied without causing breakdown.

e) Average current ($I_{T av}$): It is the average value of the forward current flowing through the thyristor

f) RMS current ($I_{T rms}$): It is the

(2) root mean square value of the forward current

g) **Peak non-repetitive surge current:** (I_T

It is the maximum value of the surge current, flows for a half cycle, produ the circuit fusing rating. (I^2t).

h) **Holding current:** It is the current at the holding point (after conduction

i) **Gate trigger current & voltage** (I_{GT} & V_G

It is the current & voltage value of the trigger pulse applied at the gate.

j) **Gate reverse voltage** (V_{GRM}): It is the reverse voltage obtained at the gate of the thyristor.

SCR Ratings: For an SCR, three types of ratings are used – i) continuous current rating ii) repetitive overload current rating iii) non repetitive surge current rating.

i) **continuous current ratings:**

continuous current ratings are specified interms of average and rms current values.

Average current is usualy smaller than the rms current. The rms current flows through to the conductive parts of the lead assembly, the ckts, device wiring and internal assembly parts and raises the junction temperature. There fore the rms current rating is limited to a safe minimum value.

ii) repititive overload current rating

when SCRs are used as rectifiers, it is required to run overload. Duration of overload may be short, but it is repititive. Hence the magnitude, duration and repititive frequency of the overload current must be limited to a minimum safe value, so that at no circumstances, the peak allowable junction temperature increases.

iii) nonrepititive surge current rating

Surge current is assumed to be imposed on the device when it is operating at the maximum rated voltage, current and temperature condition in a halfwave circuit delivering a resistive load. This non repititive surge current rating is provided by the manufacturer. This rating provides in the instantaneous overload capacity of the device and are used in designing protective device to it.

(A) 7.2 overvoltage and overcurrent protection.

Reliable operation of a thyristor always demands that it must be operated within the rated conditions. But in almost all practical applications, the rated values are exceeded causing failure or permanent damage to the device. So the device is required to be protected.

During operation, a thyristor may be subjected to overvoltage or over current conditions.

overvoltage protection: overvoltages may be caused in two ways —

a) internal overvoltage: During commutation of a thyristor, anode current reduces to zero and then reversed. Due to this sudden change in current (di/dt large), large voltages are generated ($V = L\, di/dt$).

b) External overvoltage: when a thyristor converter is fed through a transformer, voltage transients are likely to occur when the transformer primary is energized or de-energized.

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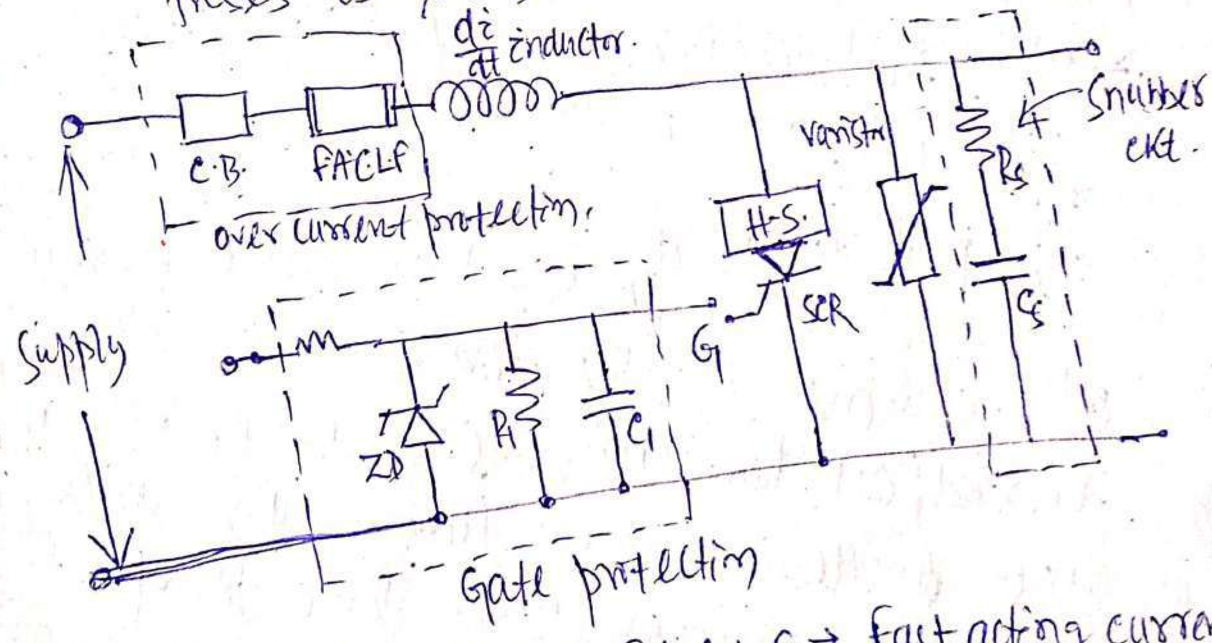
over voltage protection can be accomplished with employing a snubber circuit as shown in fig. It is an RC circuits with non linear resistors employing voltage clamping techniques.

⑤

Over current protection:

Thyristors have small time constants. Therefore, if a thyristor is subjected to overcurrent due to faults, short ckts, or surge current, its junction temperature may exceed the rated value and the device may be damaged. Hence there is the necessity of overcurrent protection of SCRs.

Overcurrent protection is achieved by using circuit brakers and fast acting fuses as shown in the figure.

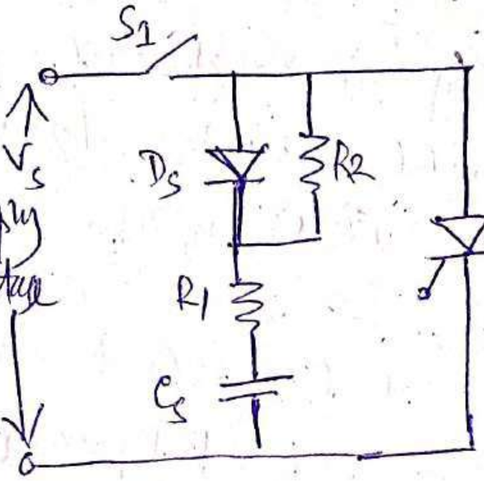


C.B. → circuit braker, F.A.C.L.F. → Fast acting current limiting fuse, H.S. → Heat sink. ZD → Zener diode

7.3 $\frac{dv}{dt}$ and $\frac{di}{dt}$ protection of SCR.

$\frac{dv}{dt}$ is the rate of change of voltage in the SCR. This rate of change of voltage

(6) produces a capacitive current i_c given by—
$i_c = C \cdot \frac{dv}{dt}$. If $\frac{dv}{dt}$ is high then i_c will be high (may be in the form of a surge) and can turn ON the device. This type of turn ON is called $\frac{dv}{dt}$ turn ON or false turn ON.

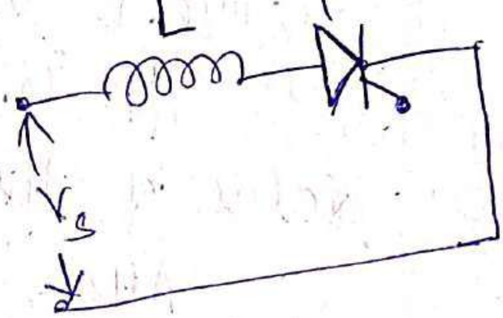


In the fig. is shown an arrangement for $\frac{dv}{dt}$ protection. The snubber arrangement of R_1 & C_s are used for ~~over vt.~~ $\frac{dv}{dt}$ protection and (R_1+R_2) for limiting the capacitor discharge current.

$\frac{di}{dt}$ protection: $\frac{di}{dt}$ is the rate of change of current in the device. When SCR is turned ON by applying a gate signal, the anode current flows. This anode current requires some time to spread inside the anode material (by spreading of charge carriers). If the rate of rise of anode current is greater than the spreading velocity of charge carriers then local hotspots are created near the gate due to increased current density. This localised heating may damage the device. (7)

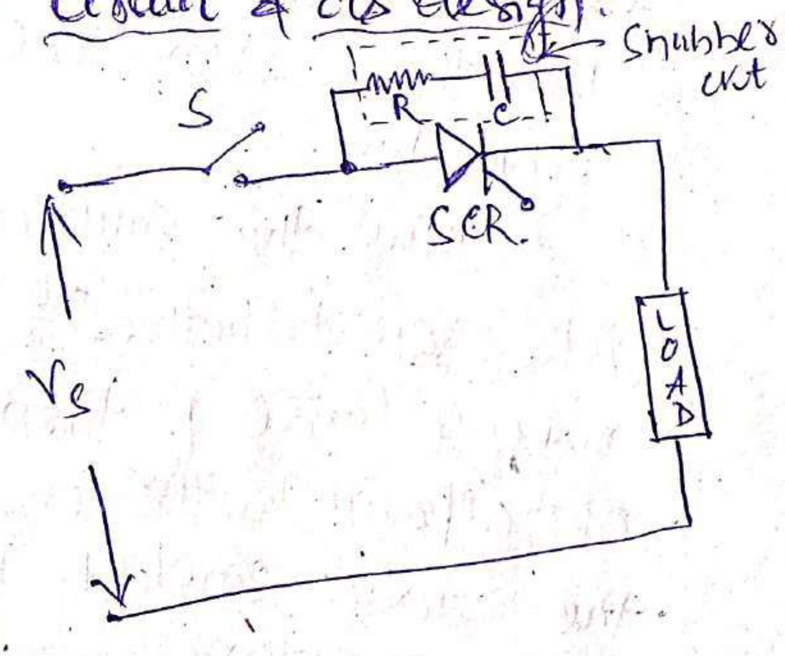
This problem can be avoided by ensuring the spreading of anode current (charge carriers) to the whole anode area rapidly or by limiting $\frac{di}{dt}$ rate below a threshold value.

Thus $\frac{di}{dt}$ protection can be achieved by connecting an inductor in series with the SCR.



When current variation is high, the inductor opposes it or smooths it and protects the SCR.

7.4 Snubber circuit & its design:



A snubber ckt is used to protect the thyristor against false turn ON, by high $\frac{dv}{dt}$ rate.

A snubber ckt. is a series combination of a resistor R and a capacitor C, connected across the SCR as shown in figure. The function of the capacitor is to limit $\frac{dv}{dt}$ rate and that of the resistor is to limit the high discharge current $(\frac{di}{dt})$ through the SCR.

(4) When switch 'S' is closed, the capacitor behaves as 'short ckt' and voltage across it is zero. As time goes on, the capacitor charges i.e, voltage across it increases slowly. ~~so the~~ capacitor finally charges to full voltage V_s and the rate of rise of voltage i.e, $\frac{dv}{dt}$ is limited below the rated value of the device.

After the capacitor is fully charged the SCR is fired by the gate trigger and the anode current flows which in turn the high discharge current of the capacitor which is being restricted by the series resistor R. So $\frac{di}{dt}$ is kept low.

Thus the snubber ckt. protects the SCR against both $\frac{dv}{dt}$ & $\frac{di}{dt}$ rise. The rate of rise of turn off voltage (charging of capacitor) ~~can~~ is determined by the time constant $R_L C$ where R_L is the load resistance.

7.5 process involved for selecting an SCR for particular application.

While selecting an SCR for a particular application, priority consideration is given

to voltage and current ratings.
Voltage ratings are given in the manufacturer's datasheet for both steady state and transient operations and for both forward and reverse blocking conditions. For specific applications, the factors required to be considered are as follows –

1. Load voltage – AC or DC, line voltage.
2. Load current – AC or DC, Max. and Min.
3. Input voltage – AC or DC, Max. and min.
4. Ambient temperature – Required for derating and heat sink calculation
5. Mounting style: PCB, chassis, DIL, Rail mounting.
6. International approvals – UL, CSA, VDE, TUV etc.

7.6. Reliability of SCR and Mean Time Between Failure (MTBF)

Reliability is a qualitative measure of any electronic component or device that how faithfully it operates in varied operating conditions and how long.

when switch S

(10) For an SCR, if it is properly designed and fabricated, then it has no inherent failure mechanism. If properly chosen and protected and operated in specified conditions it would have virtually an operating life without limits even in harsh atmospheres.

Failure is the consequence of degraded operation or derated response. If the response is zero the device is said to be completely failed or there is a total failure.

MTBF: The life expectancy of a solid state relay like SCR depend upon the electrical characteristics of the applications i.e, such as load current, duty cycle of the load, ambient temperature inside the panel surge currents, and also on mechanical factors like mounting method,

available air flow, thermal interface betw-
een relay and the panel etc. (11)

Mean time between failure is defined as the average time between failures occured in a batch of devices or components in a product family. No manufacturers provide a fixed MTBF specification. Rather it is estimated from the observations received from the users after prolonged operation.

MTBF is calculated by taking the total 'inservice hours' over the past two years period and dividing it by the total numbers of returns (failures) received from the field over the same period. In service hours are calculated by the number of products shipped over the specified period assuming they were in operation for eight hours a day and five day a week.

practically - calculated MTBF rating lies between 2 million to 40 million hrs.

(12) mathematically $\boxed{MTBF = \frac{1}{\lambda}}$

where λ is the failure rate.

7.7. Three failures of an SCR.

The three failures of an SCR are mechanical, electrical & thermal failures

Mechanical failures

1. Auxiliary cathode and gate leads not twisted: If the auxiliary cathode and gate leads are not twisted properly, then false triggering and turn ON may take place while the SCR should be OFF. proper twist is one twist per inch.

2. Loose gate connection at SCR or terminal board: loose connections are due to non soldered connections or improper matching of connectors (male & female connectors not fitted properly).

3. Bad snubber network across SCR. If proper snubber circuit is not

chosen or the circuit is malfunctioning (13)
then spikes (voltage impulses) may pass
to the SCR, causing failure.

Electrical failures:

1. cold solder joints on either the
gate drive ckt or the snubber ckt
are suspected poor electrical connections.

2. Bad firing amplifier — may cause
insufficient gate signal or no gate
drive when it should be.

3. small (micro) crack in PCB: It is the
most frustrating and hard to find
and solve problem which cause disc-
onnection.

Thermal failures

1. loss of cooling: If cooling system
fails by clogged filter, loss of coolant
pressure, or airflow, then significant
heat will be generated, which leads
to degraded response or even complete
failure.

2. Insufficient gate drive: SCRs need
hard gate drives to set the junctions

(14)

completly ON. A hard drive is a typically an initial gating pulse of 25 volts, at 1 amp for 1 microsecond, then rapidly decaying to 3 volts and 500 milliamps. If gate drive is insufficient, then the small ~~portion~~ amount of current will heat only a portion of the junction causing thermal run away and thus damaging the junction and device.

3. <u>cracked insulation</u>:

Old insulations may crack due to prolonged use and may cause short circuit, thus damaging the device.

CH 8 Industrial Electronics

8.1 Power supplies, stabilizers and generation voltage regulators.

Power supply: Power supply is an electronics device that supplies electrical energy to an electrical load. It has the energy source i.e, transmission lines or energy storage devices like batteries, fuel cells, electromechanical systems like generators and alternators, solar power converters etc.

Different types of power supplies are –
D.C. power supply, AC to DC power supply, linear regulator power supply, AC power supply, Switched mode power supply (SMPS) programmable power supply (PPS), uninterruptible power supply (UPS), High voltage power supplies (HVPS) etc.

Stabilizers: Stabilisers are voltage regulators in which the output voltage is not only regulated but also stabilised over a wide range of load conditions. It is of two types – ac voltage stabiliser and dc voltage stabiliser.

ac voltage stabiliser: In ac voltage stabilizers, both input and output are ac powers. Input is applied to a fixed position field coil and output is taken from a rotating coil that can rotate in an axis parallel to the fixed coil.

When moveable coil is positioned perpendicular to the fixed coil, magnetic forces acting on the movable coil balance each other out and voltage output is unchanged. Rotating the coil in one direction or the other, the output voltage can be increased or decreased.

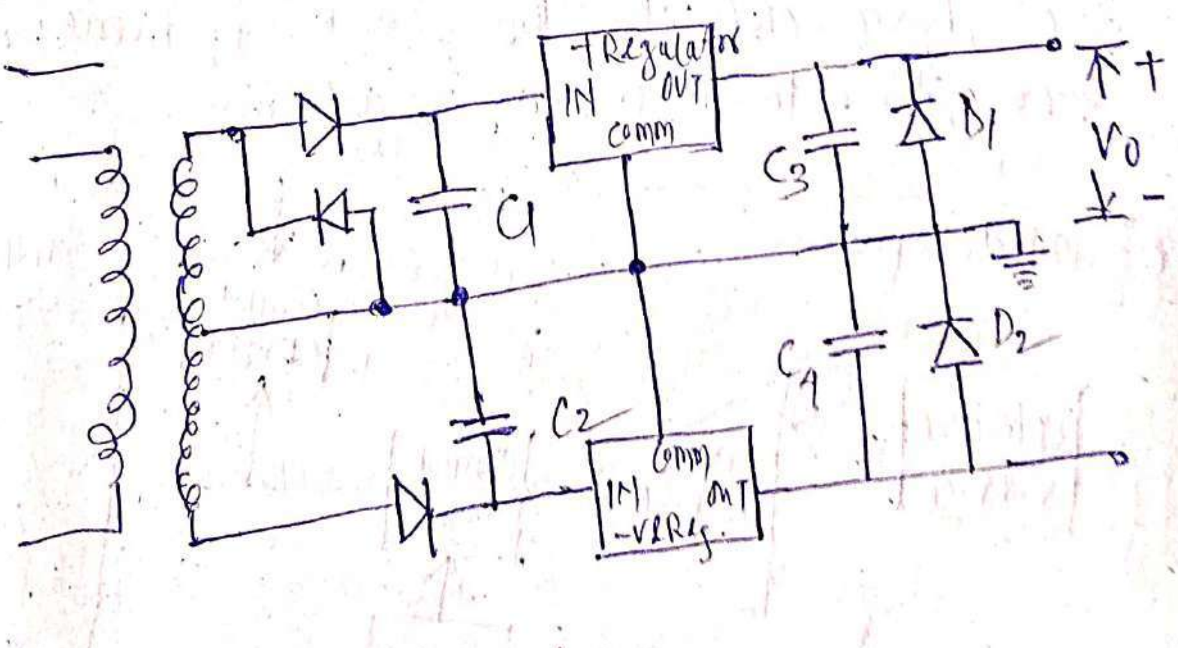
dc voltage stabilizers: Here both input and output are dc powers. The regulated output voltage is obtained by using series or shunt regulators. Mostly a shunt regulator such as zener diode, avalanche breakdown diode or voltage regulator tubes are used.

Generating voltage Regulators.

voltage regulation is a measure of change in voltage magnitude between the sending and receiving end of a component like transmission or distribution line. Hence generating voltage regulators are electronic ... maintain a constant voltage level. It can be of a simple feed-forward (open-loop) design or it may include -ve feedback control loops.

Types of voltage regulators are - Electronic voltage regulators, Electromechanical voltage regulators, Automatic voltage regulators.

8.2 Schematic diagram of a linear power supply that provides + or - 5V and + or - 15V.

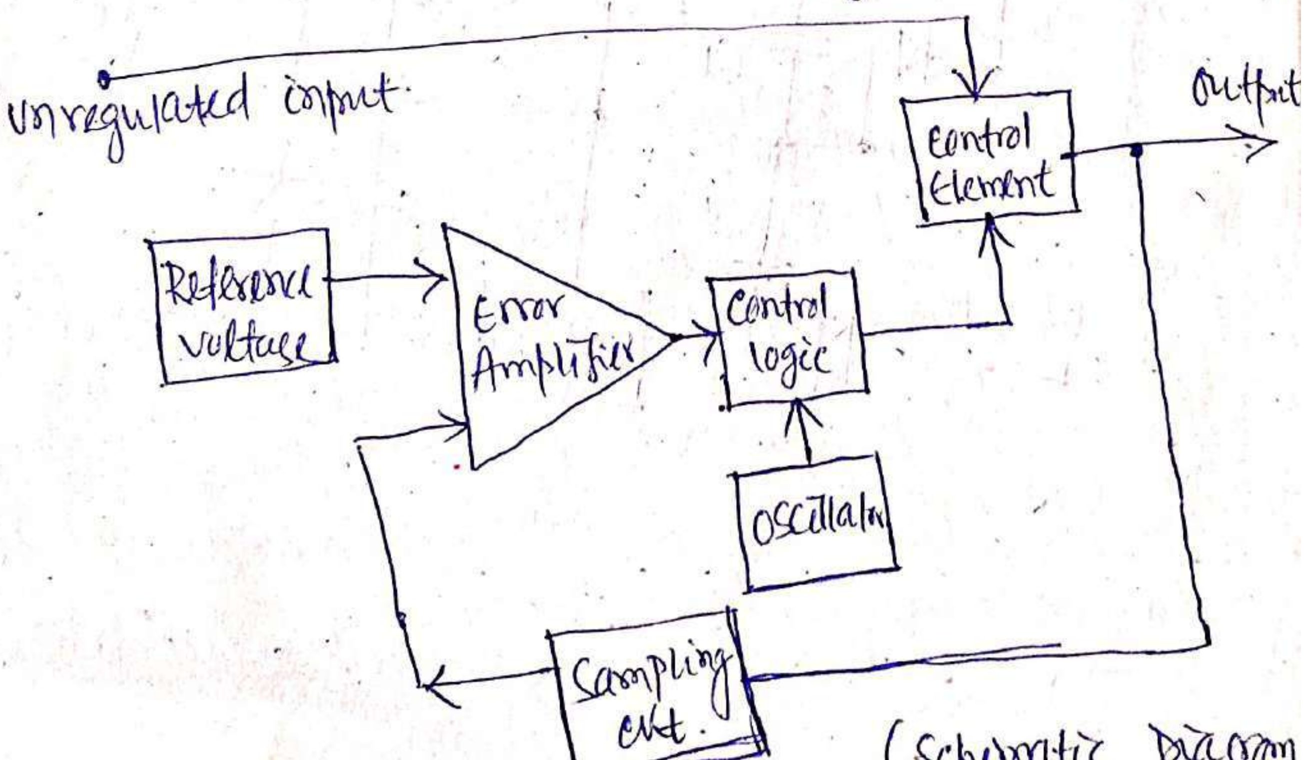


... the block diagram ...

8.3 Schematic diagram of SMPS.

Switched mode power supply principle is based upon DC chopper principle. The output dc voltage is controlled by varying the duty cycle of the chopper by PWM or FM techniques.

The input dc supply is chopped at a higher frequency around 15 to 50 KHz using an active device like the BJT, power MOSFET or SCR and the converter transformer. The transformed waveform is rectified and filtered. A sample of the output voltage is used as feedback signal from the drive ckt for the switching transistor to achieve regulation.



(Schematic Diagram of an SMPS)

In the figure is shown the schematic diagram of an SMPS. The control element consists of an active device like transistor (or MOSFET or SCR) an inductor and a diode. The control element is made ON and OFF by the pulse output of the oscillator. When the transistor is ON, energy is pumped into the magnetic field of the inductor and released to the load at the desired voltage level, during off time.

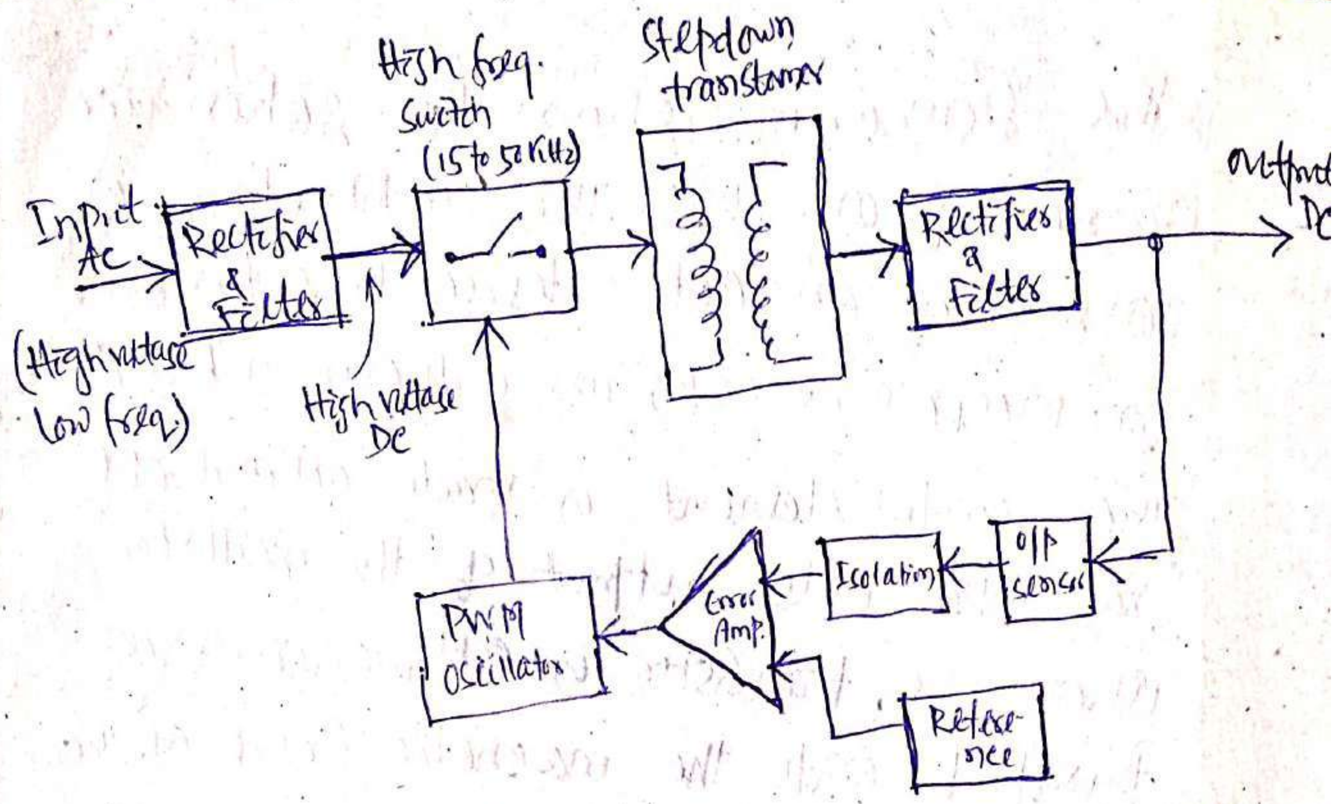
By varying the duty cycle, or frequency of switching, we can vary the stored energy in each cycle and thus control the output voltage.

SMPS can be of two types -
a) DC to DC converter b) DC to AC converters.
DC to DC converters can be further classified as - i) Fly back converter ii) Forward converter iii) push pull converter iv) Half bridge converter v) Full bridge converter.

Block Diagram of DC to DC Converter (SMPS)

In the fig. is shown the block diagram of a DC to DC converter.

5.3 Schematic



The High frequency power switch is driven by the PWM oscillator, its output being fed to the primary of the step down transformer. The duty cycle is made 50%. that is $T_{ON} = T_{OFF}$ (duty cycle $\delta = \frac{T_{ON}}{T} = \frac{T_{ON}}{T_{ON}+T_{OFF}}$), so that maximum energy will pass through the step down transformer.

Applications of SMPS.

1. In almost all computer systems.
2. In sophisticated electronics devices
3. Medical Electronics equipments.
4. Radars & navigation systems.
5. In ships and aeroplanes.

8.4. Comparison of liner PS & SMPS.

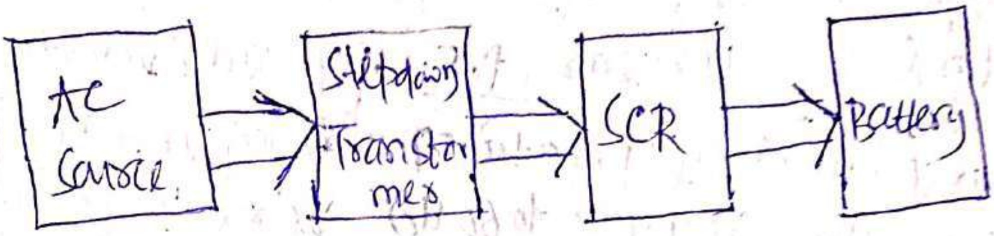
In the following table, comparison is made between linear power supply and switched mode power supplying basing on various factors of considerations.

factors	linear P.S.	switched mode P.S.
1) size and weight.	As it is operated on low freq (50 to 60 Hz) the size of the transformer is large and so heavy.	frequency of operations being large 50KHz to 1MHz the size of the transformer is very small.
2) output voltage	- any voltage at o/p with a transformer. - for transformer less o/p is less than i/p. - if unregulated voltage varies with load.	- Any voltage can be achieved at the output. voltage varies a little with load.
3) Efficiency heat and power dissipation.	- if unregulated heat and power dissipation is more - if regulated transformer iron and copper loss is more	- As the switching transformer is made fully ON or fully OFF, power dissipation is very less.
4) complexity	- in unregulated form only diode & capacitors used. - in regulated form - regulating IC or descrete components are used.	- controller IC and several transistors, transformers, diodes and filter capacitors are used.

(5) Radio fre...

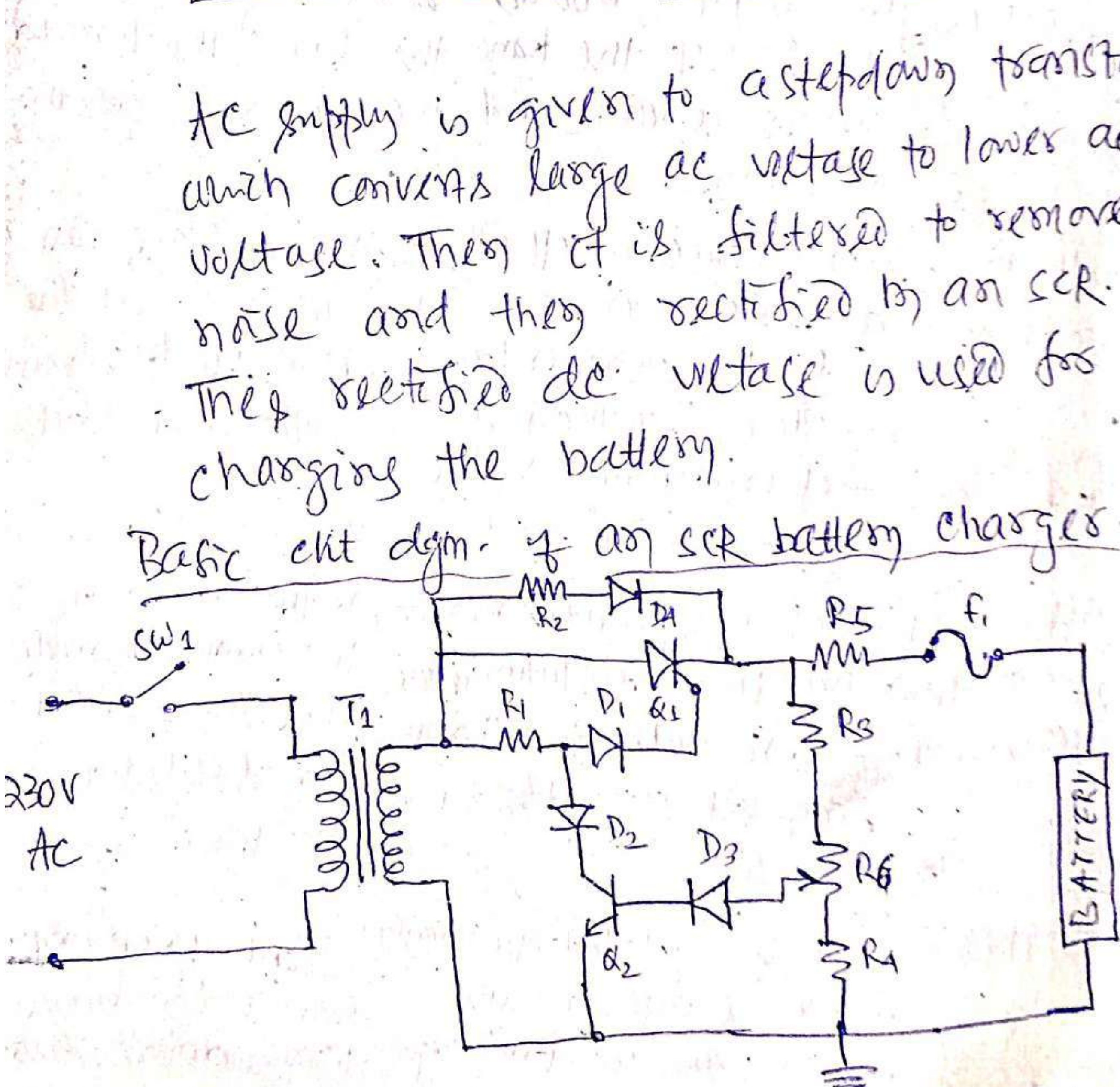
8.5 Schematic diagram of an SCR battery charger;

The basic block diagram of a battery charger using SCR can be as given –



AC supply is given to a stepdown transformer which converts large ac voltage to lower ac voltage. Then it is filtered to remove noise and then rectified by an SCR. This rectified dc voltage is used for charging the battery.

Basic ckt dgm. of an SCR battery charger



$R_1 \rightarrow 330\,\Omega$, $R_2 \rightarrow 22\,\Omega$, $R_3 \rightarrow 820\,\Omega$, $R_4 \rightarrow 100\,\Omega$, $R_5 \rightarrow 1\,\Omega$,
$R_6 \rightarrow 100\,\Omega$, $D_1, D_2, D_4 \rightarrow$ 1N4001, $D_3 \rightarrow$ 1N1615, $Q_1 \rightarrow$ TYN612,
$Q_2 \rightarrow$ BC547C, $F_1 \rightarrow 2A$.