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Department of Electronics & Communication Engineering

POWER DEVICES & MACHINES

Q.1 Draw and explain dynamic characteristics of SCR also define:

i) Reverse recovery ii) Gate recovery time

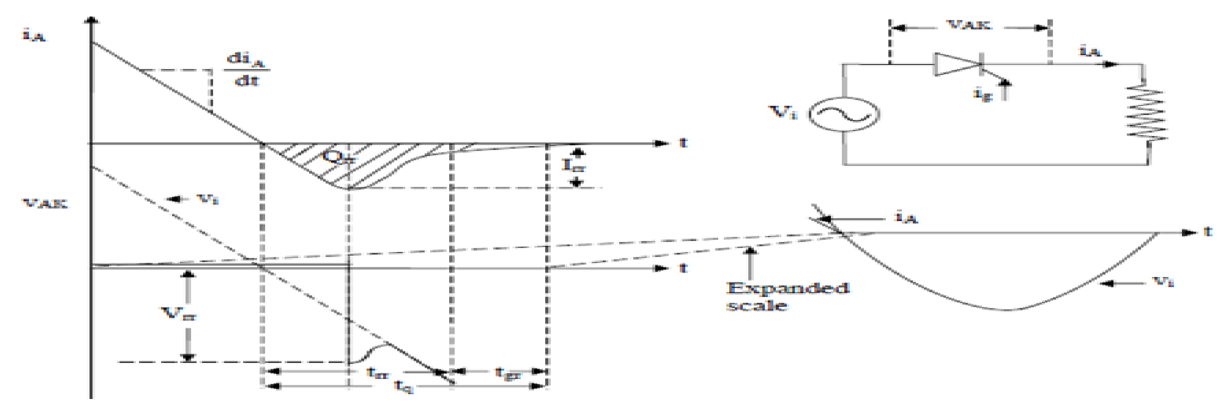
Ans:

Once the thyristor is switched on or in other point of view, the anode current is above latching current, the gate losses control over it. That means gate circuit cannot turn off the device. For turning off the SCR anode current must fall below the holding current. After anode current fall to zero we cannot apply forward voltage across the device due to presence of carrier charges into the four layers. So we must sweep out or recombine these charges to proper turn off of SCR. So turn off time of SCR can be defined as the interval between anode current falls to zero and device regains its forward blocking mode. On the basis of removing carrier charges from the four layers, turn off time of SCR can be divided into two time regions,

1. Reverse Recovery Time.
2. Gate Recovery Time

Reverse Recovery Time

It is the interval in which change carriers remove from J1, and J3 junction. At time t1, anode current falls to zero and it will continue to increase in reverse direction with same slope (di/dt) of the forward decreasing current. This negative current will help to sweep out the carrier charges from junction J1 and J3. At the time t2 carrier charge density is not sufficient to maintain the reverse current hence after t2 this negative current will start to decrease. The value of current at t2 is called reverse recovery current. Due to rapid decreasing of anode current, a reverse spike of voltage may appear across the SCR. Total recovery time t3 - t1 is called reverse recovery time. After that, device will start to follow the applied reverse voltage and it gains the property to block the forward voltage



Q.2 Explain Two transistor analogy of SCR

Ans:

Basic operating principle of SCR, can be easily understood by the two transistor model of SCR or analogy of silicon controlled rectifier, as it is also a combination of P and N layers, shown in figure below.

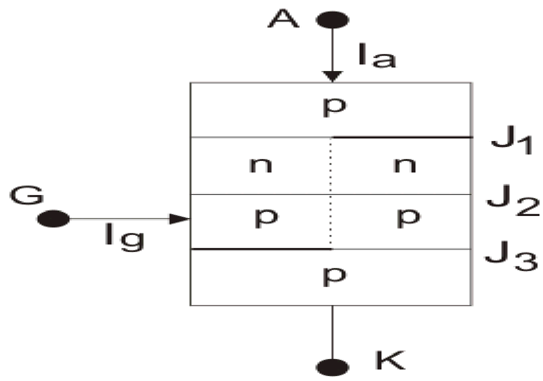
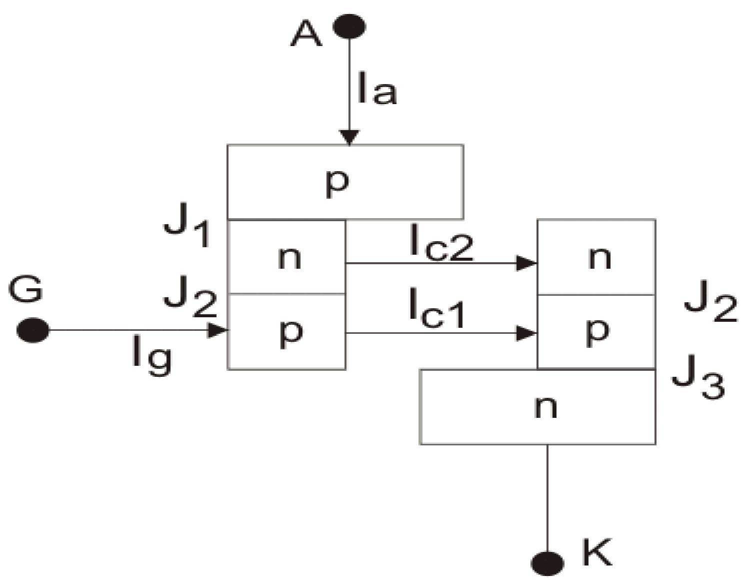


Fig:PNPN Thyristor

This is a pnpn thyristor. If we bisect it through the dotted line then we will get two transistors i.e. one pnp transistor with J_1 and J_2 junctions and another is with J_2 and J_3 junctions as shown in figure below.When the transistors are in off state, the relation between the collector current and emitter current is shown below



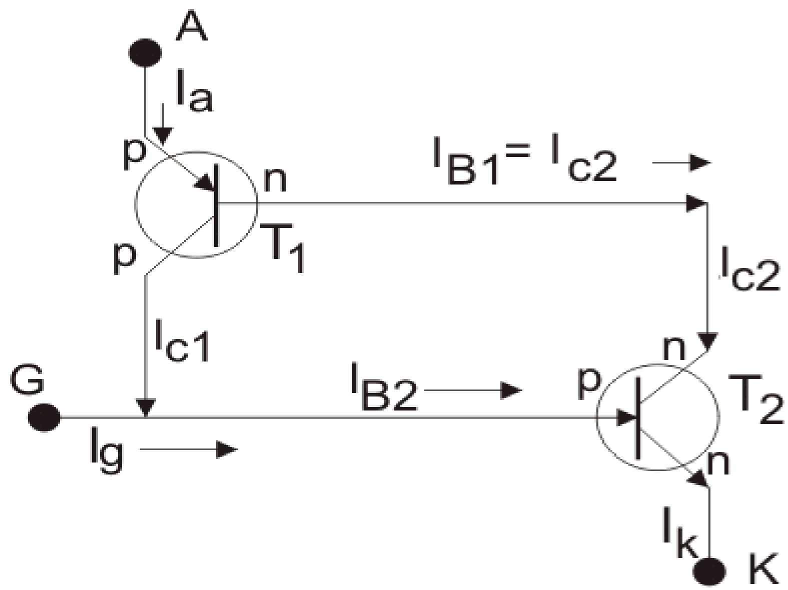


Fig:Two Transistor Analogy

Here, I_C is collector current, I_E is emitter current, I_{CBO} is forward leakage current, α is common base forward current gain and relationship between I_C and I_B is $I_C = \beta I_B$ Where, I_B is base current and β is common emitter forward current gain. Let's for transistor T_1 this relation holds

$$I_{C1} = \alpha_1 I_a + I_{CBO1} \ldots\ldots (i)$$

And that for transistor T_2

$$I_{C2} = \alpha_2 I_k + I_{CBO2} \ldots\ldots (ii)\ again\ I_{C2} = \beta_2 I_{B2}$$

Now, by the analysis of two transistors model we can get anode current,

$$I_a = I_{C1} + I_{C2}\ \ [applying\ KCL]$$

From equation (i) and (ii), we get, $I_a = \alpha_1 I_a + I_{CBO1} + \alpha_2 I_k + I_{CBO2} \ldots\ldots (iii)$

If applied gate current is I_g then cathode current will be the summation of anode current and gate current i.e.

$$I_k = I_a + I_g$$

By substituting this valyue of I_k in (iii) we get,

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

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

From this relation we can assure that with increasing the value of $(\alpha_1 + \alpha_2)$ towards unity, corresponding anode current will increase. Now the question is how $(\alpha_1 + \alpha_2)$ increasing? Here is the explanation using two transistor model of SCR. At the first stage when we apply a gate current I_g, it acts as base current of $T_{,2}$ transistor i.e. $I_{B2} = I_g$ and emitter current i.e. $I_k = I_g$ of the $T_{,2}$ transistor. Hence establishment of the emitter current gives rise α_2 as

$$\alpha_2 = \frac{I_{CBO1}}{I_g}$$

Presence of base current will generate collector current as

$$I_{C2} = \beta_2 \times I_{B2} = \beta_2 I_g$$

This I_{C2} is nothing but base current I_{B1} of transistor $T_{,1}$, which will cause the flow of collector current,

$$I_{C2} = \beta_1 \times I_{B1} = \beta_1 \beta_2 I_g$$

I_{C1} and I_{B1} lead to increase I_{C1} as

$$I_a = I_{C1} + I_{B1}$$

and hence, α_1 increases. Now, new base current of T_2 is

$$I_g + I_{C1} = (1 + \beta_1 \beta_2) I_g,$$

which will lead to increase emitter current

$$I_k = I_a + I_{C1}$$

and as a result α_2 also increases and this further increases

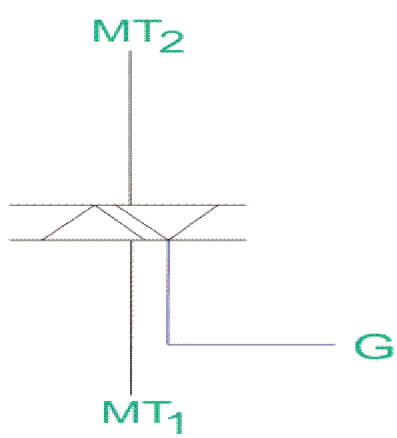
$$I_{C2} = \beta_2 (1 + \beta_1 \beta_2) I_g.$$

As $I_{B1} = I_{C2}$, α_1 again increases. This continuous positive feedback effect increases $(\alpha_1 + \alpha_2)$ towards unity and anode current tends to flow at a very large value. The value current then can only be controlled by external resistance of the circuit.

Q.3 Explain the Four operating modes of TRIAC

Ans:

Triac is a three terminal AC switch which is different from the other silicon controlled rectifiers in the sense that it can conduct in both the directions that is whether the applied gate signal is positive or negative, it will conduct. Thus, this device can be used for AC systems as a switch.



Two SCRs are connected in inverse parallel with gate terminal as common. Gate terminals is connected to both the N and P regions due to which gate signal may be applied which is irrespective of the polarity of the signal. Here, we do not have anode and cathode since it works for both the polarities which means that device is bilateral. It consists of three terminals namely, main terminal 1(MT1), main terminal 2(MT2), and gate terminal G.

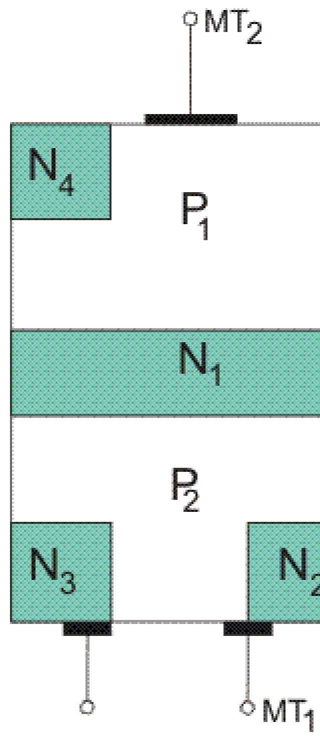


Figure shows the construction of a triac. There are two main terminals namely MT1 and MT2 and the remaining terminal is gate terminal.

Operation of Triac

The triac can be turned on by applying the gate voltage higher than break over voltage. However, without making the voltage high, it can be turned on by applying the gate pulse of 35 micro seconds to turn it on. When the voltage applied is less than the break over voltage, we use gate triggering method to turn it on. There are four different modes of operations, they are-

1. When MT2 and Gate being Positive with Respect to MT1 When this happens, current flows through the path P1-N1-P2-N2. Here, P1-N1 and P2-N2 are forward biased but N1-P2 is reverse biased. The triac is said to be operated in positively biased region. Positive gate with respect to MT1 forward biases P2-N2 and breakdown occurs.

2. When MT2 is Positive but Gate is Negative with Respect to MT1 The current flows through the path P1-N1-P2-N2. But P2-N3 is forward biased and current carriers injected into P2 on the triac.
3. When MT2 and Gate are Negative with Respect to MT1 Current flows through the path P2-N1-P1-N4. Two junctions P2-N1 and P1-N4 are forward biased but the junction N1-P1 is reverse biased. The triac is said to be in the negatively biased region.
4. When MT2 is Negative but Gate is Positive with Respect to MT1 P2-N2 is forward biased at that condition. Current carriers are injected so the triac turns on. This mode of operation has a disadvantage that it should not be used for high (di/dt) circuits. Sensitivity of triggering in mode 2 and 3 is high and if marginal triggering capability is required, negative gate pulses should be used. Triggering in mode 1 is more sensitive than mode 2 and mode 3.

Q.4 Explain AC phase control using TRIAC which is fired using DIAC

Ans:

and therefore power applied to a load, in this case a motor, for both the positive and negative halves of the input waveform. This type of AC motor speed control gives a fully variable and linear control because the voltage can be adjusted from zero to the full applied voltage as shown.

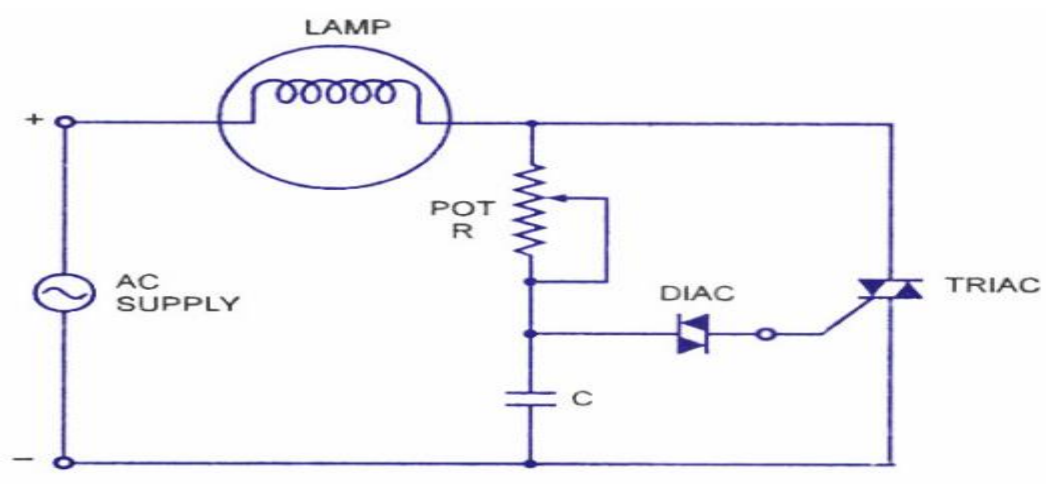


Fig:TRIAC Phase Control Circuit

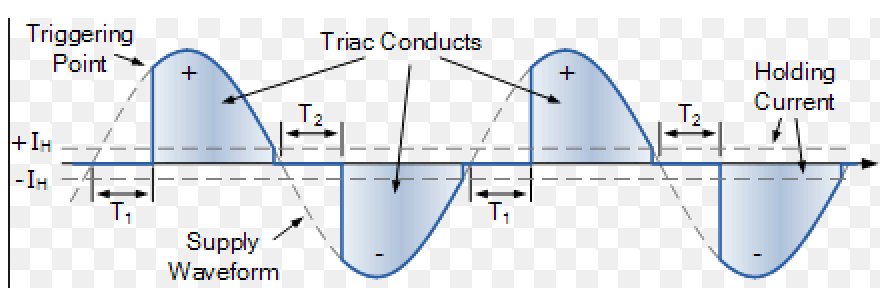


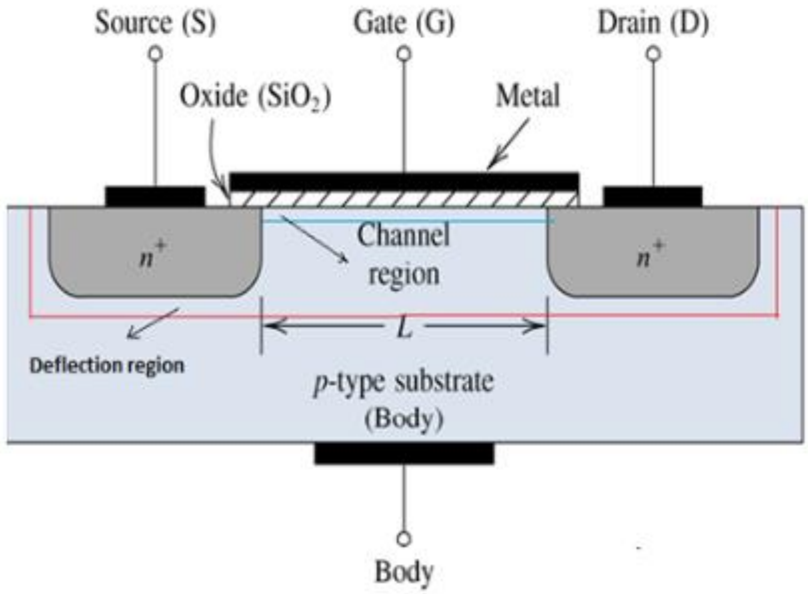
Fig:Waveform

This basic phase triggering circuit uses the triac in series with the motor across an AC sinusoidal supply. The variable resistor, VR1 is used to control the amount of phase shift on the gate of the triac which in turn controls the amount of voltage applied to the motor by turning it ON at different times during the AC cycle.The triac's triggering voltage is derived from the VR1 – C1 combination via the Diac (The diac is a bidirectional semiconductor device that helps provide a sharp trigger current pulse to fully turn-ON the triac).At the start of each cycle, C1 charges up via the variable resistor, VR1. This continues until the voltage across C1 is sufficient to trigger the diac into conduction which in turn allows capacitor, C1 to discharge into the gate of the triac turning it "ON". Once the triac is triggered into conduction and saturates, it effectively shorts out the gate triggering phase control circuit connected in parallel across it and the triac takes control for the remainder of the half-cycle. As we have seen above, the triac turns-OFF automatically at the end of the half-cycle and the VR1 – C1 triggering process starts again on the next half cycle. This simple triac speed control circuit is suitable for not only AC motor speed control but for lamp dimmers and electrical heater control and in fact is very similar to a triac light dimmer used in many homes. However, a commercial triac dimmer should not be used as a motor speed controller as generally triac light dimmers are intended to be used with resistive loads only such as incandescent lamps.

Q.5 Draw and explain the construction and working of N - channel enhancement power MOSFET

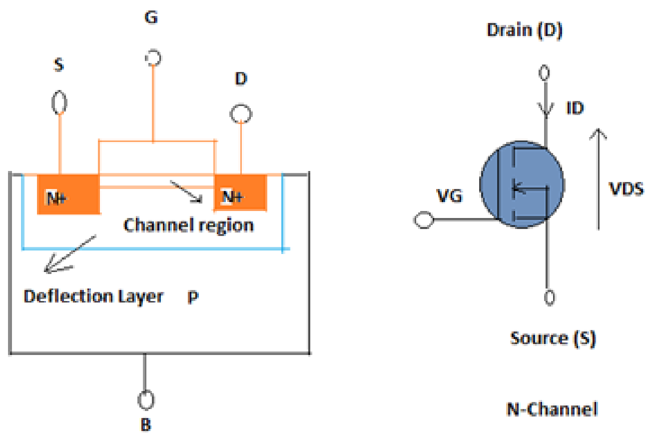
Ans:

The aim of the MOSFET is to be able to control the voltage and current flow between the source and drain. It works almost as a switch. The working of MOSFET depends upon the MOS capacitor. The MOS capacitor is the main part of MOSFET. The semiconductor surface at the below oxide layer which is located between source and drain terminal. It can be inverted from p-type to n-type by applying a positive or negative gate voltages respectively. When we apply the positive gate voltage the holes present under the oxide layer with a repulsive force and holes are pushed downward with the substrate. The depletion region populated by the bound negative charges which are associated with the acceptor atoms. The electrons reach channel is formed. The positive voltage also attracts electrons from the n+ source and drain regions into the channel. Now, if a voltage is applied between the drain and source, the current flows freely between the source and drain and the gate voltage controls the electrons in the channel. Instead of positive voltage if we apply negative voltage , a hole channel will be formed under the oxide layer.



N- Channel MOSFET:

The N-Channel MOSFET has a N- channel region between source and drain It is a four terminal device such as gate, drain , source , body. This type of MOSFET the drain and source are heavily doped n+ region and the substrate or body is P- type. The current flows due to the negatively charged electrons. When we apply the positive gate voltage the holes present under the oxide layer pushed downward into the substrate with a repulsive force. The depletion region is populated by the bound negative charges which are associated with the acceptor atoms. The electrons reach channel is formed. The positive voltage also attracts electrons from the n+ source and drain regions into the channel. Now, if a voltage is applied between the drain and source the current flows freely between the source and drain and the gate voltage controls the electrons in the channel. Instead of positive voltage if we apply negative voltage a hole channel will be formed under the oxide layer.

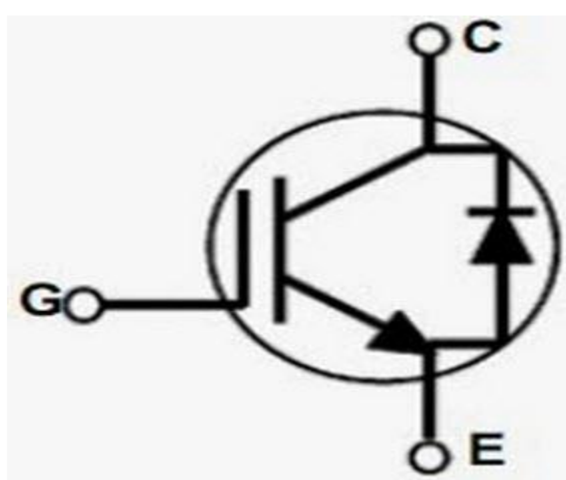


Enhancement MOSFET

Q.6 Explain IGBT structure, symbol and its output characteristics. Also explain its switching characteristic

Ans:

The IGBT (insulated gate bipolar transistor) is a three-terminal electronic component, and these terminals are termed as emitter, collector and gate. Two of its terminals namely collector and emitter are associated with a conductance path and the remaining terminal 'G' is associated with its control.The sum of amplification is achieved by the IGBT is a radio between its input and output signal. For a conventional BJT, the amount of gain is almost equal to the radio to the o/p current to the i/p current that is called a beta.

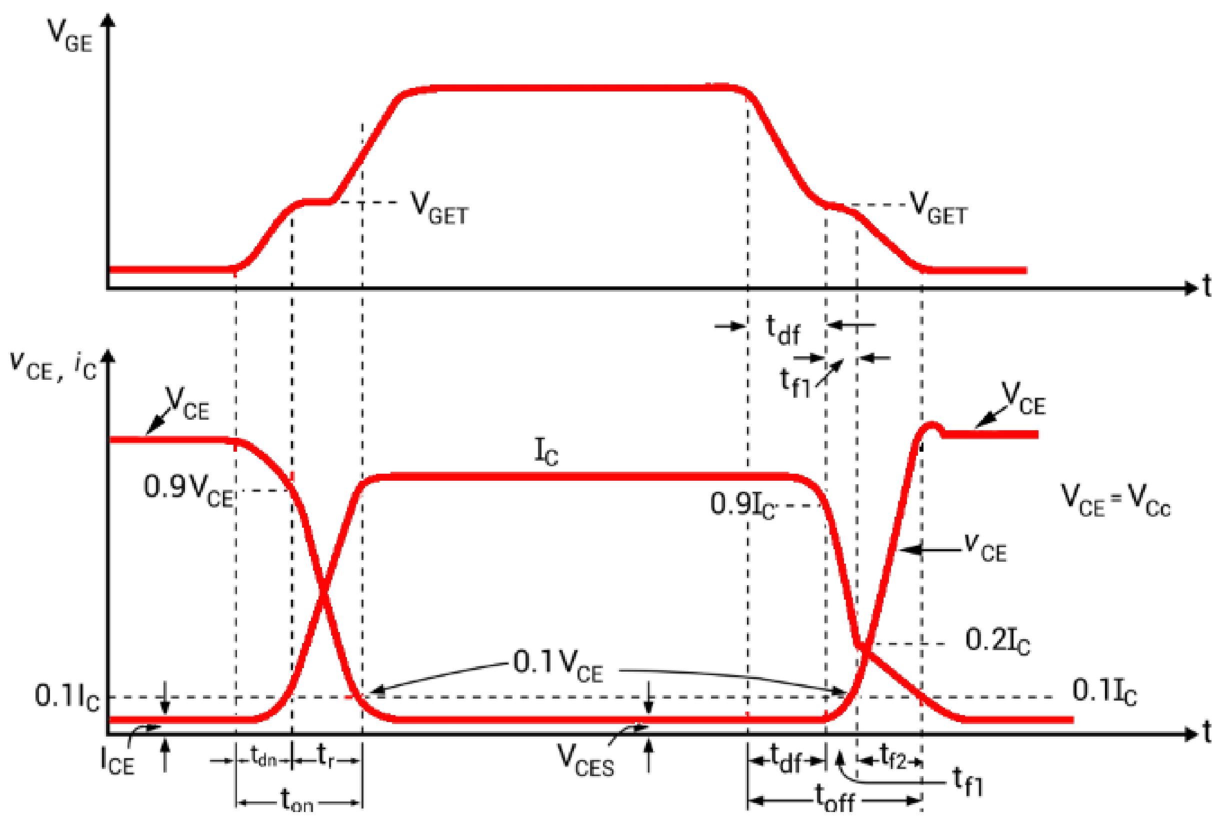


IGBT Symbol

For a MOSFET (metal oxide semiconductor field effect transistor), there is no i/p current as the gate terminal is isolated from the main current-carrying channel. Thus, the gain of the field effect transistor equals to the an FET's gain is equal to the ratio of o/p current change to i/p v change, Then the IGBT can be treated as a power BJT and the base current of this transistor is provided by an MOSFET.The IGBT is mainly used in small-signal amplifier circuits like BJT or MOSFET When the transistor combines the lower conduction loss of a BJT and MOSFET, then an ideal solid state switch occurs which is perfect for in various applications of power electronics.

An IGBT is simply switched "ON" and "OFF" by triggering and disabling its Gate terminal. A constant +Ve voltage i/p signal across the 'G' and the 'E' will retain the device in its "ON" state, while deduction of the i/p signal will cause it to turn "OFF" like BJT or MOSFET.

Switching Characteristics of IGBT:



Q.7 Draw and explain construction and working of GTO

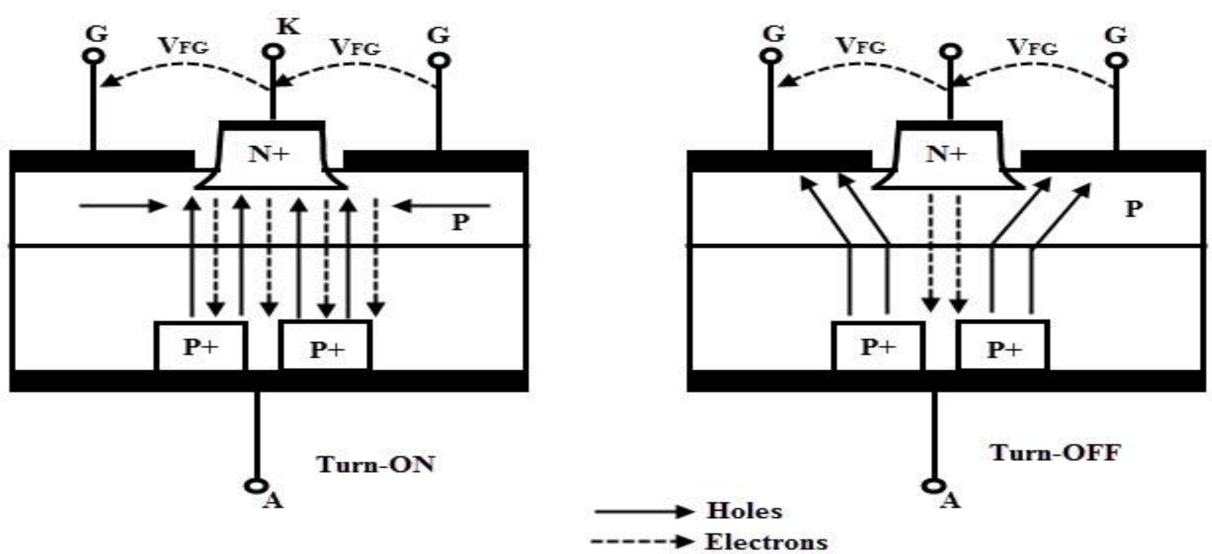
Ans:

A Gate Turn off Thyristor or GTO is a three terminal, bipolar (current controlled minority carrier) semiconductor switching device. Similar to conventional thyristor, the terminals are anode, cathode and gate as shown in figure below. As the name indicates, it has gate turn off capability.These are capable not only to turn ON the main current with a gate drive circuit, but also to turn it OFF. A small positive gate current triggers the GTO into conduction mode and also by a negative pulse on the gate, it is capable of being turned off. Observe in below figure that the gate has double arrows on it which distinguish the GTO from normal thyristor. This indicates the bidirectional current flow through the gate terminal.

The turn ON operation of GTO is similar to a conventional thyristor. When the anode terminal is made positive with respect to cathode by applying a positive gate current, the hole current injection from gate forward bias the cathode p-base junction. This results in the emission of electrons from the cathode towards the anode terminal. This induces the hole injection from the anode terminal into the base region. This injection of holes and electrons continuous till the GTO comes into the conduction state.

In case of thyristor, the conduction starts initially by turning ON the area of cathode adjacent to the gate terminal. And thus, by plasma spreading the remaining area comes into the conduction.

Unlike a thyristor, GTO consists of narrow cathode elements which are heavily interdigitated with gate terminal, thereby initial turned ON area is very large and plasma spreading is small. Hence the GTO comes into the conduction state very quickly.



To turn OFF a conducting GTO, a reverse bias is applied at the gate by making the gate negative with respect to cathode. A part of the holes from the P base layer is extracted through the gate which suppress the injection of electrons from the cathode.

In response to this, more hole current is extracted through the gate results more suppression of electrons from the cathode. Eventually, the voltage drop across the p base junction causes to reverse bias the gate cathode junction and hence the GTO is turned OFF.

During the hole extraction process, the p-base region is gradually depleted so that the conduction area squeezed. As this process continuous, the anode current flows through remote areas forming high current density filaments. This causes local hot spots which can damage the device unless these filaments are extinguished quickly.

By the application of high negative gate voltage these filaments are extinguished rapidly. Due to the N base region stored charge, the anode to gate current continues to flow even though the cathode current is ceased. This is called a tail current which decays exponentially as the excess charge carriers are reduced by the recombination process. Once the tail current reduced to a leakage current level, the device retains its forward blocking characteristics.

Q.8 Write short notes on:

i) Gate drive circuit for MOSFET and IGBT

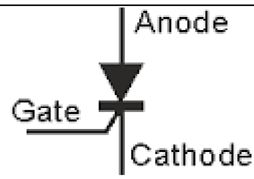
ii) Comparison between SCR,MOSFET and IGBT

Ans:

i) Gate drive circuit for MOSFET and IGBT

ii) Comparison between SCR,MOSFET and IGBT

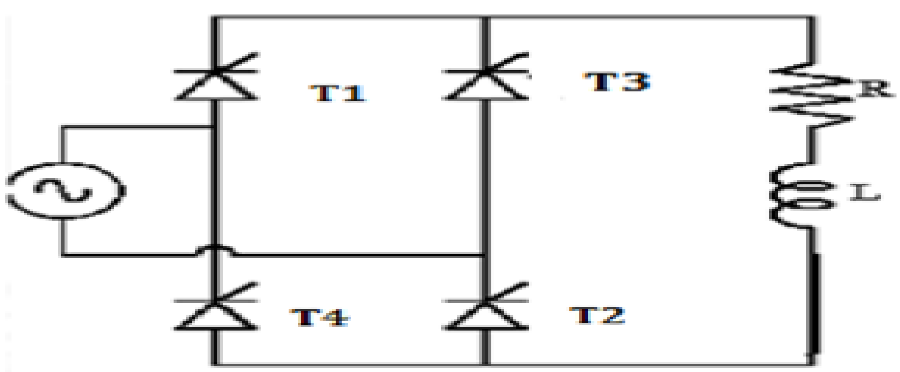
Sr.No.	**SCR**	**MOSFET**
1	Minority Carrier device	Majority Carrier device
2	Current driven Device	Voltagr driven device
3	Low switching speed	High switching speed
4	Low resistive input impedence	Purely capacitive high input impedence
5	Oly single puse required to turn ON	No DC is required to maintain conduction except during turn ON & turn OFF
6	Can be connected in series easily with	Series connection is deficult with voltage

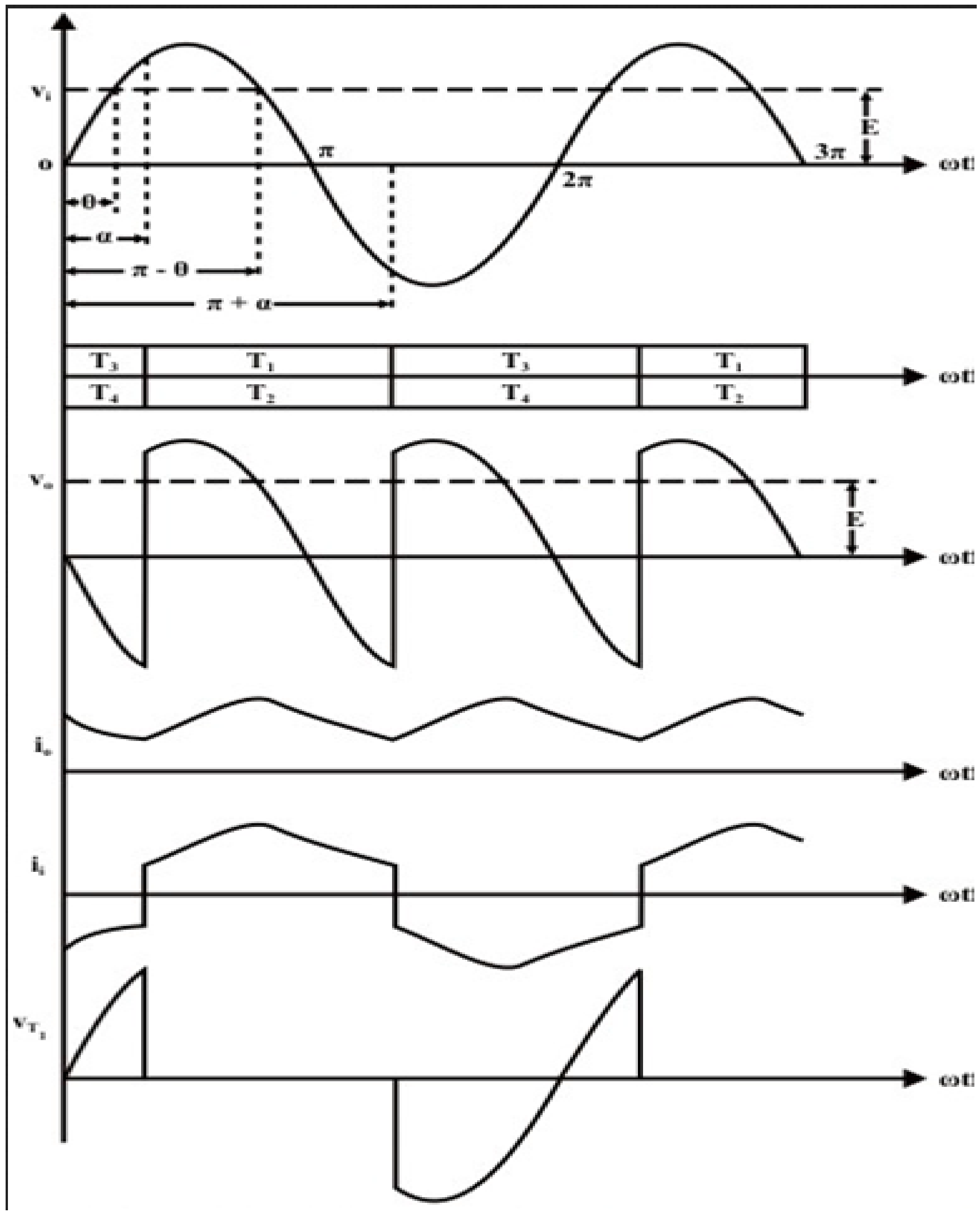
	voltage equilising circuit	euilising circuit
7	Thermal Run away	No thermal Run away
8	Line comutation or separate switching arrangement is required for turn OFF	No separate circuit is required for Turn OFF
9	Most robust device	Less robust device
10	Low ON state voltage drop	High ON state voltage drop
11	Less Temperature sensitive	Temperature sensitive
12	No second break down	Less susceptible to second breakdown
13	High voltage, high current device	High current ,medium voltage device
14		

Q.9 Explain the working of 1 phase half wave controlled rectifier with RL load

Ans:

Figure below shows Single phase Full Wave Controlled Rectifiers with RL load.





Operation of this mode can be divided between four modes

Mode 1 (α toπ)

• In positive half cycle of applied ac signal, SCR's T1 & T2 are forward bias & can be turned on at an angle α.

• Load voltage is equal to positive instantaneous ac supply voltage. The load current is positive, ripple free, constant and equal to Io.

• Due to positive polarity of load voltage & load current, load inductance will store energy.

Mode 2 (π toπ+α)

• At wt=π, input supply is equal to zero & after π it becomes negative. But inductance opposes any change through it.

• In order to maintain a constant load current & also in same direction. A self inducedemf appears across ‘L’ as shown.

• Due to this induced voltage, SCR’s T1 & T2 are forward bais in spite the negative supply voltage.

• The load voltage is negative & equal to instantaneous ac supply voltage whereas load current is positive.

• Thus, load acts as source & stored energy in inductance is returned back to the ac supply.

Mode 3 (π+α to 2π)

• At wt=π+α SCR’s T3 & T4 are turned on & T1, T2 are reversed bias.

• Thus , process of conduction is transferred from T1,T2 to T3,T4.

• Load voltage again becomes positive & energy is stored in inductor

• T3, T4 conduct in negative half cycle from (π+α) to 2π

• With positive load voltage & load current energy gets stored

Mode 4 (2π to 2π+α)

• At wt=2π, input voltage passes through zero.

• Inductive load will try to oppose any change in current if in order to maintain load current constant & in the same direction.

• Induced emf is positive & maintains conducting SCR’s T3 & T4 with reverse polarity also.

• Thus VL is negative & equal to instantaneous ac supply voltage. Whereas load current continues to be positive.

• Thus load acts as source & stored energy in inductance is returned back to ac supply

• At wt=α or 2π+α, T3 & T4 are commutated and T1,T2 are turned on.

Q.10 Explain the working of 3 phase full wave fully controlled Converter

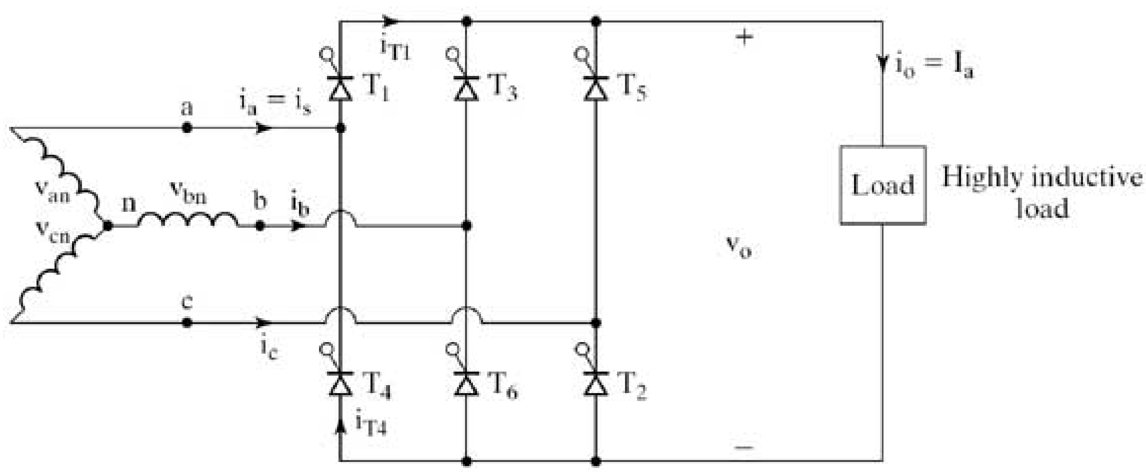
Ans:

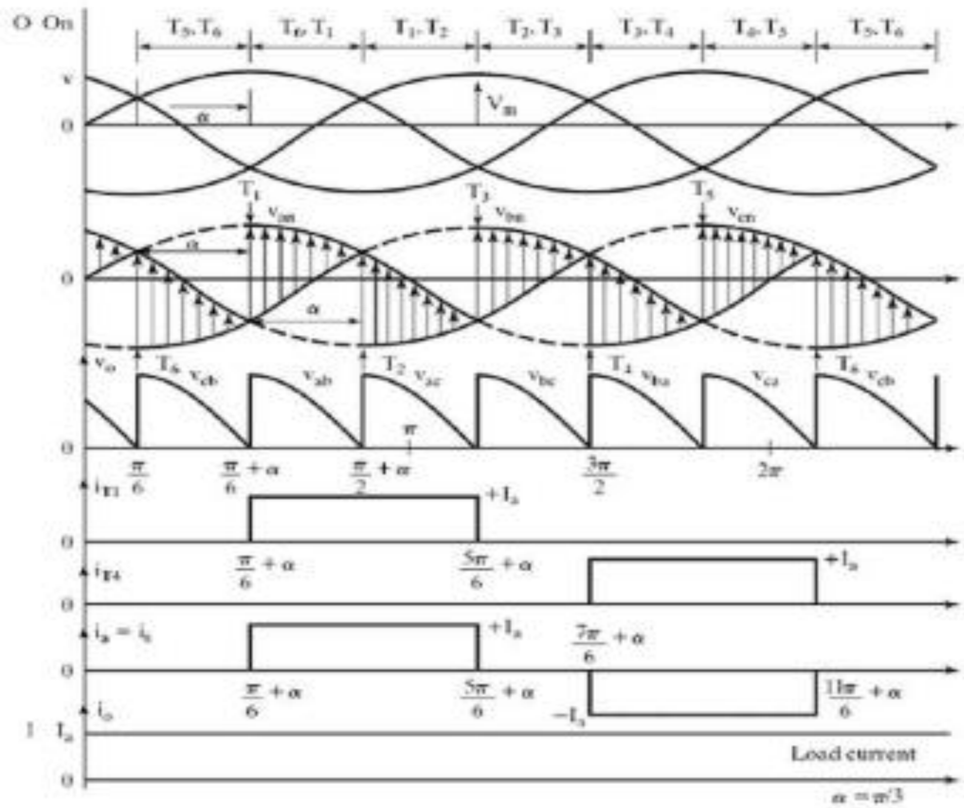
three phase full converter is a fully controlled bridge controlled rectifier using six thyristors connected in the form of a full wave bridge configuration. All the six thyristors are controlled switches which are turned on at a appropriate times by applying suitable gate trigger signals.

The**three phase full converter** is extensively used in industrial power applications upto about 120kW output power level, where two quadrant operations is required. The figure shows a **three phase full converter** with highly inductive load. This circuit is also known as three phase full wave bridge or as a six pulse converter.

The thyristors are triggered at an interval of (∏/3) radians (i.e. at an interval of 30°). The frequency of output ripple voltage is 6*fs* and the filtering requirement is less than that of **three phase semi and half wave converters**.

At ω*t=(∏/6 +α)* , thyristor is already conducting when the thyristor is turned on by applying the gating signal to the gate of . During the time period ω*t=(∏/6 +α)* to (∏/2 +α), thyristors and conduct together and the line to line supply voltage appears across the load.
At ω*t=(∏/2 +α)*, the thyristor *T2* is triggered and *T6* is reverse biased immediately and *T6* turns off due to natural commutation. During the time period ω*t=(∏/ +α) to (5∏/6 +α)*, thyristor *T1* and *T2* conduct together and the line to line supply voltage appears across the load.
The thyristors are numbered in the circuit diagram corresponding to the order in which they are triggered. The trigger sequence (firing sequence) of the thyristors is 12, 23, 34, 45, 56, 61, 12, 23, and so on. The figure shows the waveforms of three phase input supply voltages, output voltage, the thyristor current through *T1* and *T4*, the supply current through the line ‘a’.





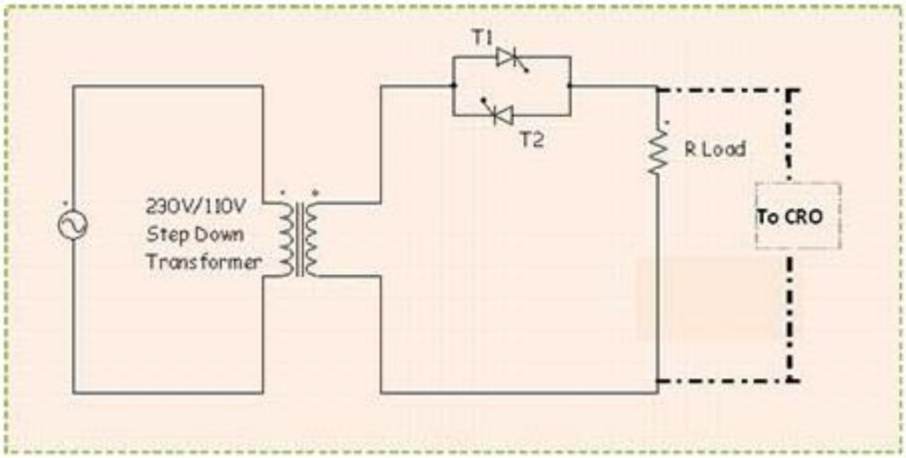
Q.11 Explain the operation of single phase AC voltage controlled with R load

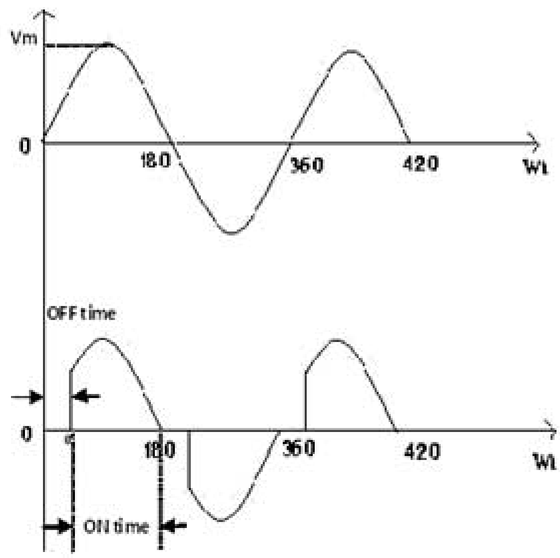
Ans:

AC voltage controllers (**ac line voltage controllers**) are employed to vary the RMS value of the alternating voltage applied to a load circuit by introducing Thyristors between the load and a constant voltage ac source. The RMS value of alternating voltage applied to a load circuit is controlled by controlling the triggering angle of the Thyristors in the ac voltage controller circuits.
In phase control the Thyristors are used as switches to connect the load circuit to the input ac supply, for a part of every input cycle. That is the ac supply voltage is chopped using Thyristors during a part of each input cycle.

The thyristor switch is turned on for a part of every half cycle, so that input supply voltage appears across the load and then turned off during the remaining part of input half cycle to disconnect the ac supply from the load.

By controlling the phase angle or the trigger angle 'α' (delay angle), the output RMS voltage across the load can be controlled. The trigger delay angle ‘α’ is defined as the phase angle (the value of ωt) at which the thyristor turns on and the load current begins to flow.





Q. 12 Draw and explain the working of step up chopper. Also derive an expression of output voltage

Ans:

A chopper is a high speed ON/OFF switch. It connects source to load and disconnect the load from the source at very fast speed. Hence a chopped output voltage is obtained from a constant DC supply. If in a chopper average output voltage Vo is greater than the input voltage Vs, then this type of chopper is called as step up chopper. In this chopper, a large inductor is in series with with source voltage. When chopper CH is ON, the path is closed and inductor store energy during this period.

When CH is ON it short circuits the load. Hence output voltage during T_{ON} is zero. During this period inductor gets charged. So,

$$V_S = V_L$$

$$L\frac{di}{dt} = V_s \Rightarrow \frac{\Delta I}{T_{ON}} = \frac{V_s}{L} \Rightarrow \Delta I = \frac{V_s}{L}T_{ON} \cdots (iii)$$

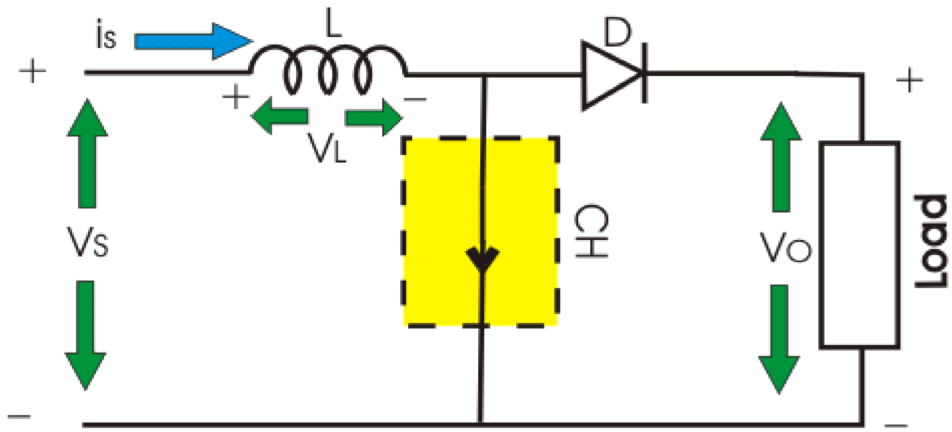


Fig:Step up Chopper

Where ΔI is the peak to peak inductor current. When CH is OFF inductor L discharges through the load. So, we will get summation of both source voltage V_S and inductor Voltage V_L as output voltage, i.e.

$$V_o = V_s + V_L \Rightarrow V_L = V_o - V_s \Rightarrow L\frac{di}{dt} = V_o - V_s$$

$$\Rightarrow L\frac{\Delta I}{T_{OFF}} = V_o - V_s \Rightarrow \Delta I = \frac{V_o - V_s}{L}T_{OFF} \cdots (iv)$$

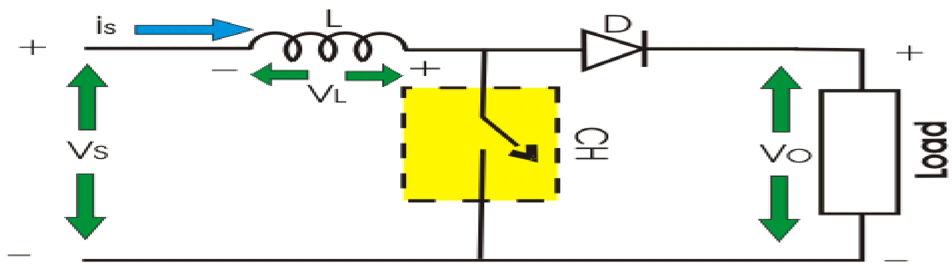


Fig:Step up Chopper

Now, by equating (iii) & (iv),

$$\frac{V_s}{L}T_{ON} = \frac{V_o - V_s}{L}T_{OFF} \Rightarrow V_s(T_{ON} + T_{OFF}) = V_o T_{OFF}$$

$$\Rightarrow V_o = \frac{TV_s}{T_{OFF}} = \frac{V_s}{(T - T_{ON})/T}$$

$$Therefore,\ average\ output\ voltage,\ V_o = \frac{V_s}{1 - D}$$

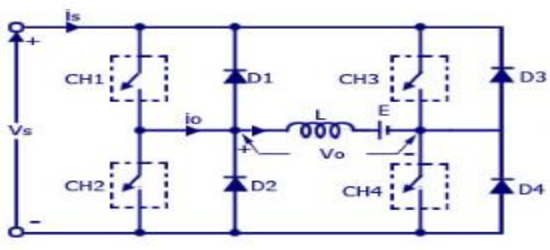
Where, $D = T_{ON}/T$, Duty cycle of chopper.

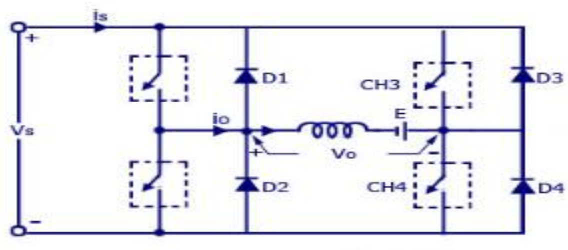
As we can vary T_{ON} from 0 to T, cso $0 \leq D \leq 1$. Hence V_O can be varied from V_S to ∞. It is clear that output voltage is always greater than the input voltage and hence it boost up or increase the voltage level.

Q.13 Explain the working of Four Quadrant Chopper

Ans:

Type E chopper is the four quadrant chopper. Type E or the fourth quadrant chopper consists of four semiconductor switches and four diodes arranged in antiparallel. The 4 choppers are numbered according to which quadrant they belong. Their operation will be in each quadrant and the corresponding chopper only be active in its quadrant





- **First Quadrant**

During the first quadrant operation the chopper CH4 will be on . Chopper CH3 will be off and CH1 will be operated. AS the CH1 and CH4 is on the load voltage v_0 will be equal to the source voltage V_s and the load current i_0 will begin to flow . v_0 and i_0 will be positive as the first quadrant operation is taking place. As soon as the chopper CH1 is turned off, the positive current freewheels through CH4 and the diode D2 . The type E chopper acts as a step- down chopper in the first quadrant.

- **Second Quadrant**

In this case the chopper CH2 will be operational and the other three are kept off. As CH2 is on negative current will starts flowing through the inductor L . CH2 ,E and D4. Energy is stored in the inductor L as the chopper CH2 is on. When CH2 is off the current will be fed back to the source through the diodes D1 and D4. Here (E+L.di/dt) will be more than the source voltage V_s . In second quadrant the chopper will act as a step-up chopper as the power is fed back from load to source

- **Third Quadrant**

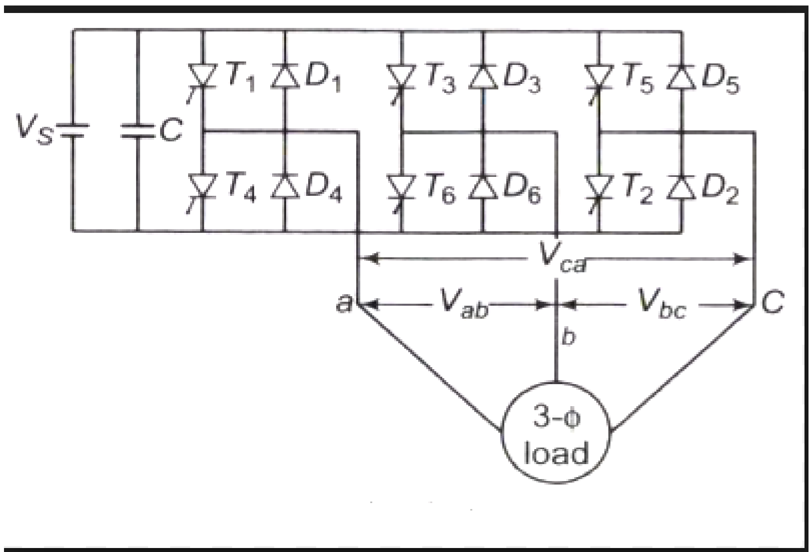
In third quadrant operation CH1 will be kept off , CH2 will be on and CH3 is operated. For this quadrant working the polarity of the load should be reversed. As the chopper CH3 is on, the load gets connected to the source V_s and v_0 and i_0 will be negative and the third quadrant operation will takes place. This chopper acts as a step-down chopper

- **Fourth Quadrant**

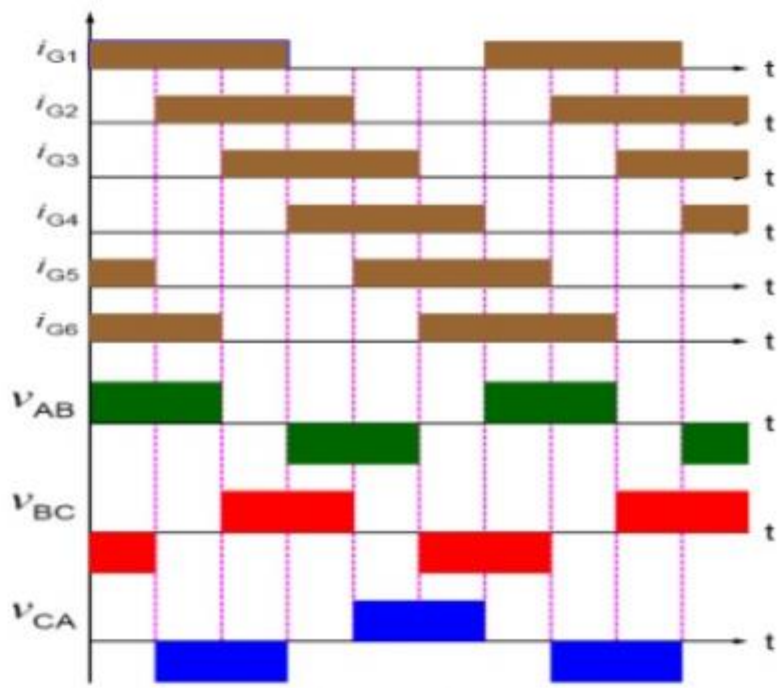
CH4 will be operated and CH1, CH2 and CH3 will be off. When the chopper CH4 is turned on positive current starts to flow through CH4, D2 ,E and the inductor L will store energy. As the CH4 is turned off the current is feedback to the source through the diodes D2 and D3 , the operation will be in fourth quadrant as the load voltage is negative but the load current is positive. The chopper acts as a step up chopper as the power is fed back from load to source.

Q.14 Explain the operation of 3 phase full bridge inverter in 180 degree mode operation feeding a star connected purely resistive load.

Ans:



V_S
C
T_1
D_1
T_3
D_3
T_5
D_5
T_4
D_4
T_6
D_6
T_2
D_2
V_{ca}
a
V_{ab}
V_{bc}
C
b
3-ϕ
load



i_{G1}
i_{G2}
i_{G3}
i_{G4}
i_{G5}
i_{G6}
v_{AB}
v_{BC}
v_{CA}
t

Q. 15 Explain the operation of 1 phase full bridge inverter. Draw the input and output waveforms

Ans:

- Full bridge converter is also basic circuit to convert dc to ac.

- An ac output is synthesized from a dc input by closing and opening switches in an appropriate sequence.
- There are also four different states depending on which swithces are closed.

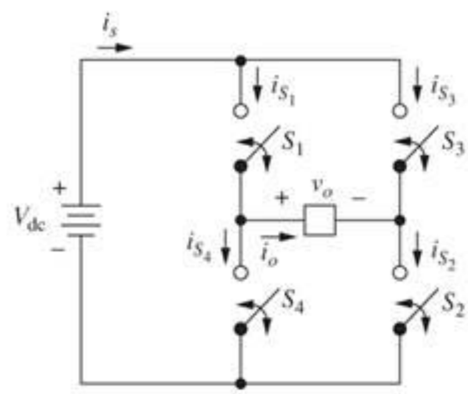


Fig: Single phase bridge inverter

State	Switches Closed	Vo
1	S1 & S2	+ Vdc
2	S3 & S4	-Vdc
3	S1 & S3	0
4	S2 & S4	0

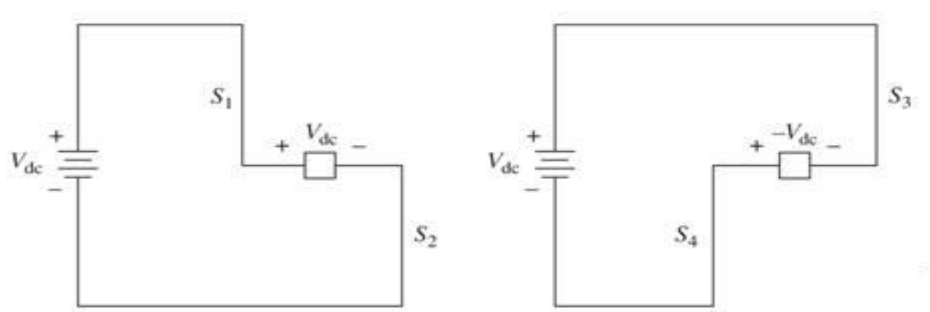


Fig: State 1 and State 2

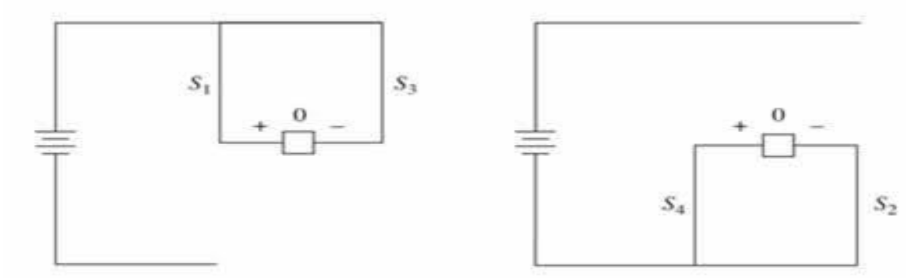
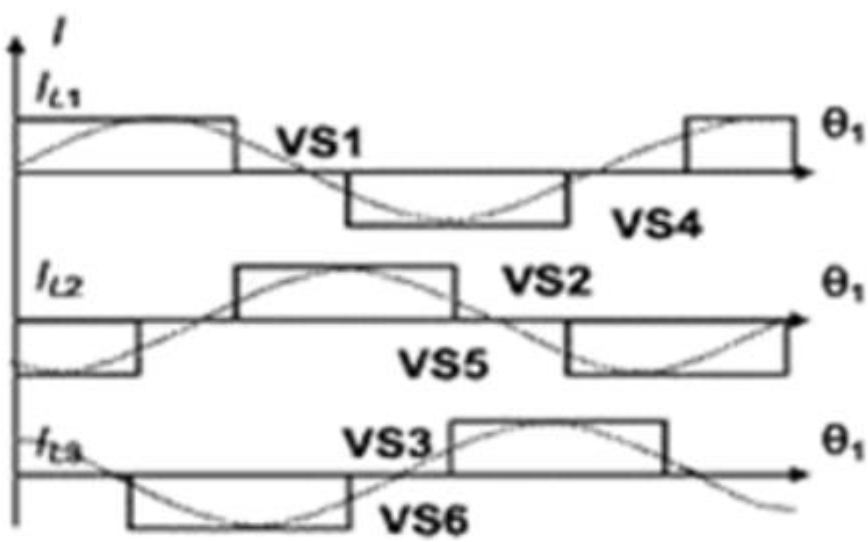


Fig: State 3 and State 4

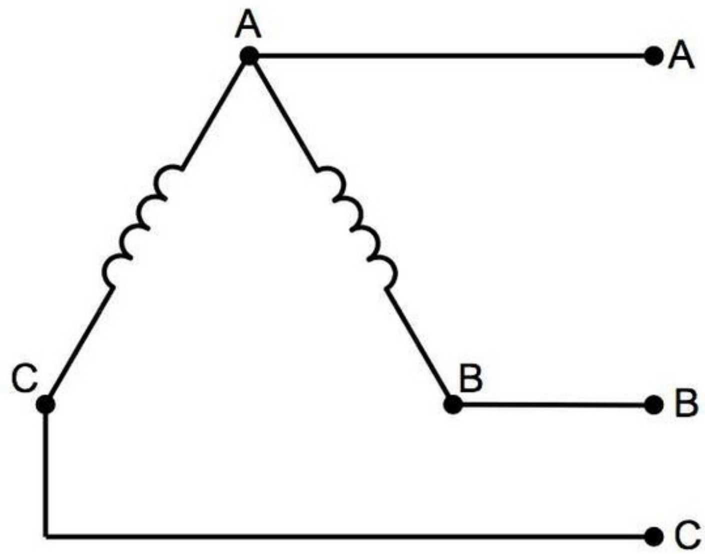
- Switches S1 and S4 should not be closed at the same time. S2 and S3 should be be closed in parallel too.
- Otherwise, a short circuit would exist across the dc source.
- Real switches do not turn on or off instantaneously. Hence, switching transition times must be accomodated in the control of switches.
- Overlap of switch "on" will cause short circuit (shoot-through fault) across the dc voltage source.
- The time allowed for switching is called *blanking time*.



Q. 16 Write short notes on:

i) open-delta connection

Ans:

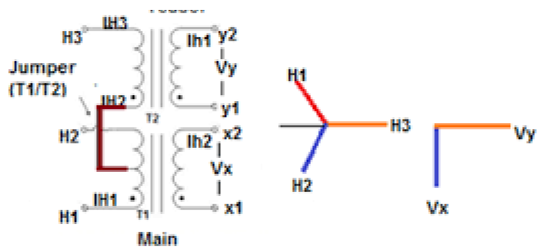


Open-delta connection is also called **V-connection** and can be explained as a temporary or emergency connection made with a three-phase electrical circuit in which one out of the three transformers is omitted and the load it used to carry is distributed among the rest two transformers and the one side of the delta phase is left open. As compared to a conventional option, it only delivers 57.7% of the transformer. It is typically utilised for small loads where cost is considered important. Open Delta Connection is used in underground mines, where the chances of winding failure are high

ii) Scott connection

There are two main reasons for the need to transform from three phases to two phases,

To give a supply to an existing two phase system from a three phase supply.
To supply two phase furnace transformers from a three phase source.
Two-phase systems can have 3-wire, 4-wire, or 5-wire circuits. It is needed to be considering that a two-phase system is not 2/3 of a three-phase system. Balanced three-wire, two-phase circuits have two phase wires, both carrying approximately the same amount of current, with a neutral wire carrying 1.414 times the currents in the phase wires. The phase-to-neutral
voltages are 90° out of phase with each other.
Two phase 4-wire circuits are essentially just two ungrounded single-phase circuits that are electrically 90° out of phase with each other. Two phase 5-wire circuits have four phase wires plus a neutral; the four phase wires are 90° out of phase with each other.



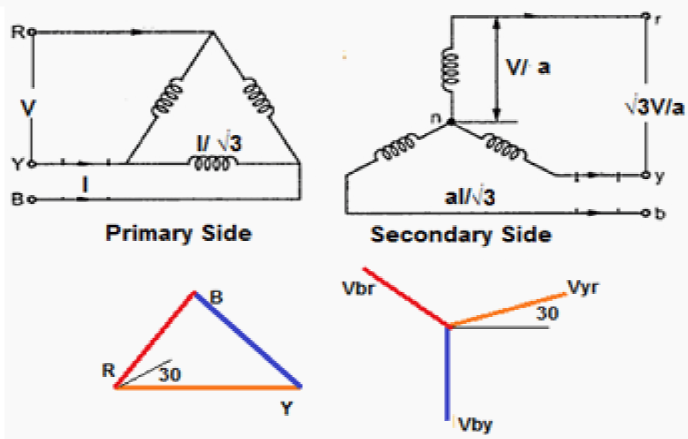
Scott T Connection

Applications:

- Use for Traction Purpose
- Use as Industrial Furnace Transformer

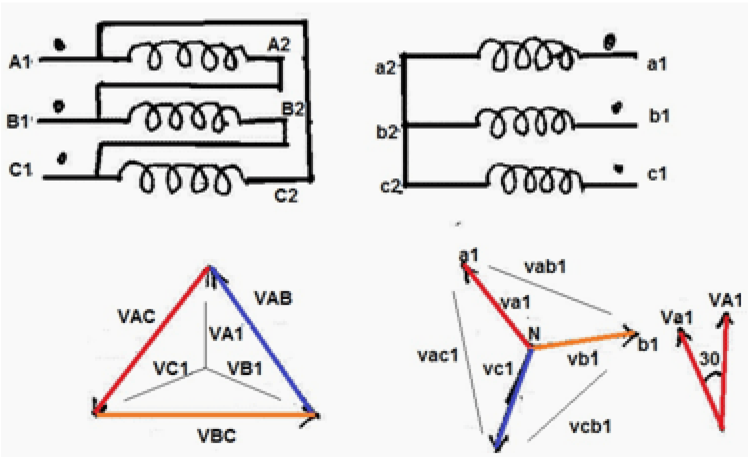
iii) Delta-star connection

In this type of connection, the ***primary connected in delta*** fashion while the secondary current is connected in ***star***.



Delta-Star Connection of Transformer

The main use of this connection is to step up the voltage i.e. at the begining of high tension transmission system. It can be noted that there is a phase shift of 30° between primary line voltage and secondary line voltage as leading.



Applications

- Commonly used in a step-up transformer
- Commonly used in commercial, industrial, and high-density residential locations
- Used as Generator Transformer

Q.17 Explain the conditions of parallel operation of Three phase transformer

Ans:

The transformers are connected in parallel means that the two primary windings are connected to supply bus and the two secondary windings are connected to load bus-bars as shown in the figure.

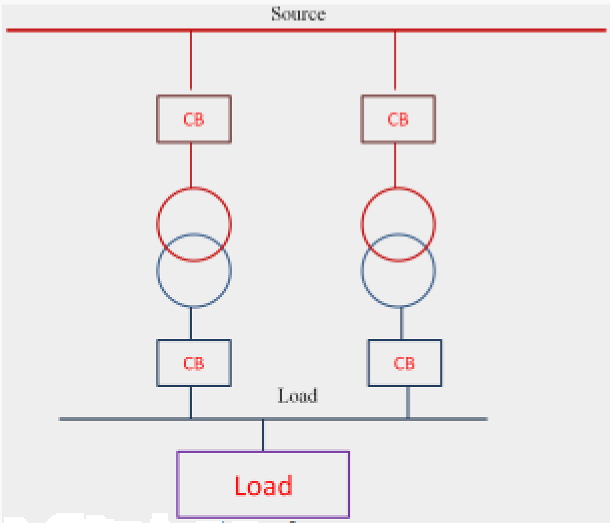


Fig:Parallel operation of Transformer

Need of parallel Operation of Transformers

- To supply a load in excess of the ratings of an existing transformer, Two or more transformers may be connected in parallel with the existing transformer. This is more economical connecting an extra small transformer in parallel instead of keeping an another large capacity transformer. The cost is also less for purchasing extra small rating transformer.
- Parallel operation of transformers provides more reliability i.e. even in the failure or out off service of one transformer half of the bus load can be driven using signal transformer in emergency cases.

Conditions for Parallel Operation of Transformers

When two or more transformers run in parallel, they must satisfy the following conditions for satisfactory performance. These are the conditions for **parallel operation of transformers**.

1. Same voltage ratio of transformer.
2. Same percentage impedance.
3. Same polarity.
4. Same phase sequence.

Same Voltage Ratio

If two transformers of different voltage ratio are connected in parallel with same primary supply voltage, there will be a difference in secondary voltages. Now say the secondary of these transformers are connected to same bus, there will be a circulating current between secondaries and therefore between primaries also. As the internal impedance of transformer is small, a small voltage difference may cause sufficiently high circulating current causing unnecessary extra I^2R loss.

Same Percentage Impedance

The current shared by two transformers running in parallel should be proportional to their MVA ratings. Again, current carried by these transformers are inversely proportional to their internal impedance. From these two statements it can be said that, impedance of transformers running in parallel are inversely proportional to their MVA ratings. In other words, percentage impedance or per unit values of impedance should be identical for all the transformers that run in parallel.

Same Polarity

Polarity of all transformers that run in parallel, should be the same otherwise huge circulating current that flows in the transformer but no load will be fed from these transformers. Polarity of transformer means the instantaneous direction of induced emf in secondary. If the instantaneous directions of induced secondary emf in two transformers are opposite to each other when same input power is fed to both of the transformers, the transformers are said to be in opposite polarity. If the instantaneous directions of induced secondary emf in two transformers are same when same input power is fed to the both of the transformers, the transformers are said to be in same polarity.

Same Phase Sequence

The phase sequence or the order in which the phases reach their maximum positive voltage, must be identical for two parallel transformers. Otherwise, during the cycle, each pair of phases will be short circuited. The above said conditions must be strictly followed for parallel operation of transformers but totally identical percentage impedance of two different transformers is difficult to achieve practically, that is why the transformers run in parallel may not have exactly same percentage impedance but the values would be as nearer as possible.

Q.18 Explain direct on-line starting method of 3 phase induction motor in detail

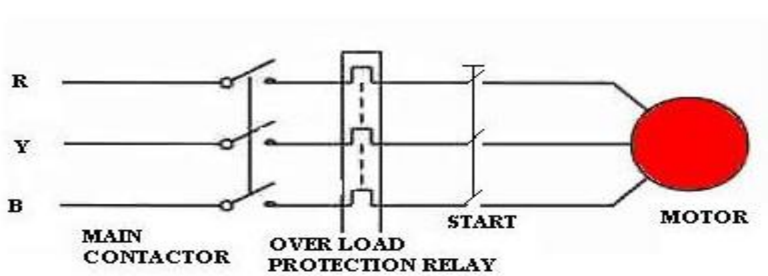
Ans:

An induction motor is similar to a poly-phase transformer whose secondary is short circuited. Thus, at normal supply voltage, like in transformers, the initial current taken by the primary is very large for a short while. Unlike in DC motors, large current at starting is due to the absence of back emf. If an induction motor is directly switched on from the supply, it takes 5 to 7 times its full load current and develops a torque which is only 1.5 to 2.5 times the full load torque. This large starting current produces a large voltage drop in the line, which may affect the operation of other devices connected to the same line. Hence, it is not advisable to start induction motors of higher ratings (generally above 25kW) directly from the mains supply

Direct-On-Line (DOL) Starters

Small three phase induction motors can be started direct-on-line, which means that the rated supply is directly applied to the motor. But, as mentioned above, here, the starting current would be very large, usually 5 to 7 times the rated current. The starting torque is likely to be 1.5 to 2.5 times the full load torque. Induction motors can be started directly on-line using a DOL starter which generally consists of a contactor and a motor protection equipment such as a circuit breaker. A DOL starter consists of a coil operated contactor which can be controlled by start and stop push buttons. When the start push button is pressed, the contactor gets energized and it closes all the three phases of the motor to the supply phases at a time. The stop push button de-energizes the contactor and disconnects all the three phases to stop the motor.

In order to avoid excessive voltage drop in the supply line due to large starting current, a DOL starter is generally used for motors that are rated below 5kW.



1. It is simple and cheap starter for a 3-phase induction motor.
2. The contacts close against spring action.
3. This method is normally limited to smaller cage induction motors, because starting current can be as high as eight times the full load current of the motor. Use of a double –cage rotor requires lower staring current(approximately four times) and use of quick acting A.V.R enables motors of 75 Kw and above to be started direct on line.
4. An isolator is required to isolate the starter from the supply for maintenance.
5. Protection must be provided for the motor. Some of the safety protections are over-current protection, under-voltage protection, short circuit protection, etc. Control circuit voltage is sometimes stepped down through an autotransforme

Q.19 Draw and explain the construction and working of

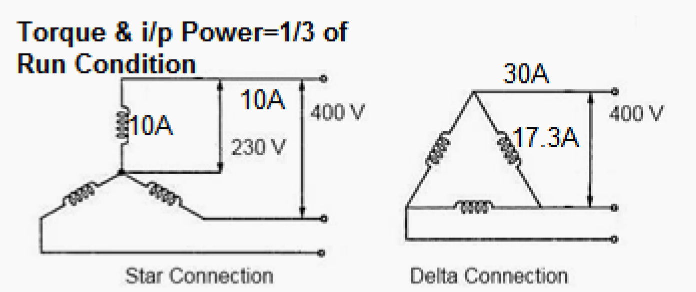
i) Star-delta starter

Ans:

Most induction motors are started directly on line, but when very large motors are started that way, they cause a disturbance of voltage on the supply lines due to large starting current surges

To limit the starting current surge, large induction motors are started at reduced voltage and then have full supply voltage reconnected when they run up to near rotated speed.

This is the reduced voltage starting method. Voltage reduction during star-delta starting is achieved by physically reconfiguring the motor windings as illustrated in the figure below. During starting the motor windings are connected in star configuration and this reduces the voltage across each winding 3. This also reduces the torque by a factor of three.



Scheme – Working Principle of Star-Delta Starter

After a period of time the winding are reconfigured as delta and the **motor** runs normally. Star/Delta starters are probably the most common reduced voltage starters. They are used in an attempt to reduce the start current applied to the motor during start as a means of reducing the disturbances and interference on the electrical supply.

The Star/Delta starter is manufactured from three contactors, a timer and a thermal overload. The contactors are smaller than the single contactor used in a Direct on Line starter as they are controlling winding currents only. The currents through the winding are 1/root 3 (58%) of the current in the line.

There are two contactors that are close during run, often referred to as the main contractor and the delta contactor. These are AC3 rated at 58% of the current rating of the motor. The third contactor is the star contactor and that only carries star current while the motor is connected in star.

The current in star is one third of the current in delta, so this contactor can be AC3 rated at one third (33%) of the motor rating.

Application of star-delta starter

The star-delta method is usually only applied to **low to medium voltage and light starting Torque** motors.

The received starting current is about **30 %** of the starting current during direct on line start and the starting torque is reduced to about **25 %** of the torque available at a D.O.L start. This starting method only works when the application is light loaded during the start.

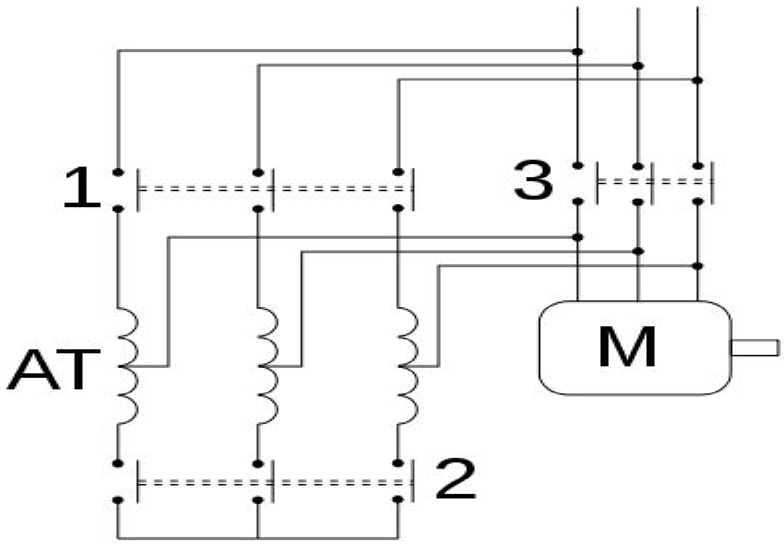
If the motor is too heavily loaded, there will not be enough torque to accelerate the motor up to speed before switching over to the delta position

ii) Auto-Transformer starter

Ans:

Auto-transformers are also known as auto-starters. They can be used for both star connected or delta connected squirrel cage motors. It is basically a three phase step down transformer with different taps provided that permit the user to start the motor at, say, 50%, 65% or 80% of line voltage. With auto-transformer starting, the current drawn from supply line is always less than the motor current by an amount equal to the transformation ratio. For example, when a motor is started on a 65% tap, the applied voltage to the motor will be 65% of the line voltage and the applied current will be 65% of the line voltage starting value, while the line current will be 65% of 65% (i.e. 42%) of the line voltage starting value. This difference between the line current and the motor current is due to transformer action. The internal connections of an auto-starter are as shown in the figure. At starting, switch is at "start" position, and a reduced voltage (which is selected using a tap) is applied across the stator. When the motor gathers an appropriate speed, say upto 80% of its rated speed, the auto-transformer automatically gets disconnected from the circuit as the switch goes to "run"position.

The switch changing the connection from start to run position may be air-break (small motors) or oil-immersed (large motors) type. There are also provisions for no-voltage and overload, with time delay circuits on an autostarter.



Q.20 Derive the emf equation of DC motor

Ans:

As the armature rotates, a voltage is generated in its coils. In the case of a generator, the emf of rotation is called the **Generated emf** or **Armature emf**and is denoted as Er = Eg. In the case of a motor, the emf of rotation is known as **Back emf** or **Counter emf** and represented as Er = Eb.The expression for emf is same for both the operations. I.e., for Generator as well as for Motor

Let,

- **P** – Number of poles of the machine
- **ϕ** – Flux per pole in Weber.
- **Z** – Total number of armature conductors.
- **N** – Speed of armature in revolution per minute (r.p.m).
- **A** – Number of parallel paths in the armature winding.

In one revolution of the armature, the flux cut by one conductor is given as

$$\text{Flux cut by one conductor} = P\varphi \quad \text{wb} \ldots \ldots (1)$$

Time taken to complete one revolution is given as

$$t = \frac{60}{N} \quad \text{seconds} \quad \ldots \ldots (2)$$

Therefore, the average induced e.m.f in one conductor will be

$$e = \frac{P\varphi}{t} \quad \ldots \ldots (3)$$

Putting the value of (t) from Equation (2) in the equation (3) we will get

$$e = \frac{P\varphi}{60/N} = \frac{P\varphi N}{60} \quad \text{volts} \quad \ldots \ldots (4)$$

The number of conductors connected in series in each parallel path = Z/A.

Therefore, the average induced e.m.f across each parallel path or the armature terminals is given by the equation shown below.

$$E = \frac{P\varphi N}{60} \times \frac{Z}{A} = \frac{PZ\varphi N}{60\,A} \quad \text{volts} \quad \text{or}$$

$$E = \frac{PZ\varphi n}{A} \quad \ldots \ldots (5)$$

Where n is the speed in revolution per second (r.p.s) and given as

$$n = \frac{N}{60}$$

For a given machine, the number of poles and the number of conductors per parallel path (Z/A) are constant. Hence, the equation (5) can be written as

$$E = K\varphi n$$

Where, K is a constant and given as

$$K = \frac{PZ}{A}$$

Therefore, the average induced emf equation can also be written as

$$E \propto \varphi n \quad \text{or}$$

$$E = K_1 \varphi N$$

Where K1 is another constant and hence induced emf equation can be written as

$$E \propto \varphi N \quad \text{or}$$

$$E \propto \varphi \omega$$

Where ω is the angular velocity in radians/second is represented as

$$\omega = \frac{2\pi N}{60}$$

Thus, it is clear that the induced emf is directly proportional to the speed and flux per pole. The polarity of induced emf depends upon the direction of the magnetic field and the direction of rotation.

If either of the two is reverse the polarity changes, but if two are reversed the polarity remains unchanged.

This induced emf is a fundamental phenomenon for all the DC Machines whether they are working as a generator or motor.

If the machine DC Machine is working as a Generator, the induced emf is given by the equation shown below.

$$E_g = \frac{PZ\varphi N}{60A} \quad \text{volts}$$

Where **Eg** is the **Generated Emf**

If the machine DC Machine is working as a Motor, the induced emf is given by the equation shown below.

$$E_b = \frac{PZ\varphi N}{60A} \quad \text{volts}$$

In a motor, the induced emf is called **Back Emf (Eb)** because it acts opposite to the supply voltage.

Q.21 Write short notes on Ward-Leonard System of Speed control.

Ans:

Ward Leonard control system is introduced by Henry Ward Leonard in 1891. Ward Leonard method of speed control is used for controlling the speed of a DC motor. It is a basic armature control method. This control system is consisting of a DC motor M_1 and powered by a DC generator G. In this method the speed of the DC motor (M_1) is controlled by applying variable voltage across its armature. This variable voltage is obtained using a motor-generator set which consists of a motor M_2 (either AC or DC motor) directly coupled with the generator G. It is a very widely used method of speed control of DC motor.

Principle of Ward Leonard Method

Basic connection diagram of the Ward Leonard speed control system is shown in the figure below

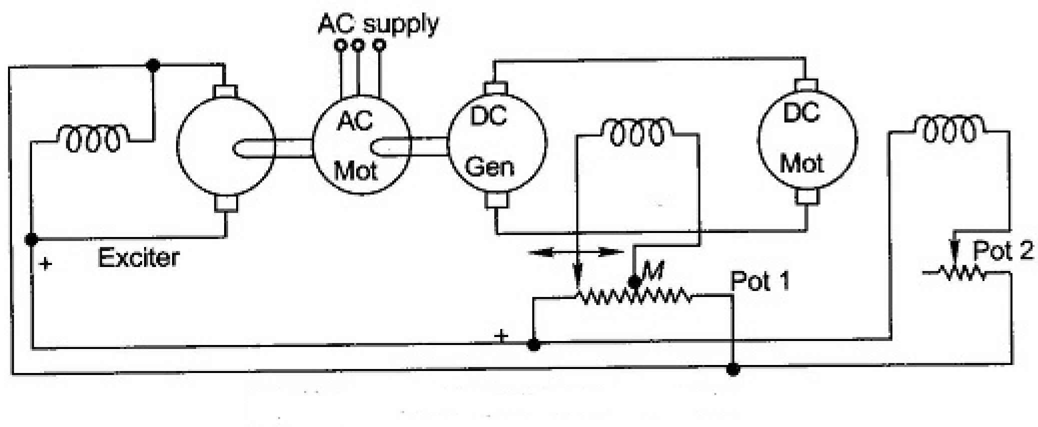


Fig: Ward Leonard Method

The speed of motor M_1 is to be controlled which is powered by the generator G. The shunt field of the motor M_1 is connected across the DC supply lines. Now, generator G is driven by the motor M_2. The speed of the motor M_2 is constant. When the output voltage of the generator is fed to the motor M_1 then the motor starts to rotate. When the output voltage of the generator varies then the speed of the motor also varies. Now controlling the output voltage of the generator the speed of motor can also be controlled. For this purpose of controlling the output voltage, a field regulator is connected across the generator with the dc supply lines to control the field excitation. The direction of rotation of the motor M_1 can be reversed by excitation current of the generator and it can be done with the help of the reversing switch R.S. But the motor-generator set must run in the same direction.

Advantages of Ward Leonard System

1. It is a very smooth speed control system over a very wide range (from zero to normal speed of the motor).

2. The speed can be controlled in both the direction of rotation of the motor easily.
3. The motor can run with a uniform acceleration.
4. Speed regulation of DC motor in this ward Leonard system is very good.
5. It has inherent regenerative braking property.

Application of Ward Leonard System

This Ward Leonard method of speed control system is used where a very wide and very sensitive speed control is of a DC motor in both the direction of rotation is required. This speed control system is mainly used in colliery winders, cranes, electric excavators, mine hoists, elevators, steel rolling mills, paper machines, diesel-locomotives, etc.

Q.22 Explain with neat diagram construction and working principle of operation of universal motor. Also write applications of Universal Motor

Ans:

A universal motor is a special type of motor which is designed to run on either DC or single phase AC supply. These motors are generally series wound (armature and field winding are in series), and hence produce high starting torque. That is why, universal motors generally comes built into the device they are meant to drive. Most of the universal motors are designed to operate at higher speeds, exceeding 3500 RPM. They run at lower speed on AC supply than they run on DC supply of same voltage, due to the reactance voltage drop which is present in AC and not in DC. There are two basic types of universal motor : (i)compensated type and (ii) uncompensated type. Compensated type of motor has a field winding distributed in slots, much the same as the split-phase motor. And uncompensated motor has the small two-pole series motor with two concentrated field poles.

Construction:

Construction of a universal motor is very similar to the construction of a DC machine. It consists of a stator on which field poles are mounted. Field coils are wound on the field poles. However, the whole magnetic path (stator field circuit and also armature) is laminated. Lamination is necessary to minimize the eddy currents which induce while operating on AC. The rotary armature is of wound type having straight or skewed slots and commutator with brushes resting on it. The commutation on AC is poorer than that for DC. because of the current induced in the armature coils. For that reason brushes used are having high resistance.

Working of Universal Motor

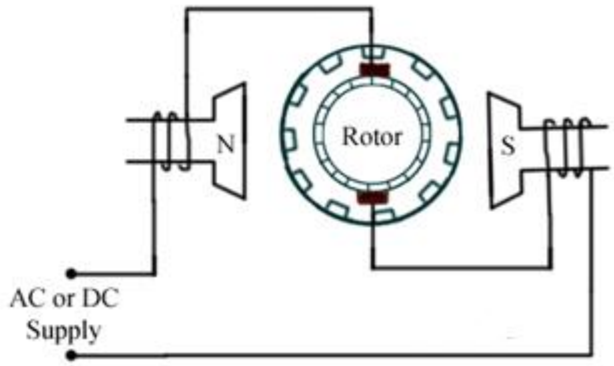


Fig:Universal Motor

A universal motor works on either DC or single phase AC supply. When the universal motor is fed with a DC supply, it works as a DC series motor. When current flows in the field winding, it produces an electromagnetic field. The same current also flows from the armature conductors. When a current carrying conductor is placed in an electromagnetic field, it experiences a mechanical force. Due to this mechanical force, or torque, the rotor starts to rotate. The direction of this force is given by [Fleming's left hand rule]. When fed with AC supply, it still produces unidirectional torque. Because, [armature winding] and field winding are connected in series, they are in same phase. Hence, as polarity of AC changes periodically, the direction of current in armature and field winding reverses at the same time. Thus, direction of magnetic field and the direction of armature current reverses in such a way that the direction of force experienced by armature conductors remains same. Thus, regardless of AC or DC supply, universal motor works on the same principle that DC series motor works.

Speed/Load Characteristics

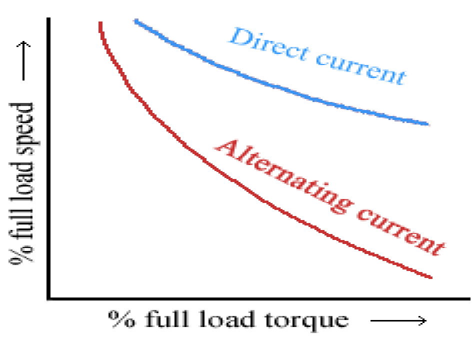


Fig:Speed/Load Characteristics

Speed/load characteristics of a universal motor is similar to that of DC series motor. The speed of a universal motor is low at full load and very high at no load. Usually, gears trains are used to get the required speed on required load. The speed/load characteristics are (for both AC as well as DC supply) are shown in the figure.

mixers and power tools which are used only intermittently, and often have high starting-torque demands

Applications of Universal Motor

- Universal motors find their use in various home appliances like vacuum cleaners, drink and food mixers, domestic sewing machine etc.
- The higher rating universal motors are used in portable drills, blenders etc.