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e-TEXTBOOK
on
INDUSTRIAL POWER ELECTRONICS
for
V Semester DICE

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34273 - INDUSTRIAL POWER ELECTRONICS
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I UNIT

Power devices and Trigger circuits

1.1 Power Electronics Defined It has been said that people do not use electricity, but rather they use communication, light, mechanical work, entertainment, and all the tangible benefits of energy and electronics. In this sense, electrical engineering as a discipline is much involved in energy conversion and information. In the general world of electronics engineering, the circuits engineers design and use are intended to convert information. This is true of both analog and digital circuit design. In radio-frequency applications, energy and information are on more equal footing, but the main function of any circuit is information transfer.

What about the conversion and control of electrical energy itself? Energy is a critical need in every human ndeavor. The capabilities and flexibility of modern electronics must be brought to bear to meet the challenges of reliable, efficient energy. It is essential to consider how electronic circuits and systems can be applied to the challenges of energy conversion and management. This is the framework of *power electronics*, a discipline defined in terms of *electrical energy conversion*, *applications*, and *electronic devices*. More specifically,

DEFINITION *Power electronics* involves the study of electronic circuits which is used to control the flow of electrical energy.

Key Characteristics All power electronic circuits manage the flow of electrical energy between an electrical source and a load.. A general power conversion systemis shown in Fig. 1.1. The function of the power converter in the middle is to control the energy flow between a source and a load. For our purposes, the power converter will be implemented with a power electronic circuit. Because a power converter appears between a source and a load, any energy used within the converter is lost to the overall system.

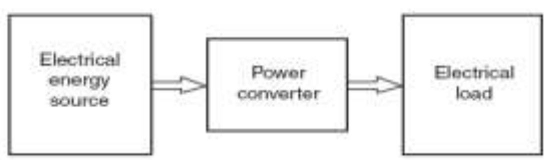


Fig 1.1

The Efficiency Objective – The Switch

A circuit element as simple as a light switch reminds us that the extreme requirements in power electronics are not especially novel. Ideally, when a switch is on, it has zero voltage drop and will carry any current imposed on it. When a switch is off, it blocks the flow of current regardless of the voltage across it. The *device power*, the product of the switch voltage and current, is identically zero at all times. A switch therefore controls energy flow with no loss. In addition, reliability is also high. Household light switches perform over decades of use and perhaps 100,000 operations. Unfortunately, a mechanical light switch does not meet all practical needs. A switch in a power supply may function 100,000 times each second. Even the best mechanical switch will not last beyond a few million cycles. Semiconductor switches (without this limitation) are the devices of choice in power converters.

A circuit built from ideal switches will be lossless. As a result, switches are the main components of power converters, and many people equate power electronics with the study of switching power converters. Magnetic transformers and lossless storage elements such as capacitors and inductors are also valid components for use in power converters. The complete concept, shown in Fig. 1.2, illustrates a *power electronic system*. Such a system consists of an electrical energy source, an electrical load, a *power electronic circuit*, and a control function. The power electronic circuit contains switches, lossless energy storage elements, and magnetic transformers. The controls take information from the source, the load, and the designer, and then determine how the switches operate to achieve the desired conversion. The controls are built up with low-power analog and digital electronics.

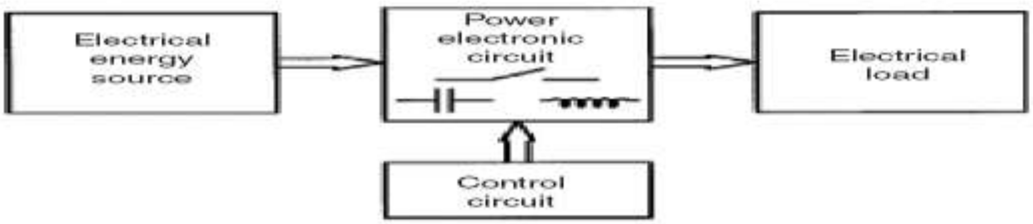


Fig 1.2

1.2 Thyristor and Family

Introduction The modern power electronics area truly began with advent of thyristors. One of the first developments was the publication of the P-N-P-N transistor switch concept in 1956 by J.L. Moll and others at Bell Laboratories. However, engineers at General Electric quickly recognized its **significance to power conversion and control** and within nine months announced the first commercial Silicon Controlled Rectifier in 1957. This had a continuous current carrying capacity of 25A and a blocking voltage of 300V.

Thyristors (**also known as the Silicon Controlled Rectifiers or SCRs**) have come a long way from this modest beginning and now high power light triggered thyristors with blocking voltage in excess of 6kv and continuous current rating in excess of 4kA are available.

Along the way a large number of other devices with broad similarity with the basic thyristor (invented originally as a phase control type device) have been developed. They include,

inverter grade fast thyristor
Silicon Controlled Switch (SCS)
light activated SCR (LASCR)
Asymmetrical Thyristor (ASCR)
Reverse Conducting Thyristor (RCT)
Diac
Triac
and the Gate turn off thyristor (GTO).

From the construction and operational point of view a thyristor is a four layer, three terminal, minority carrier semi-controlled device. It can be turned on by a current signal but can not be turned off without interrupting the main current. It can block voltage in both directions but can conduct current only in one direction. During conduction it offers very low forward voltage drop due to an internal latch-up mechanism. Thyristors have longer switching times (measured in tens of μs) compared to a BJT. This, coupled with the fact that a thyristor can not be turned off using a control input, have all but eliminated thyristors in high frequency switching applications involving a DC input (i.e, choppers, inverters).

1.3 Silicon Controlled Rectifiers (SCR)

Thyristors are usually three-terminal devices that have four layers of alternating *p*-type and *n*-type material (i.e. three *p*–*n* junctions) comprising its main power handling section. The control terminal of the thyristor, called the gate (*G*) electrode, may be connected to an integrated and complex structure as a part of the device. The other two terminals, called the anode (*A*) and cathode

(*K*), handle the large applied potentials (often of both polarities) and conduct the major current through the thyristor. The anode and cathode terminals are connected in series with the load to which power is to be controlled.

Thyristor circuits must have the capability of delivering large currents and be able to withstand large externally applied voltages. All thyristor types are controllable in switching from a forward-blocking state (positive potential applied to the anode with respect to the cathode, with correspondingly little anode current flow) into a forward-conduction state (large forward anode current flowing, with a small anode–cathode potential drop). Most thyristors have the characteristic that after switching from a forward-blocking state into the forward-conduction state, the gate signal can be removed and the thyristor will remain in its forward-conduction mode. This property is termed “latching” and is an important distinction between thyristors and other types of power electronic devices.

1.3.1 Basic Structure and Operation

Figure 1.3 shows a conceptual view of a typical thyristor with the three *p*–*n* junctions and the external electrodes labeled. Also shown in the figure is the thyristor circuit symbol used in electrical schematics.

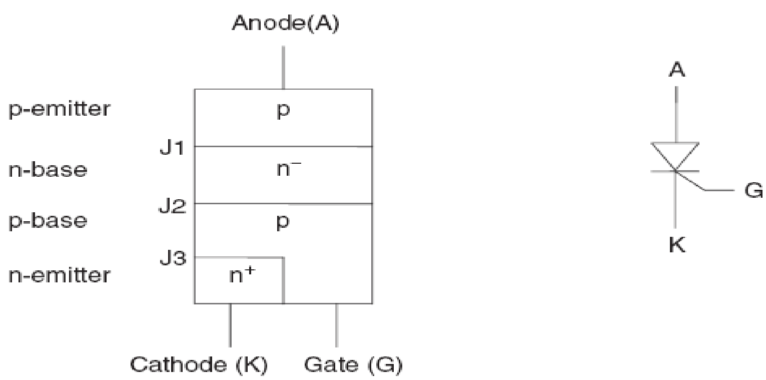


Fig 1.3

A high-resistivity region, *n*-base, is present in all thyristors. It is this region, the *n*-base and associated junction, J2 of Fig. 1.3, which must support the large applied forward voltages that occur when the switch is in its off- or forward-blocking state (non-conducting). The *n*-base is typically doped with impurity phosphorous atoms at a concentration of 1013 to 1014 cm−3.

High-voltage thyristors are generally made by diffusing aluminum or gallium into both surfaces to create *p*-doped regions forming deep junctions with the *n*-base. The doping profile of the *p*-regions ranges from about 1015 to 1017 cm−3.

The cathode region (typically only a few micrometer thick) is formed by using phosphorous atoms at a doping density of 1017 to 1018 cm−3.

Operation of thyristors is as follows.When a positive voltage is applied to the anode (with respect to cathode), the thyristor is in its forward-blocking state. The center junction, J2 (see Fig. 1.3) is reverse biased. In this operating mode the gate current is held to zero (open circuit). In practice, the gate electrode is biased to a small negative voltage (with respect to the cathode) to reverse bias the GK-junction J3 and prevent charge-carriers from being injected into the *p*-base. In this condition only thermally generated leakage current flows through the device and can often be pproximated as zero in value. As long as the forward applied voltage does not exceed the value necessary to cause excessive carrier multiplication in the depletion region around J2 (avalanche breakdown), the thyristor remains in an off-state (forward-blocking). If the applied voltage exceeds the maximum forward-blocking voltage of the thyristor, it will switch to its on-state. However, this mode of turn-on causes non-uniformity in the current flow, is generally destructive, and should be avoided.

When a positive gate current is injected into the device, J3 becomes forward biased and electrons are injected from the *n*-emitter into the *p*-base. Some of these electrons diffuse across the *p*-base and get collected in the *n*-base. This collected charge causes a change in the bias condition of J1. The change in bias of J1 causes holes to be injected from the *p*-emitter into the *n*-base. These holes diffuse across the *n*-base and are collected in the *p*-base. The addition of these collected holes in the *p*-base acts the same as gate current. The entire process is regenerative and will cause the increase in charge carriers until J2 also becomes forward biased and the thyristor is latched in its on-state (forward-conduction). The regenerative action will take place as long as the gate current is applied in sufficient amount and for a sufficient length of time. This mode of turnon is considered to be the desired one as it is controlled by the gate signal.

1.3.2 Static Characteristics – Forward bias

A plot of the anode current (*iA*) as a function of anode– cathode voltage (*vAK*) is shown in Fig.1.4. The forwardblocking mode is shown as the low-current portion of the graph .With zero gate current and positive *vAK* , the forward characteristic in the offor blocking-state is determined by the center junction J2,which is reverse biased.

At operating point "1" very little current flows (*Ico* only) through the device. However, if the applied voltage exceeds the forward-blocking voltage, the thyristor switches to its on- or conducting-state (shown as operating point "2") because of carrier multiplication .The effect of gate current is to lower the blocking voltage at which switching takes place. The portion of the graph indicating forward-conduction shows the large values of *iA* that may be conducted at relatively low values of *vAK* , similar to a power diode. As the thyristor moves from forward-blocking to forward conduction, the external circuit must allow sufficient anode current to flow to keep the device latched.

BREAKOVER VOLTAGE I t is the minimum forward voltage gate being open at which SCR starts conducting heavily i.e turned on

The minimum anode current that will cause the device to remain in forward conduction as it switches from forward-blocking is called **the latching current *IL***.

If the thyristor is already in forward conduction and the anode current is reduced, the device can move its operating mode from forward-conduction back to forward-blocking. The minimum value of anode current necessary to keep the device in forward-conduction after it has been operating at a high anode current value is called the **holding current *IH***. The holding current value is lower than the latching current value as indicated in Fig. 1.4.

di/dt rating The time rate of rise of anode current (*di*/*dt*) during turn-on

dv/dt rating The time rate of rise of anode–cathode voltage (*dv*/*dt*) during turn-off are important parameters to control for ensuring proper and reliable operation.

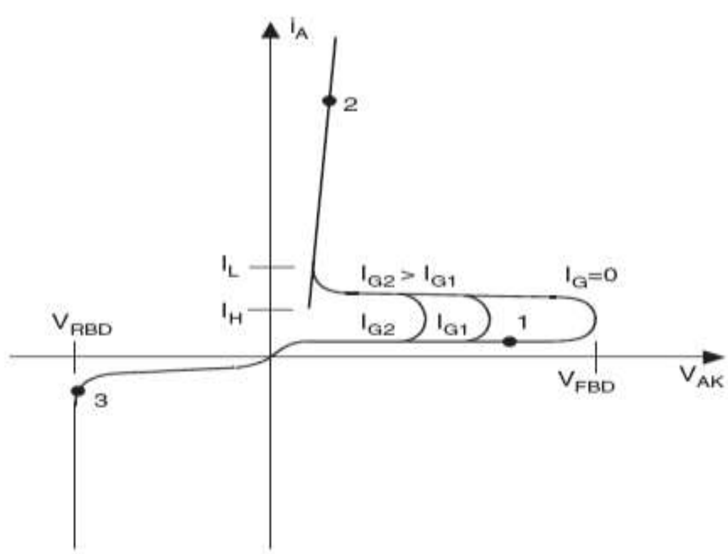


Fig 1.4

Reverse Bias When anode is negative with respect to cathode the curve between Voltage & current is known as reverse characteristics reverse voltage come across SCR when it is operated with ac supply reverse voltage is increased anode current remains small avalanche breakdown occurs and SCR starts conducting heavily is known as reverse breakdown voltage

The two-transistor analogy

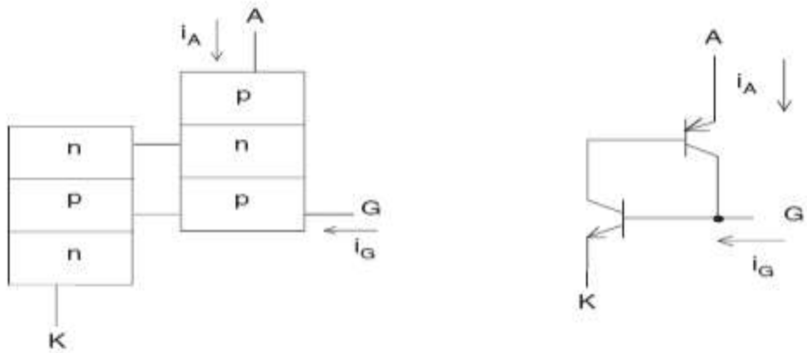


Fig 1.5

Application

SCR as a static contactor

SCR for power control

SCR for speed control of d. c. shunt motor

Over light detector

1.4 Insulated Gate Bipolar Transistor (IGBT)

The insulated gate bipolar transistor (IGBT), which was introduced in early 1980s, is becoming a successful device because of its superior characteristics. IGBT is a three-terminal power semiconductor switch used to control the electrical energy.

Prior to the advent of IGBT, power bipolar junction transistors (BJT) and power metal oxide field effect transistors (MOSFET) were widely used in low to medium power and high-frequency applications, where the speed of gate turn-off thyristors was not adequate.

Power BJTs have good on-state characteristics but have long switching times especially at turn-off. They are current-controlled devices with small current gain because of high-level injection effects and wide base width required to prevent reach-through breakdown for high blocking voltage capability. Therefore, they require complex base drive circuits to provide the base current during on-state, which increases the power loss in the control electrode.

On the other hand power MOSFETs are voltage-controlled devices, which require very small current during switching period and hence have simple gate drive requirements. Power MOSFETs are majority carrier devices, which exhibit very high switching speeds.

Their ON state resistance increases with increasing breakdown voltage. Furthermore, as the voltage rating increases the inherent body diode shows inferior reverse recovery characteristics, which leads to higher switching losses.

In order to improve the power device performance, it is advantageous to have the low on-state resistance of power BJTs with an insulated gate input like that of a power MOSFET. The Darlington configuration of the two devices shown in Fig. 1.6 has superior characteristics as compared to the two discrete devices. This hybrid device could be gated like a power MOSFET with low on-state resistance.

A more powerful approach to obtain the maximum benefits of the MOS gate control and bipolar current conduction is to integrate the physics of MOSFET and BJT within the same semiconductor region. This concept gave rise to the commercially available IGBTs with superior on-state characteristics, good switching speed and excellent safe operating area.

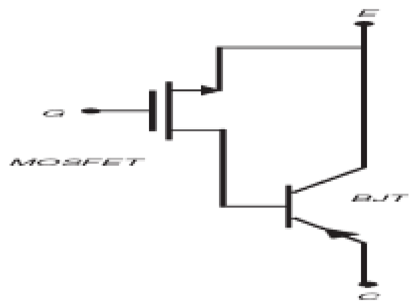


Fig 1.6

1.4.1 Basic Structure and Operation

The vertical cross section of a half cell of one of the parallel cells of an n-channel IGBT shown in Fig.1.7 This layer forms the IGBT collector and a pn junction with n− drift region, where conductivity modulation occurs by injecting minority carriers into the drain drift region of the vertical MOSFET. Therefore, the current density is much greater than a power MOSFET and the forward voltage drop is reduced. The p+ substrate, n− drift layer, and p+ emitter constitute a BJT with a wide base region and hence small current gain. The device operation can be explained by a BJT with its base current controlled by the voltage applied to the MOS gate. For simplicity, it is assumed that the emitter terminal is connected to the ground potential. By applying a negative voltage to the collector, the pn junction between the p+ substrate and the n− drift region is reverse biased which prevents any current flow and the device is in its reverse blocking state. If the gate terminal is kept at ground potential but a positive potential is applied to the collector, the pn junction between the p-base and n− drift region is reverse biased. This prevents any current flow and the device is in its forward blocking state until the open base breakdown of the pnp transistor is reached.

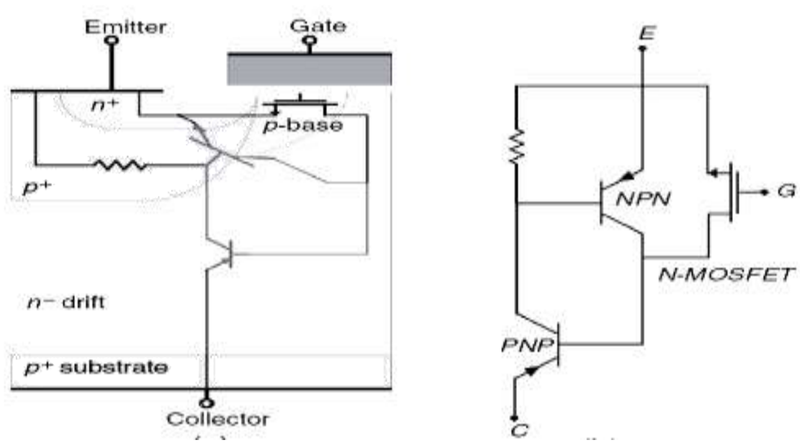


Fig 1.7

When a positive potential is applied to the gate and exceeds the threshold voltage required to invert the MOS region under the gate an n channel is formed, which provides a path for electrons to flow into the n− drift region. The pn junction between the p+ substrate and n− drift region is forward biased and holes are injected into the drift region. The electrons in the drift region recombine with these holes to maintain space charge neutrality and the remaining holes are collected at the emitter, causing a vertical current flow between the emitter and collector. For small values of collector potential and a gate voltage larger than the threshold voltage the on-state characteristics can be defined by a wide base power BJT. As the current density increases, the injected carrier density exceeds the low doping of the base region and becomes much larger than the background doping. This conductivity modulation decreases the resistance of the drift region, and therefore IGBT has a much greater current density than a power MOSFET with reduced forward voltage drop. The base–collector junction of the pnp BJT cannot be forward biased, and therefore this transistor will not operate in saturation. But when the potential drop across the inversion layer becomes comparable to the difference between the gate voltage and threshold voltage, channel pinch-off occurs. The pinch-off limits the electron current and as a result the holes injected from the p+ layer. Therefore, base current saturation causes the collector current to saturate.

Typical forward characteristics of an IGBT as a function of gate potential and IGBT transfer characteristics are shown in Fig.1.8. The transfer characteristics of IGBT and MOSFET are similar. The IGBT is in the off-state if the gate–emitter potential is below the threshold voltage. For gate voltages greater than the threshold voltage, the transfer curve is linear over most of the drain current range. Gate-oxide breakdown and the maximum IGBT drain current limit the maximum gate–emitter voltage.

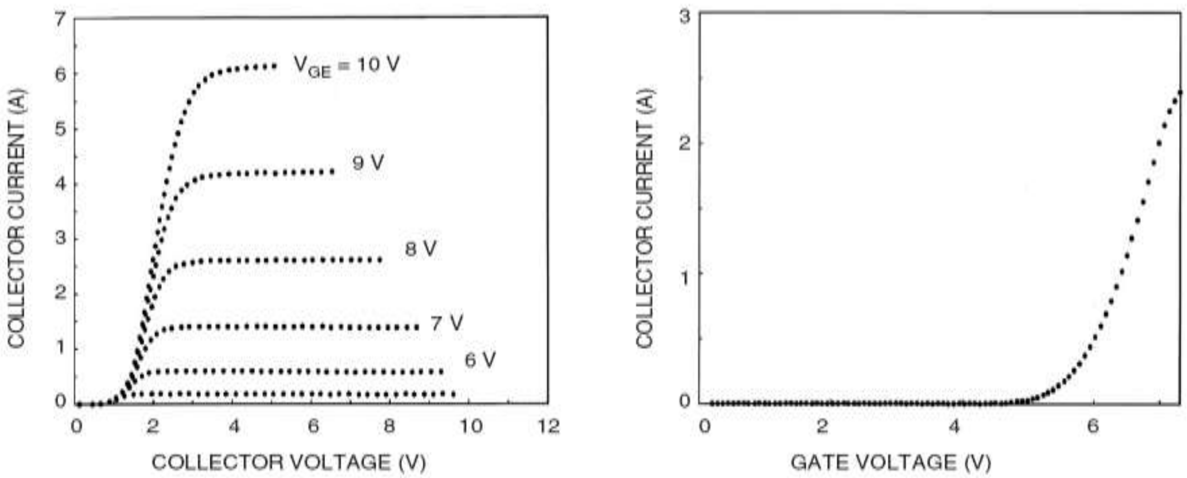


Fig 1.8

The main advantages of IGBT over a Power MOSFET and a BJT are:

1. It has a very low on-state voltage drop due to conductivity modulation and has superior on-state current density. So smaller chip size is possible and the cost can be reduced.

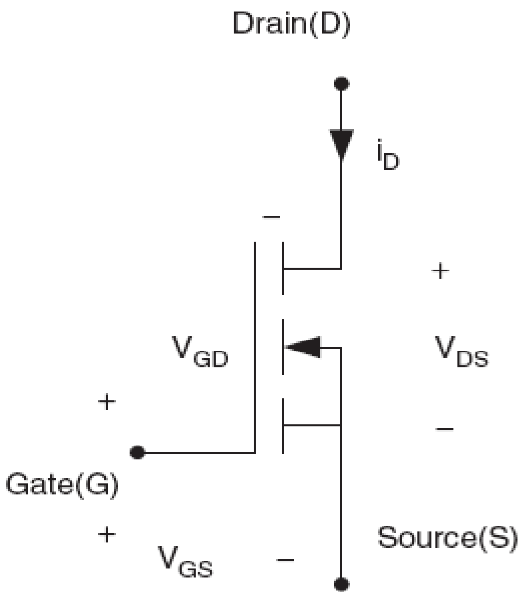
2. Low driving power and a simple drive circuit due to the input MOS gate structure. It can be easily controlled as compared to current controlled devices (thyristor, BJT) in high voltage and high current applications.

Applications An insulated-gate bipolar transistor (IGBT) is a three-**terminal** power semiconductor device primarily used as an electronic switch which, as it was developed, came to combine high efficiency and fast **switching**.

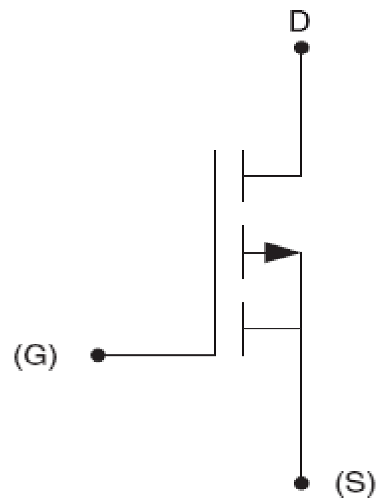
1.5 The Power MOSFET

Unlike the bipolar junction transistor (BJT), the MOSFET device belongs to the *Unipolar Device family, since it uses only the majority carriers in conduction.* The development of the metal oxide semiconductor technology for microelectronic circuits opened the way for developing the power metal oxide semiconductor field effect transistor (MOSFET) device in 1975. Selecting the most appropriate device for a given application is not an easy task, requiring knowledge about the device characteristics, its unique features,

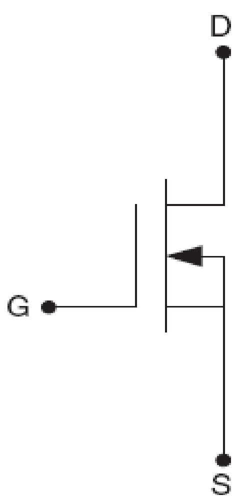
The device symbol for a p- and n-channel enhancement and depletion types are shown in Fig.1.9. The n-channel enhancement-type MOSFET. It is the fastest power switching device with switching frequency more than 1 MHz, with voltage power ratings up to 1000V and current rating as high as 300 A.



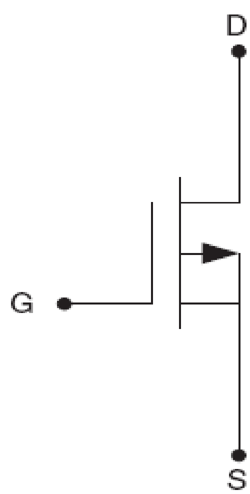
1.9 (a) n-channel enhancement-mode;



1.9 (b) p-channel enhancement-mode;



1.9 c)n-channel depletion-mode;



1.9 d) p-channel depletion-mode.

1.5.1 MOSFET Structure

Figure 1.10 a shows vertical cross-sectional view for a power MOSFET. Figure 1.10 b shows a more simplified representation and also shown symbol fig 1.11

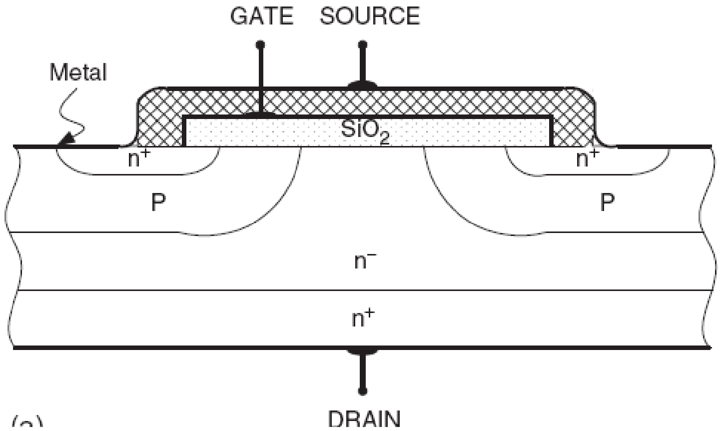


Fig 1.10 a

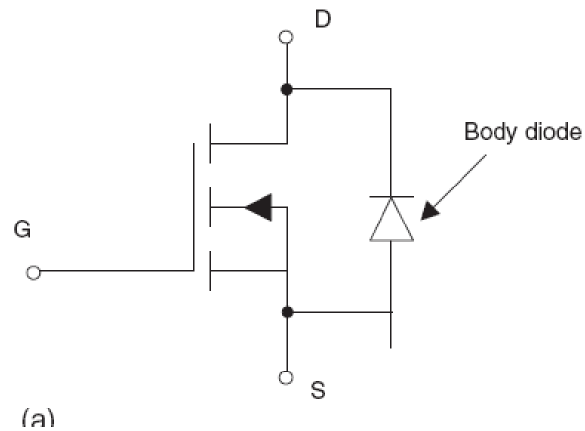


Fig 1.10 b

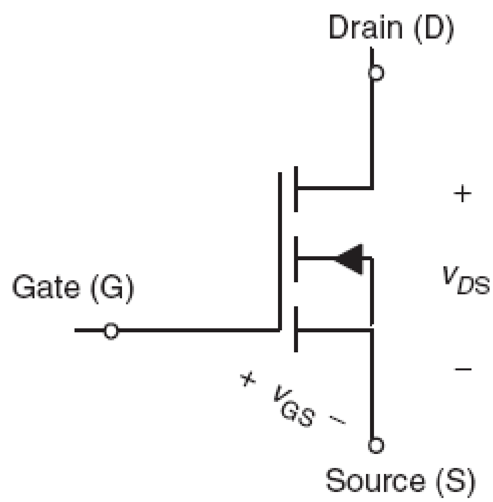


Fig 1.11

The P–N junction between p-base (also referred to as body or bulk region) and the n-drift region provide the forward voltage blocking capabilities. The source metal contact is connected directly to the p-base region through a break in the n+ source region in order to allow for a fixed potential to p-base region during the normal device operation. When the gate and source terminal are set the same potential (*VGS* =0), no channel is established in the p-base region, i.e. the channel region remain unmodulated. The lower doping in the n-drift region is needed in order to achieve higher drain voltage blocking capabilities. For the drain–source current, *ID*, to flow, a conductive path must be established between the n+ and n− regions through the p-base diffusion region.

A. On-state Resistance When the MOSFET is in the ON state (triode region), the channel of the device behaves like a constant resistance, *RDS*(*on*), that is linearly proportional to the change between *vDS* Unlike the current-controlled bipolar device, which requires base current to allow the current to flow in the collector, the power MOSFET device is a voltage-controlled unipolar device and requires only a small amount of input (gate) current. As a result, it requires less drive power than the BJT. However, it is a non-latching current like the BJT i.e. a gate source voltage must be maintained. Moreover, since only majority carriers contribute to the current flow, MOSFETs surpass all other devices in switching speed with switching speeds exceeding a few megahertz. Comparing the BJT and the MOSFET, the BJT has higher power handling capabilities and smaller switching speed, while the MOSFET device has less power handling capabilities and relatively fast switching speed. The MOSFET device has higher *on*-state resistor than the bipolar transistor. Another difference is that the BJT parameters are more sensitive to junction temperature when compared to the MOSFET, and unlike the BJT, MOSFET devices do not suffer from second breakdown voltages, and sharing current in parallel devices is possible

1.5.2 MOSFET Regions of Operation

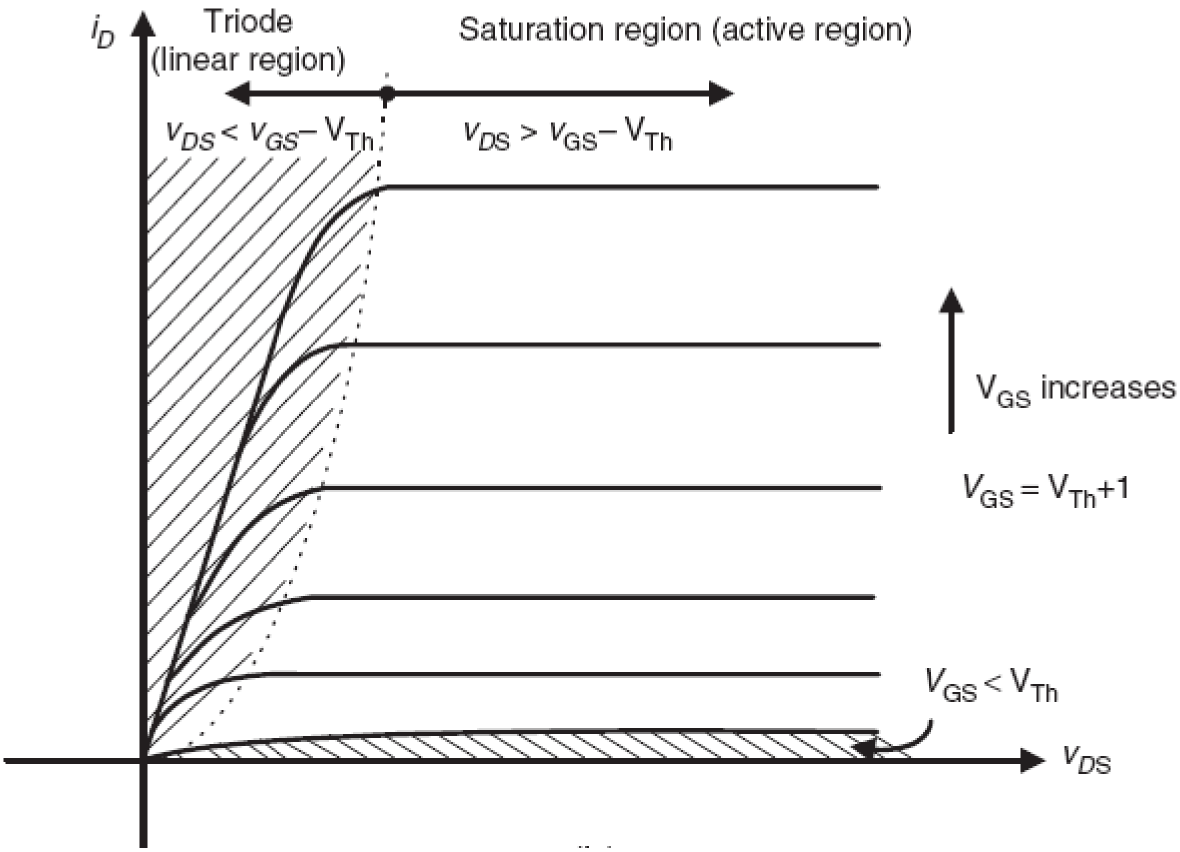


Fig 1.14

Most of the MOSFET devices used in power electronics applications are of the n-channel, enhancement-type like that which is shown in Fig. 4.6a. For the MOSFET to carry drain current, a channel between the drain and the source must be created. This occurs when the gate-to-source voltage exceeds the device threshold voltage, V_{Th}.

For $v_{GS} > V_{Th}$, the device can be either in the triode region, which is also called "constant resistance" region, or in the saturation region, depending on the value of v_{DS}. For given v_{GS}, with small v_{DS}($v_{DS} < v_{GS} - V_{Th}$), the device operates in the triode region(saturation region in the BJT), and for larger v_{DS}($v_{DS} > v_{GS} - V_{Th}$), the device enters the saturation region (active region in the BJT). For $v_{GS} < V_{Th}$, the device turns off, with drain current almost equals zero. Under both regions of operation, the gate current is almost zero. This is why the MOSFET is known as a voltage-driven device, and therefore, requires simple gate control circuit.

The characteristic curves in Fig.1.14 show that there are three distinct regions of operation labeled as triode region, saturation region, and cut-off-region. When used as a switching device, only triode and cut-off regions are used, whereas, when it is used as an amplifier, the MOSFET must operate in the saturation region, which corresponds to the active region in the BJT. The device operates in the cut-off region (off-state) when $v_{GS} < V_{Th}$, resulting in no induced channel. In order to operate the MOSFET in either the triode or saturation region, a channel must first be induced. This can be accomplished by applying gate-to-source voltage that exceeds V_{Th}, i.e. $v_{GS} > V_{Th}$ Once the channel is induced, the MOSFET can either operate in the triode region (when the channel is continuous with no pinch-off, resulting in the drain current proportioned to the channel resistance) or in the saturation region (the channel pinches off, resulting in constant I_D). The gate-to-drain bias voltage (v_{GD}) determines whether the induced channel enter pinch-off or not. This is subject to the following restriction. For triode mode of operation, we have

$$v_{GD} > V_{Th}$$

$$v_{GD} < V_{Th}$$

And for the saturation region of operation, Pinch-off occurs when $v_{GD} = V_{Th}$.

1.6 Gate turn-off thyristor (known as a GTO)

A gate turn-off thyristor (known as a GTO) is a three terminal power semiconductor device. GTOs belong to a thyristor family having a four-layer structure. GTOs also belong to a group of power semiconductor devices that have the ability for full control of on- and off-states via the control terminal (gate).

Like a conventional thyristor, applying a positive gate signal to its gate terminal can turn-on to a GTO. Unlike a standard thyristor, a GTO is designed to turn-off by applying a negative gate signal.

1.6.1 Basic Structure and Operation

The basic structure of a GTO consists of a four-layer-PNPN semiconductor device, which is very similar in construction to a thyristor. It has several design features which allow it to be turned on and off by reversing the polarity of the gate signal. The most important differences are that the GTO has long narrow emitter fingers surrounded by gate electrodes and no cathode shorts.

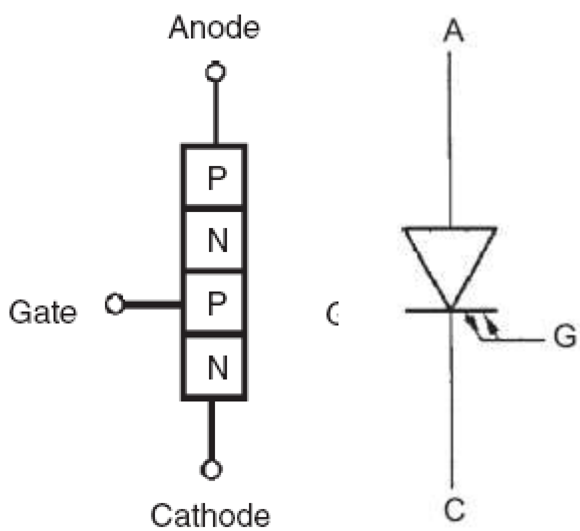


Fig 1.15

The turn-on mode is similar to a standard thyristor. The injection of the hole current from the gate forward biases the cathode p-base junction causing electron emission from the cathode. These electrons flow to the anode and induce hole injection by the anode emitter. The injection of holes and electrons into the base regions continues until charge multiplication effects bring the GTO into conduction.

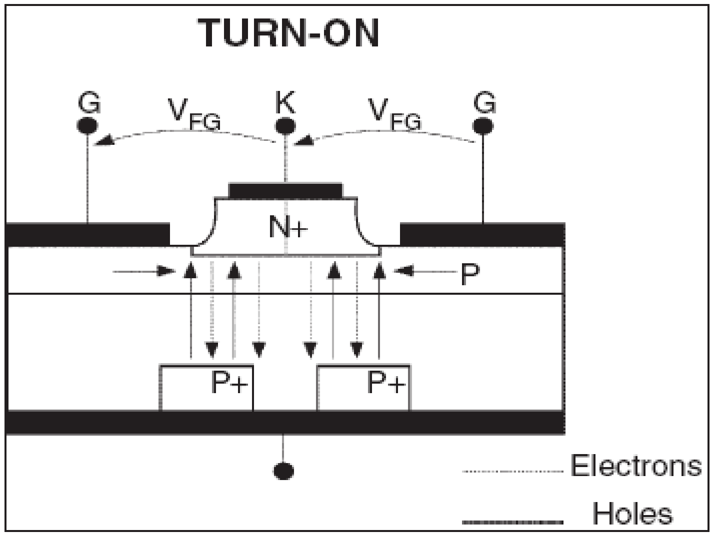


Fig 1.16

In order to turn-off a GTO, the gate is reversed biased with respect to the cathode and holes from the anode are extracted from the p-base. This is shown in Fig. 7.2b. As a result a voltage drop is developed in the p-base region, which eventually reverses biases the gate cathode junction cutting off the injection of electrons. As the hole extraction continues, the p-base is further depleted, thereby squeezing the remaining conduction area. The anode current then flows through the most remote areas from the gate contacts, forming high current density filaments. This is the most crucial phase of the turnoff process in GTOs,

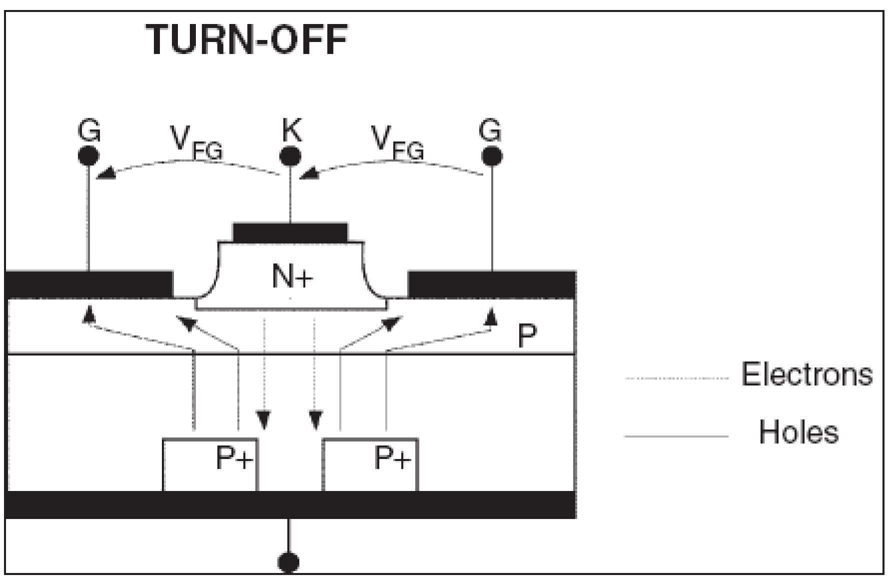


Fig 1.17

1.6.2 GTO Thyristor Models

One-dimensional two-transistor model of GTOs is shown in Fig. 7.3.

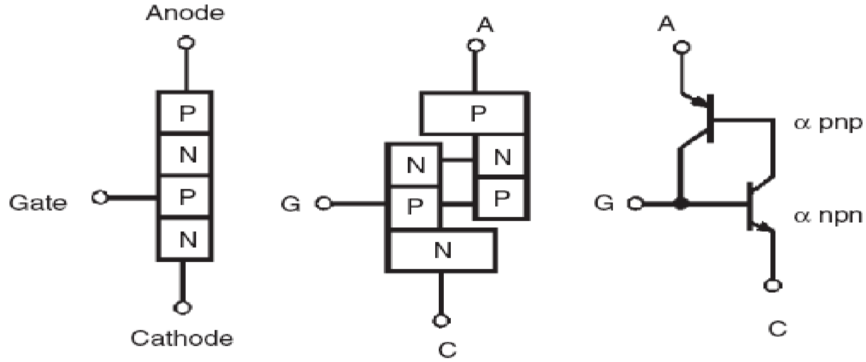


Fig 1.18

where *IA* is the anode current and *IG* the gate current at turn-off, and *αnpn* and *αpnp* are the common-base current gains in the NPN and PNP transistors sections of the device. For a non-shorted device, the charge is drawn from the anode and regenerative action commences,

1.6.3 V-I Characteristics

In the on-state the GTO operates in a similar manner to the thyristor. If the anode current remains above the holding current level then positive gate drive may be reduced to zero and the GTO will remain in conduction. However, as a result of the turn-off ability of the GTO, it does posses a higher holding current level than the standard thyristor, and in addition, the cathode of the GTO thyristor is sub-divided into small finger elements to assist turn-off. Thus, if the GTO thyristor anode current transiently dips below the holding current level, localized regions of the device may turn-off, thus forcing a high anode current back into the GTO at a high rate of rise of anode current after this partial turn-off. This situation could be potentially destructive. It is recommended, therefore, that the positive gate drive is not removed during conduction but is held at a value *IG*(*ON*), where *IG*(*ON*) is greater than the maximum critical trigger current (*IGT*) over the expected operating temperature range of the GTO thyristor. Figure 7.5 shows the typical on-state *V–I* characteristics

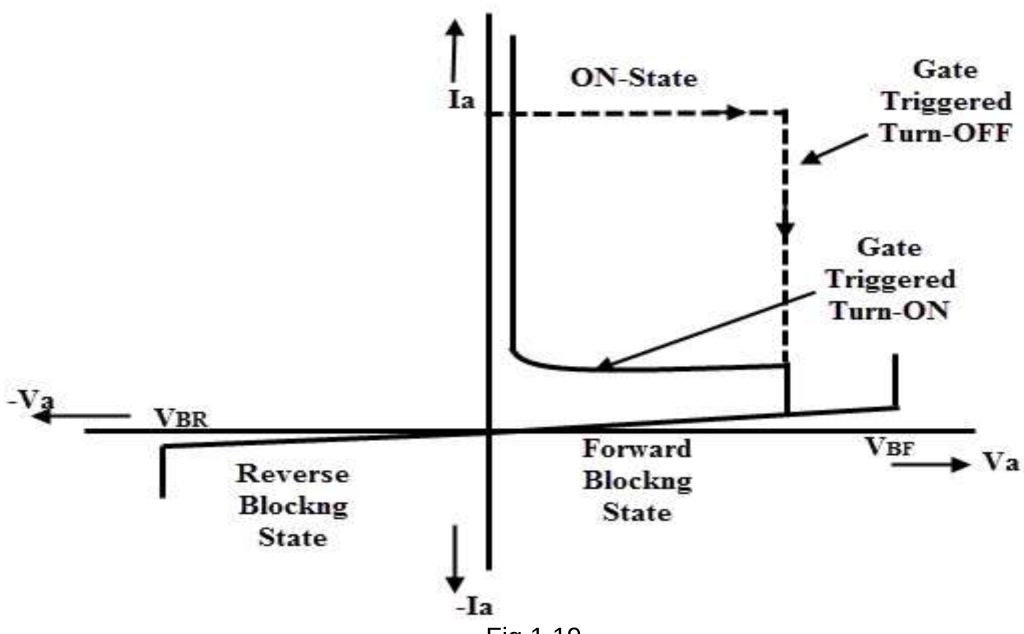


Fig 1.19

Gate Turn-Off Thyristor Applications

Due to the advantages like excellent switching characteristics, no need of commutation circuit, maintenance-free operation, etc makes the GTO usage predominant over thyristor in many applications. It is used as a main control device in choppers and inverters. Some of these applications are

- AC drives
- DC drives or DC choppers
- AC stabilizing power supplies
- DC circuit breakers
- Induction heating
- And other low power applications

1.7 TRIGGERING SCR

Triggering (Turn on) Methods of Thyristor:

Triggering:-

The turning on Process of the SCR is known as Triggering. In other words, turning the SCR from Forward-Blocking state to Forward-Conduction state is known as Triggering. The various methods of SCR triggering are discussed here.

The various SCR triggering methods are

- Forward Voltage Triggering
- Thermal or Temperature Triggering
- Radiation or Light triggering
- dv/dt Triggering
- Gate Triggering

(a) Forward Voltage Triggering:-

- In this mode, an additional forward voltage is applied between anode and cathode.
- When the anode terminal is positive with respect to cathode (V_{AK}) , Junction J1 and J3 is forward biased and junction J2 is reverse biased.
- No current flow due to depletion region in J2 is reverse biased (except leakage current).
- As V_{AK} is further increased, at a voltage V_{BO} (Forward Break Over Voltage) the junction J2 undergoes avalanche breakdown and so a current flows and the device tends to turn ON(even when gate is open)

(b) Thermal (or) Temperature Triggering:-

- The width of depletion layer of SCR decreases with increase in junction temperature.
- Therefore in SCR when V_{AR} is very near its breakdown voltage, the device is triggered by increasing the junction temperature.
- By increasing the junction temperature the reverse biased junction collapses thus the device starts to conduct.

(c) Radiation Triggering (or) Light Triggering:-

- For light triggered SCRs a special terminal niche is made inside the inner P layer instead of gate terminal.
- When light is allowed to strike this terminal, free charge carriers are generated.
- When intensity of light becomes more than a normal value, the thyristor starts conducting.
- This type of SCRs are called as LASCR

(d) dv/dt Triggering:-

- When the device is forward biased, J1 and J3 are forward biased, J2 is reverse biased.
- Junction J2 behaves as a capacitor, due to the charges existing across the junction.
- If voltage across the device is V, the charge by Q and capacitance by C then
- i_c =dQ/dt

  Q=CV

  i_c =d(CV)/dt

- =C.dV/dt+V.dC/dt

  as dC/dt = 0

i_c = C.dV/dt

- Therefore when the rate of change of voltage across the device becomes large, the device may turn ON, even if the voltage across the device is small.

(e) Gate Triggering:-

- This is most widely used SCR triggering method.
- Applying a positive voltage between gate and cathode can Turn ON a forward biased thyristor.
- When a positive voltage is applied at the gate terminal, charge carriers are injected in the inner P-layer, thereby reducing the depletion layer thickness.
- As the applied voltage increases, the carrier injection increases, therefore the voltage at which forward break-over occurs decreases.
- Three types of signals are used for gate triggering.

1. DC gate triggering:-

- A DC voltage of proper polarity is applied between gate and cathode (Gate terminal is positive with respect to Cathode).
- When applied voltage is sufficient to produce the required gate Current, the device starts conducting.
- One drawback of this scheme is that both power and control circuits are DC and there is no isolation between the two.
- Another disadvantage is that a continuous DC signal has to be applied. So gate power loss is high.

2. AC Gate Triggering:-

Here AC source is used for gate signals.

- This scheme provides proper isolation between power and control circuit.
- Drawback of this scheme is that a separate transformer is required to step down ac supply.
- There are two methods of AC voltage triggering namely (i) R Triggering (ii) RC triggering

Resistance Triggering

The following circuit shows the resistance triggering shown in fig 1.20

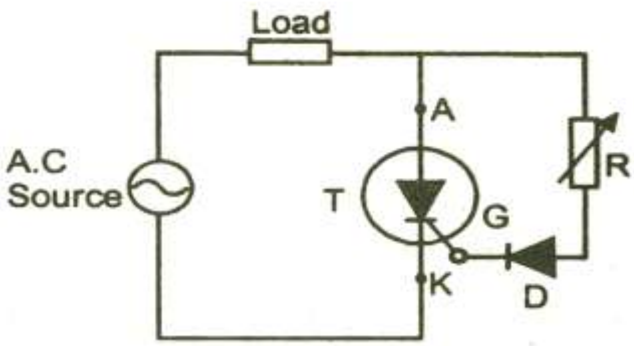


Fig 1,20

- In this method, the variable resistance R is used to control the gate current.
- Depending upon the value of R, when the magnitude of the gate current reaches the sufficient value (latching current of the device) the SCR starts to conduct.
- The diode D is called as blocking diode. It prevents the gate cathode junction from getting damaged in the negative half cycle.
- By considering that the gate circuit is purely resistive, the gate current is in phase with the applied voltage.
- By using this method we can achieve maximum firing angle up to 90°.

(ii) RC Triggering

The following circuit shows the resistance-capacitance triggering shown in 1.21

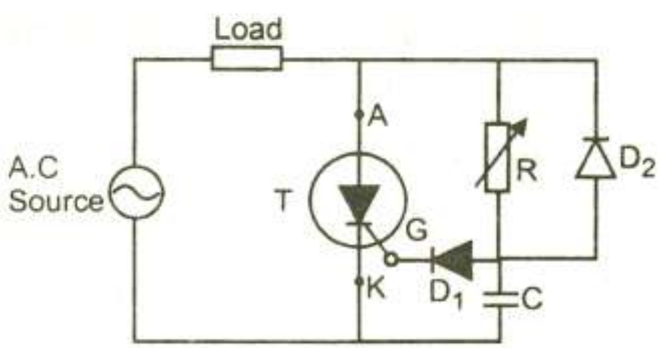


Fig 1.21

- By using this method we can achieve firing angle more than 90°.
- In the positive half cycle, the capacitor is charged through the variable resistance R up to the peak value of the applied voltage.
- The variable resistor R controls the charging time of the capacitor.
- Depends upon the voltage across the capacitor, when sufficient amount of gate current will flow in the circuit, the SCR starts to conduct.
- In the negative half cycle, the capacitor C is charged up to the negative peak value through the diode D2.
- Diode D1 is used to prevent the reverse break down of the gate cathode junction in the negative half cycle.

3. Pulse Gate Triggering:-

- In this method the gate drive consists of a single pulse appearing periodically (or) a sequence of high frequency pulses.
- This is known as carrier frequency gating.
- A pulse transformer is used for isolation.
- The main advantage is that there is no need of applying continuous signals, so the gate losses are reduced.

Advantages of pulse train triggering:

- Low gate dissipation at higher gate current.
- Small gate isolating pulse transformer
- Low dissipation in reverse biased condition is possible.So simple trigger circuits are possible in some cases
- When the first trigger pulse fails to trigger the SCR, the following pulses can succeed in latching SCR. This important while
- Triggering inductive circuits and circuits having back emf's.

1.8 Pulse Transformer

Pulse transformer designers usually seek to minimize voltage droop, rise time, and **pulse** distortion. Droop is the decline of the put **pulse** voltage over the duration of one **pulse**. ... The magnetic flux in a typical A.C. **transformer** core alternates between positive and negative values.

Pulse transformer is always used to be the isolator between **gate driver** and power MOSFET. There are many topologies about the peripheral circuit.

Galvanic isolation

A pulse transformer usually has galvanic isolation between its windings. This allows for the primary driving circuit to operate at a different electric potential from the secondary driven circuit. The isolation can be very high, e.g. 4 kV for small electronic transformers. This is especially true for very high-power applications in which the output voltage can reach 200 kV. The galvanic isolation also allows meeting safety requirements if one part of the circuit is unsafe to touch, due to the danger of higher voltage, even if for a brief period of time (e.g. if current path is broken in series with inductance).

Pulse transformation

For a gate driving applications usually a rectangular voltage pulse with fast rising and falling edges is required. The frequency bandwidth must be high enough for a given application, so that the delay in signal transmission is acceptably small and there are no severe distortions of the signal. The frequency bandwidth and signal fidelity are dictated mostly by the non-ideal and parasitic parameters of the transformer: inter-winding capacitance, self-capacitance of each winding, equivalent resistance, etc. Combination of these parameters can cause a number of effects on the transformed pulse: overshoot, droop, back swing, rise time and fall time, which appear as unwanted signal distortions.[18)] A good quality pulse transformer should have low leakage inductance and distributed capacitance as well as high open-circuit inductance. The transformed pulse will be only a poorer copy of the input pulse. So the if the driving circuit produces a non-ideal pulse then the pulse shape will suffer from additional distortions

Windings and turns ratio

In most low-power or applications the turns ratio is around unity 1:1 (or similar like 1:2). Only when the level of signal must be changed to a different voltage then a significantly different turns ratio will be used, as it is the case for most transformers in forward converters (low or high power).Pulse transformer can have more than two windings, which can be used for instance to drive several transistors simultaneously, so that any phase shifts or delays between signals are minimized between signals are minimized.

Typical configurations of low-power pulse transformers shown in fig 1.22

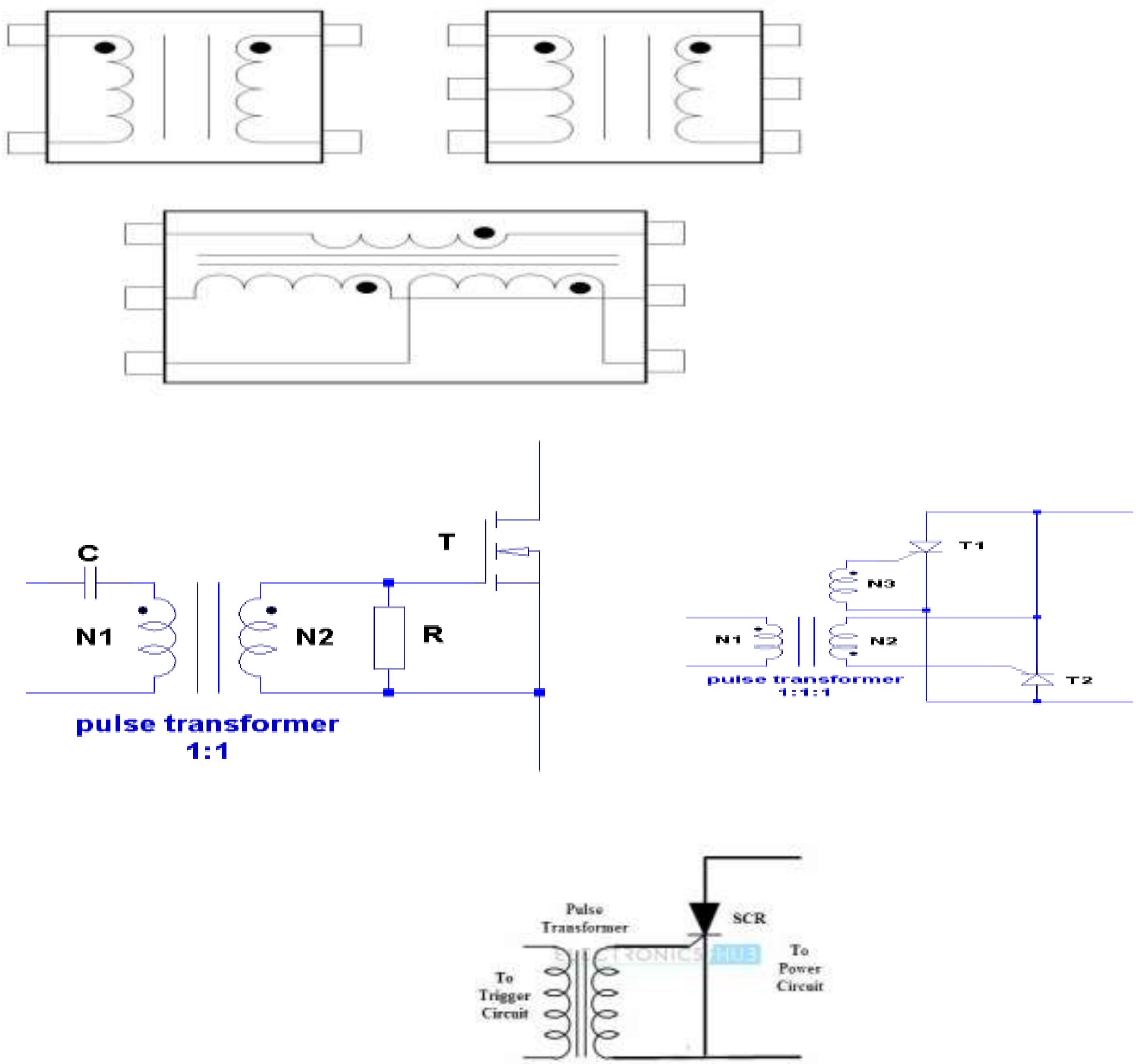


Fig 1.22

1.9 Opto Isolator

An **Opto coupler**, also known as an **Opto-isolator** or **Photo-coupler**, is an electronic components that interconnects two separate electrical circuits by means of a light sensitive optical interface.

We know from our tutorials about Transforms that they can not only provide a step-down voltage, but they also provide "electrical isolation" between the higher voltage on the primary side and the lower voltage on the secondary side.

In other words, transformers isolate the primary input voltage from the secondary output voltage using electromagnetic coupling by means of a magnetic flux circulating within the iron laminated core.

Fig 1.23

But we can also provide electrical isolation between an input source and an output load using just light by using a very common and valuable electronic component called an **Opto coupler**.

The basic design of an opto coupler consists of an LED that produces infra-red light and a semiconductor photo-sensitive device that is used to detect the emitted infra-red beam. Both the LED and photo-sensitive device are enclosed in a light-tight body or package with metal legs for the electrical connections as shown.

An Opto coupler or Opto-isolator consists of a light emitter, the LED and a light sensitive receiver which can be a single photo-diode, photo-transistor, photo-resistor, photo-SCR, or a photo-TRIAC with the basic operation of an Opto coupler being very simple to understand. Shown fig 1.24

Opto coupler Types

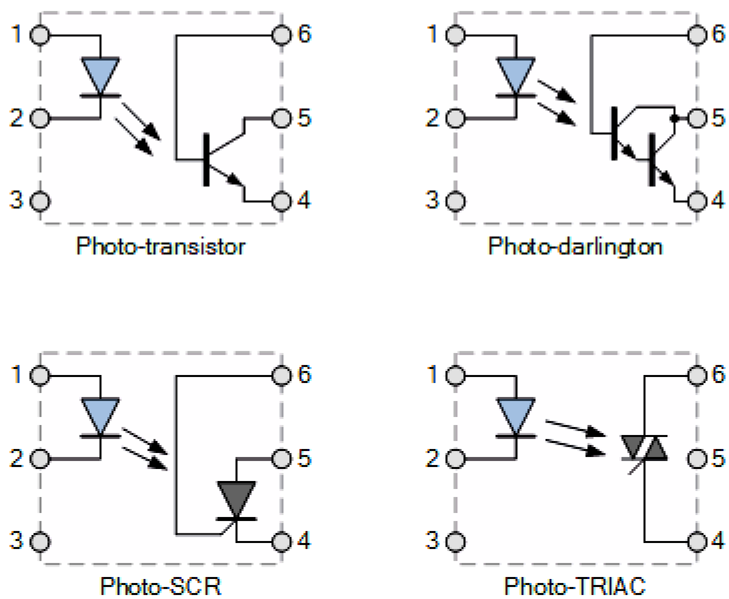


Fig 1.24

Opto coupler Applications

Opto couplers and opto-isolators can be used on their own, or to switch a range of other larger electronic devices such as transistors and triacs providing the required electrical isolation between a lower voltage control signal and the higher voltage or current output signal. Common applications for opto couplers include microprocessor input/output switching, DC and AC power control, PC communications, signal isolation and power supply regulation which suffer from current ground loops, etc. The electrical signal being transmitted can be either analogue (linear) or digital (pulses).

In this application, the opto coupler is used to detect the operation of the switch or another type of digital input signal. This is useful if the switch or signal being detected is within an electrically noisy environment. The output can be used to operate an external circuit, light or as an input to a PC or microprocessor.

Triac Opto coupler Application

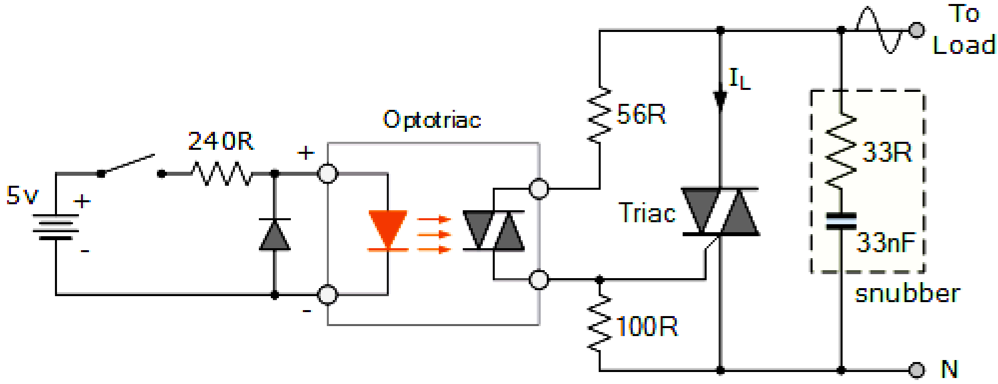


Fig 1.25

This type of opto coupler configuration forms the basis of a very simple solid state relay application which can be used to control any AC mains powered load such as lamps and motors. Also unlike a thyristor (SCR), a triac is capable of conducting in both halves of the mains AC cycle with zero-crossing detection allowing the load to receive full power without the heavy inrush currents when switching inductive loads.

Opto couplers and **Opto-isolators** are great electronic devices that allow devices such as power transistors and triacs to be controlled from a PC's output port, digital switch or from a low voltage data signal such as that from a logic gate. The main advantage of opto-couplers is their high electrical isolation between the input and output terminals allowing relatively small digital signals to control much large AC voltages, currents and power.

1.10 Resistance firing circuit and waveform

A simple resistance triggering circuit is as shown. The resistor *R*1 limits the current through the gate of the SCR. *R*2 is the variable resistance added to the circuit to achieve control over the triggering angle of SCR. Resistor 'R' is a stabilizing resistor. The diode D is required to ensure that no negative voltage reaches the gate of the SCR shown fig 1.26 and fig 1.27

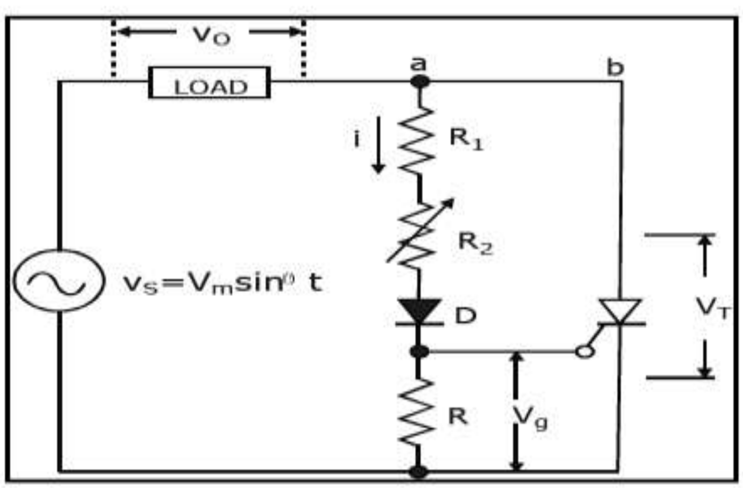


Fig 1.26

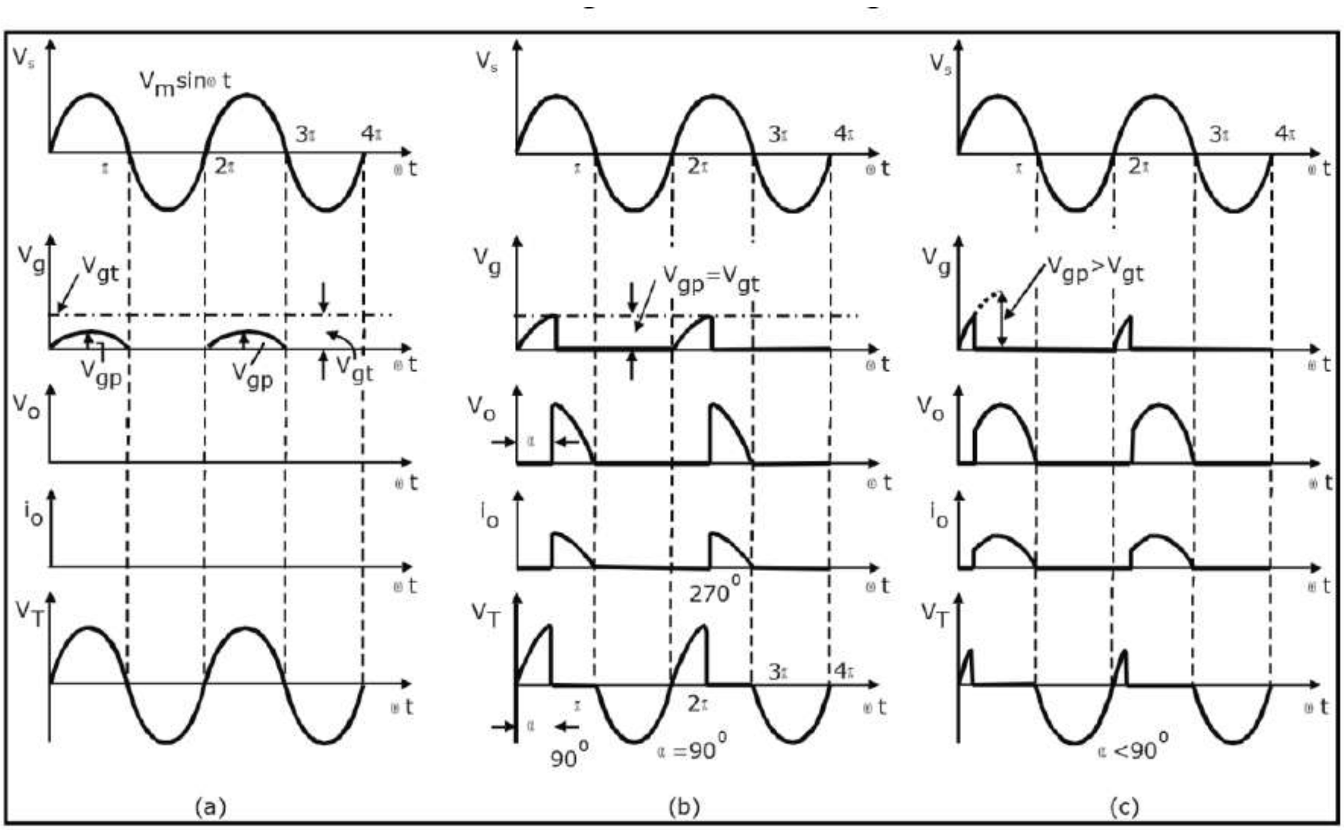


Fig 1.27

Case 1 : $V_{gp}<V_{gt}$

V_{gp}, the peak date voltage is less then V_{gt} since R2 is very large. Therefore current I flowing through the gate is very small. SCR will not turn on and therefore the load voltage is zero and V_{scr} is equal to Vs. This is because we are using a resistive network. Therefore output will be in phase with input.

Case 2: $V_{gp}> V_{gt}$

The triggering value V_{gt} is reached much earlier than 90˚. Hence the SCR turns on earlier than V_s reaches its peak value. The waveforms as shown with respect to Vs= V_m sinwt.

1.11 Resistance Capacitance Triggering

Capacitor 'C' in the circuit is connected to shift the phase of the gate voltage. *D*1 is used to prevent negative voltage from reaching the gate cathode of SCR. In the negative half cycle, the capacitor charges to the peak negative voltage of the supply V_m through the diode *D*2. The capacitor maintains this voltage across it, till the supply voltage crosses zero. As the supply becomes positive, the capacitor charges through resistor 'R' from initial voltage of V_m, to a positive value. When the capacitor voltage is equal to the gate trigger voltage of the SCR, the SCR is fired and the capacitor voltage is clamped to a small positive value. Shown fig 1.28 and fig 1.29

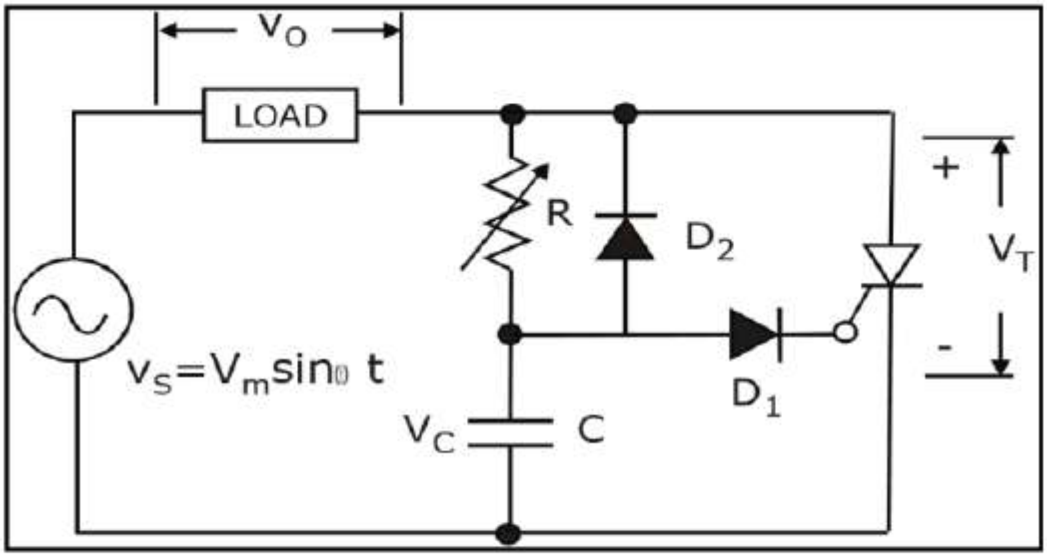


Fig 1.28

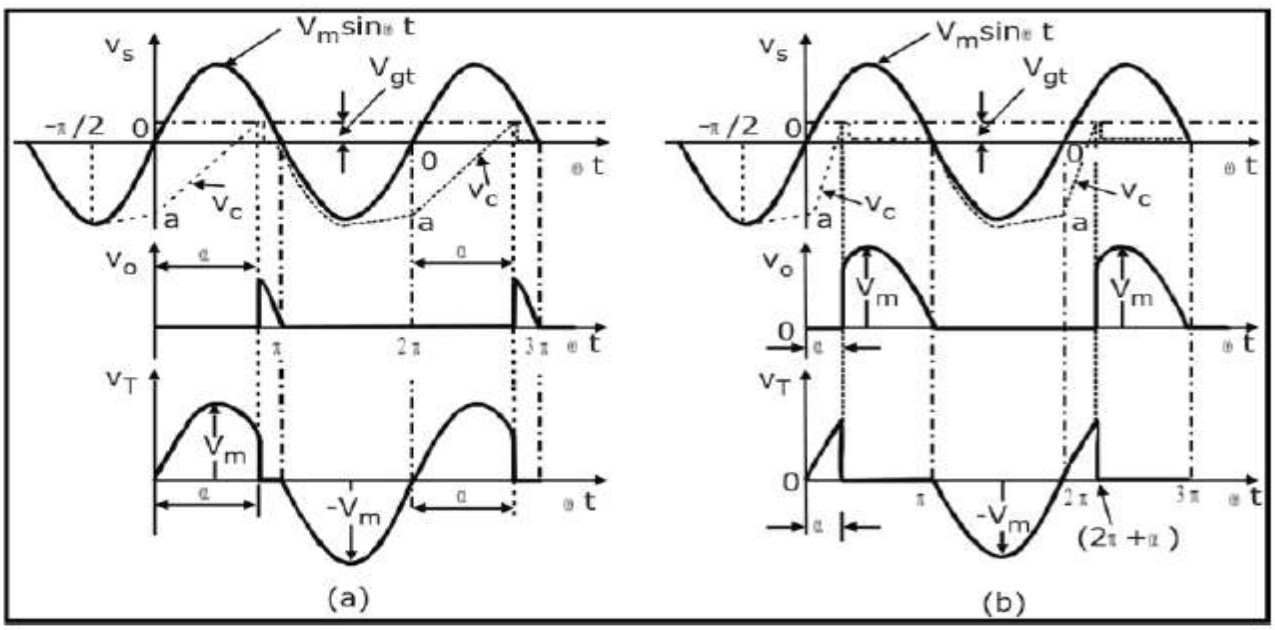


Fig 1.29

Case 1: R Large.

When the resistor 'R' is large, the time taken for the capacitance to charge from V_m to V_{gt} is large, resulting in larger firing angle and lower load voltage.

Case 2: R Small

When 'R' is set to a smaller value, the capacitor charges at a faster rate towards V_{gt} resulting in early triggering of SCR and hence *VL* is more. When the SCR triggers, the voltage drop across it falls to 1 – 1.5V. This in turn lowers, the voltage across R & C. Low voltage across the SCR during conduction period keeps the capacitor discharge during the positive half cycle.

1.12 Synchronized UJT Oscillator

A synchronized UJT triggering circuit is as shown in figure below. The diodes rectify the input ac to dc, resistor Rd lowers V_{dc} to a suitable value for the zener diode and UJT. The zener diode 'Z' functions to clip the rectified voltage to a standard level VZ which remains constant except near V_{dc} 0. This voltage VZ is applied to the charging RC circuit. The capacitor 'C' charges at a rate determined by the RC time constant. When the capacitor reaches the peak point VP the UJT starts conducting and capacitor discharges through the primary of the pulse transformer. As the current through the primary is in the form of a pulse the secondary windings have pulse voltages at the output. The pulses at the two secondary's feed SCRs in phase. As the zener voltage VZ goes to zero at the end of each half cycle the synchronization of the trigger circuit with the supply voltage across the SCRs is archived, small variations in supply voltage and frequency are not going to effect the circuit operation. In case the resistor 'R' is reduced so that the capacitor voltage reaches UJT threshold voltage twice in each half cycle there will be two pulses in each half cycle with one pulse becoming redundant shown fig 1.30 and fig 1.31

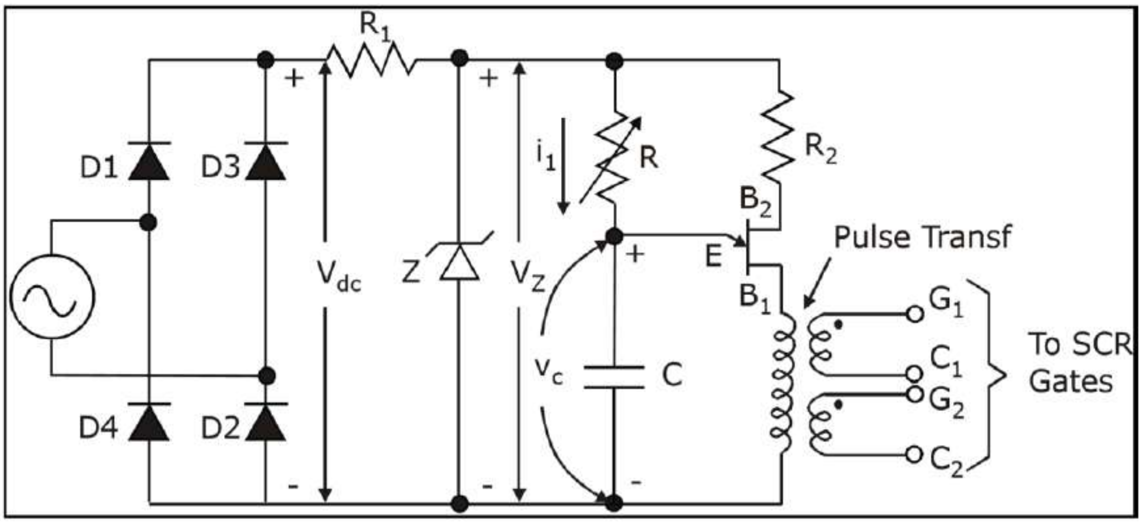


fig 1.30

Waveform

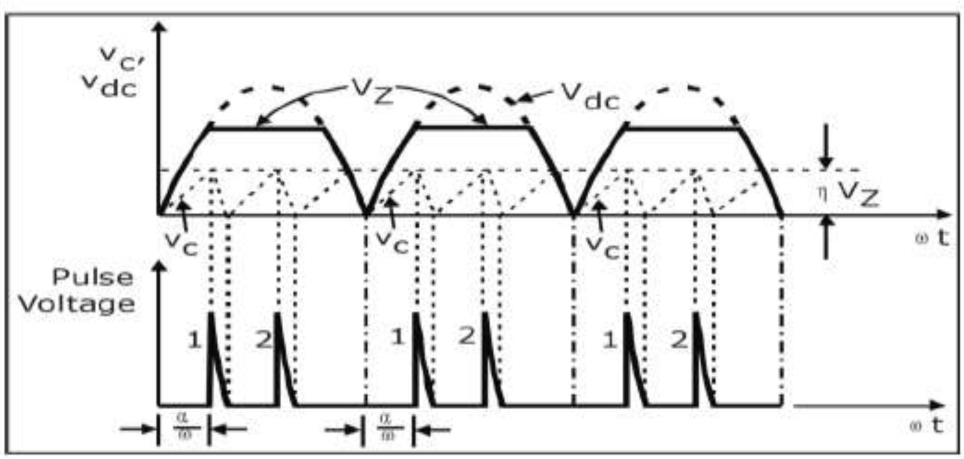


fig 1.31

1.13 Ramp-Pedestal UJT-SCR Control Circuit:

The circuit, shown below, uses a UJT to trigger a SCR. The UJT is used to more accurately trigger the SCR. Shown fig 1.32

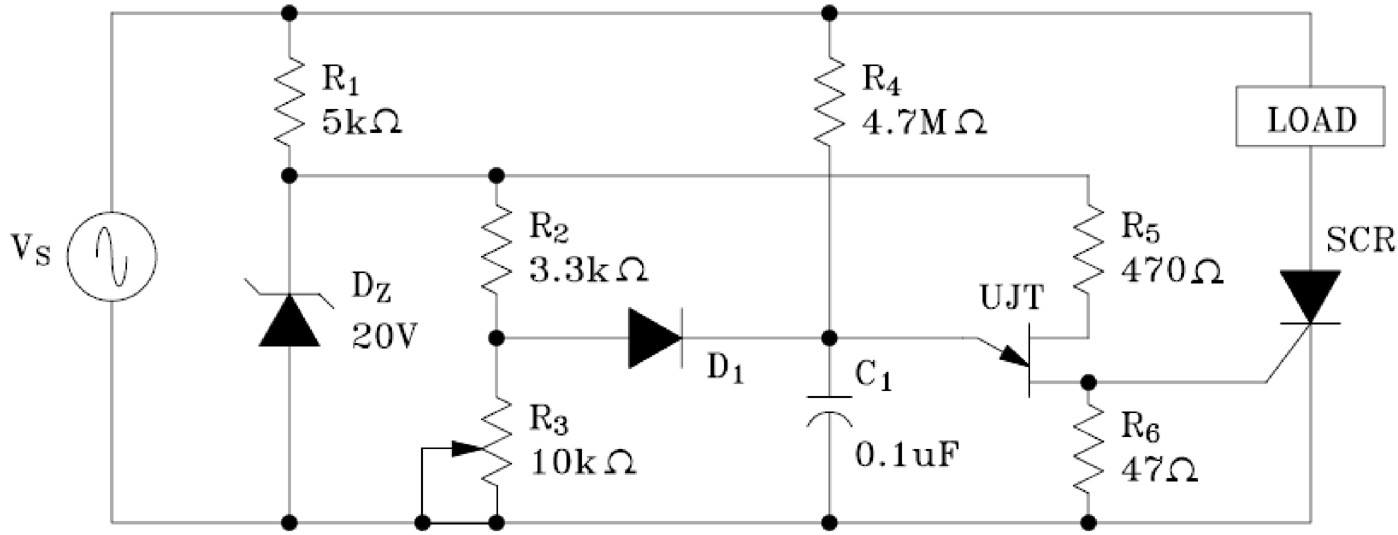


fig 1.32

When the source voltage exceeds 20V, the zener diode (D_Z) will begin to conduct, applying a DC voltage across the base connections of the UJT. At the same time, diode D_1 will be forward biased, and the capacitor will quickly charge through R_1 and R_2. This represents the left-hand pedestal portion of the of the emitter voltage. Once the capacitor charges to the voltage across R_3, D_1 will become reverse biased and the capacitor will continue to slowly charge through R_4. This represents the ramp portion of the emitter voltage. The capacitor continues to charge until the UJT fires. At this point the capacitor will quickly discharge through R_6, and this represents the right-hand pedestal of the emitter voltage. The capacitor discharge is sufficient to trigger the SCR.

The point at which the UJT fires can be adjusted by varying the pot R_3. With a large setting on R_3, the capacitor must charge to a larger value before D_2 becomes reverse biased. This causes the UJT to fire faster, resulting in more of the source voltage appearing across the SCR. This can be seen graphically shown fig fig 1.32

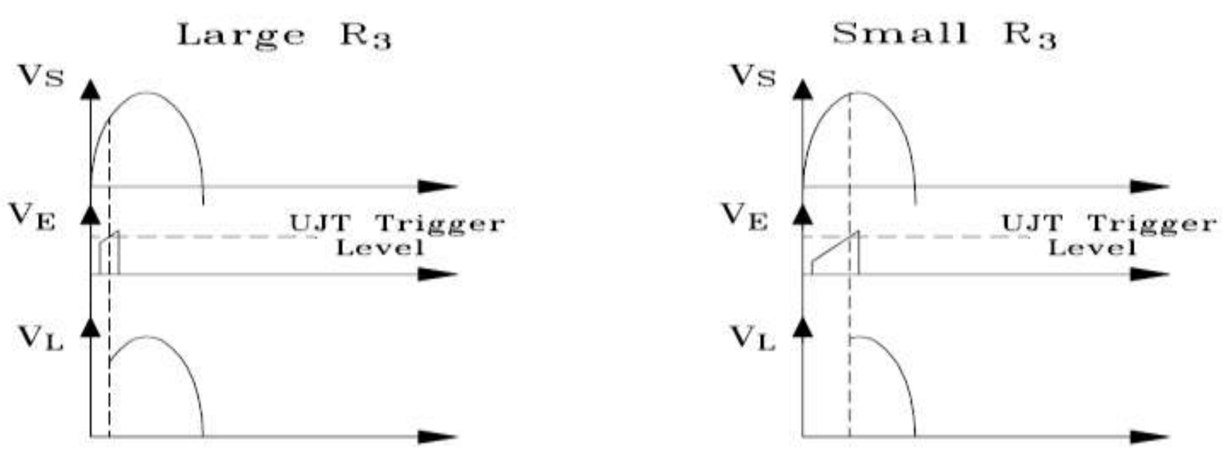


fig 1.33

Model Questions

PART – A

1. Define Holding current and latching current of SCR.

2. Draw the symbols for the following:

(i) SCR (ii) IGBT (iii) MOSFET (iv) GTO

3. Define di/dt and dv/dt rating of SCR

4. Mention the applications of SCR.

5. What is forward blocking region and forward breakover voltage of SCR?

6. What are the positive attributes combined in IGBT.

7. State the applications of IGBT.

8. How does a GTO differ from a conventional SCR?

9. List the different methods of gate triggering of SCR.

10. What are the basic requirements of a gate triggering cicuit?

11. What are the methods used for triggering the SCR?

12. State the necessity of a opto isolator used in triggering circuit with its working.

13. Define gate trigger voltage and gate power loss.

14. Mention the applications of MOSFET.

15. Mention the use of pulse transformer in the triggering circuit.

16. Give the advantages of RC firing circuit over R firing circuits.

PART – B

1. Explain the principle of operation of SCR with neat diagram.

2. Draw the VI characteristics of SCR.

3. Explain the characteristics of IGBT with its circuit diagram.

4. Draw the basic structure and symbol of MOSFET.

5. Explain the operation of resistance firing circuit.

6. Explain pulsed gate signal triggering.

7. Explain opto coupler.

8. Draw the circuit diagram of ramp and pedestal triggering for AC load.

PART- C

1. Explain the working of SCR with its characteristics.

2. Draw and explain the working of GTO and its characteristics.

3. Explain the operation of MOSFET with necessary diagrams.

4. What is the purpose of isolation between the control and power? what are the devices used for isolation?

5. Draw and explain the circuit diagram for the synchronized UJT triggering. Also draw the associated voltage waveforms.

6. Explain the operation of RC firing circuit with necessary waveforms.

7. Draw the circuit diagram for the ramp and pedestal trigger circuit and explain its operation with appropriate waveforms.

########################

II UNIT

CONVERTERS

Many Industrial applications make use of controlled dc power. Examples of such applications are as follows

(a) Steel-rolling mills, paper mills, printing presses and textile mills demploying dc motor drives.

(6) Traction systems working on dc.

(c) Electrochemical and electrornetallurgical processes,

(d) Magnet power supplies.

(e) Portable hand tool drives.

(f) High-voltage dc transmission.

Earlier, dc power was obtained from motor-generator (MG) sets or **ac power was converted to de power by means of mercury-arc rectifiers or thyratrons.** The advent of thyristors has changed the art of ac to dc conversion. Presently, **phase-controlled ac to dc converters employing thyristors are extensively used for changing constant ac input voltage to controlled do output voltage. In an industry where there is a provision for modernization, mercury-arc rectifiers and thyratrons are being replaced by thyristors**.

In phase-controlled rectifiers, a thyristor is turned off as ac supply voltage reverse biases it provided anode current has fallen to a level below the holding current. The turning-off, or commutation, of a thyristor by supply voltage itself is called *natural,* or *line commutation.*,

In industrial applications, rectifier circuits make use of more than one SCR. In such circuits, when an incoming SCR is turned on by triggering, it immediately reverse biases the outgoing SCR and turns it off. As phase-controlled rectifiers need no commutation circuitry, these are simple, less expensive and are therefore widely used in industries where controlled dc power is required.

In the study of thyristor systems, SCRs and diodes are assumed ideal switches which means that *(i)* there is no voltage drop across them, *(ii)* no reverse current exists under reverse voltage conditions and *(iii)* holding current is zero.

2.2 PRINCIPLE OF PHASE CONTROL

2.2.1 Single phase Half controlled bridge converter with resistive load

The simplest form of controlled rectifier circuits consist of a single thyristor feeding dc power to a resistive load R as shown in Fig. 2.1 *(a).* The source voltage is = V„, sin tat, Fig. 2.1 *(b).* An SCR can conduct only when anode voltage is positive'and a gating signal is applied. As such, a thyristor blocks the flow of load 'current i_0 until it is triggered. At some delay angle α, a positive gate signal applied between gate and cathode turns on the SCR, Immediately, full supply voltage is applied to the load as y_o, Fig. 2.1 (b). At the instant of delay angle a, v_o rises from zero to V, sin a as shown. For resistive load, current i_0 is in phase with 0_0.

Firing angle of a thyristor is measured from the instant it would start conducting if it were replaced by a diode. In Fig. 2.1, if Ihyristor is replaced by diode, it would begin conduction at cot 0, 27c, 47t etc. ; fixing angle is therefore measured from these instants. A *firing angle* may thus be defined as the angle between the instant thyristor would conduct if it were a diode and the instant it is triggered.

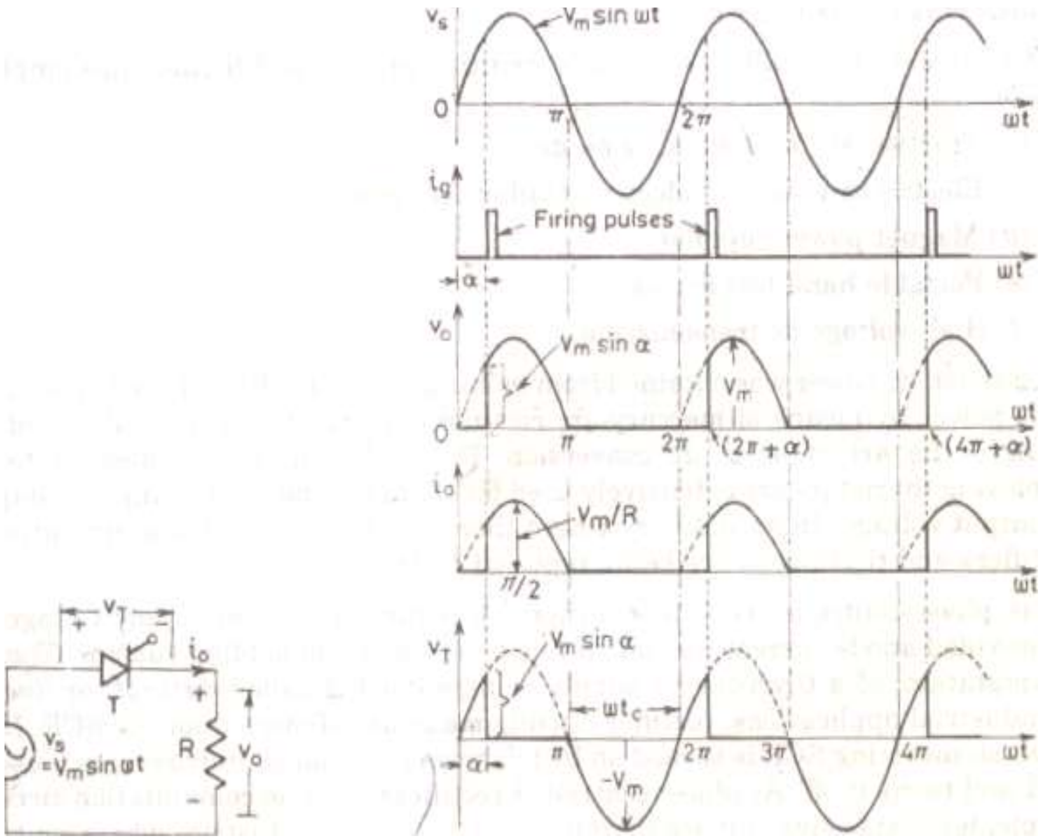


Fig. 2.1

A firing angle may also be (termed as follows: A *firing angle* is measured from the angle that gives the largest average output voltage, or the highest load voltage. A firing *angle* may thus be defined as the angle measured from the instant that gives the lamest average output voltage to the instant it is triggered.

Once the SCR is on, load current flows, until it is turned-off by reversal of voltage, 3n etc. At these angles of n, 3n, 5n etc, load current falls to zero and soon after the supply voltage reverse biases the SCR, the device is therefore turned off. It is seen from Fig. 2.1 *(b)* that by varying the firing angle α, the *phase* relationship between the start of the in a.c current aid the supply voltage can be controlled; hence the term Male control is used for such a method of controlling the load currents

A single-phase half-wave circuit is one which produces only one puIse of load current during one cycle of source voltage. As the circuit shown in Fig. 61 (a) produces only one load current. pulse for one cycle of sinusoidal source voltage, this circuit represents a single-phase half-wave thyristor circuit

$$V_0 = \frac{1}{2\pi}\int_{\alpha}^{\pi} V_m \sin \omega t \cdot d\,(\omega t) = \frac{V_m}{2\pi}\,(1 + \cos \alpha)$$

The maximum value of V_0 occurs at $\alpha = 0°$.

$$\therefore \qquad V_{o \cdot m} = \frac{V_m}{2\pi} \cdot 2 = \frac{V_m}{\pi}$$

Average load current, $I_0 = \frac{V_0}{R} = \frac{V_m}{2\pi R}\,(1 + \cos \alpha)$

2.2.2 Single-phase Half-wave Circuit with RL Load

A single-phase half-wave thyristor circuit with RL load is shown in Fig. 2.2 (a). Line voltage *u,* is sketched in the top of Fig,2 .2 (b). At wt =α, thyristor is turned on by gating signal. The load voltage u_o at once becomes equal to source voltage as shown.. But the inductance *L* forces the load, or output, current i_o to rise gradually. After some time, 4_0 reaches maximum value and then begins to decrease. At wt = Π, Vo=0. but i_o is not zero because of the load inductance *L.* After wt = Π, SR is subjected to reverse anode voltage but it will not be turned off as load current i_0 is not lees than the holding current. At some angle > i reduces'to zero and SCR is -turned off as it is already reverse biased, After tot f3, ti_c = 0 and 4, = 0. At tot =27t + a, SCR is triggered again, ri·] is applied to the load and load

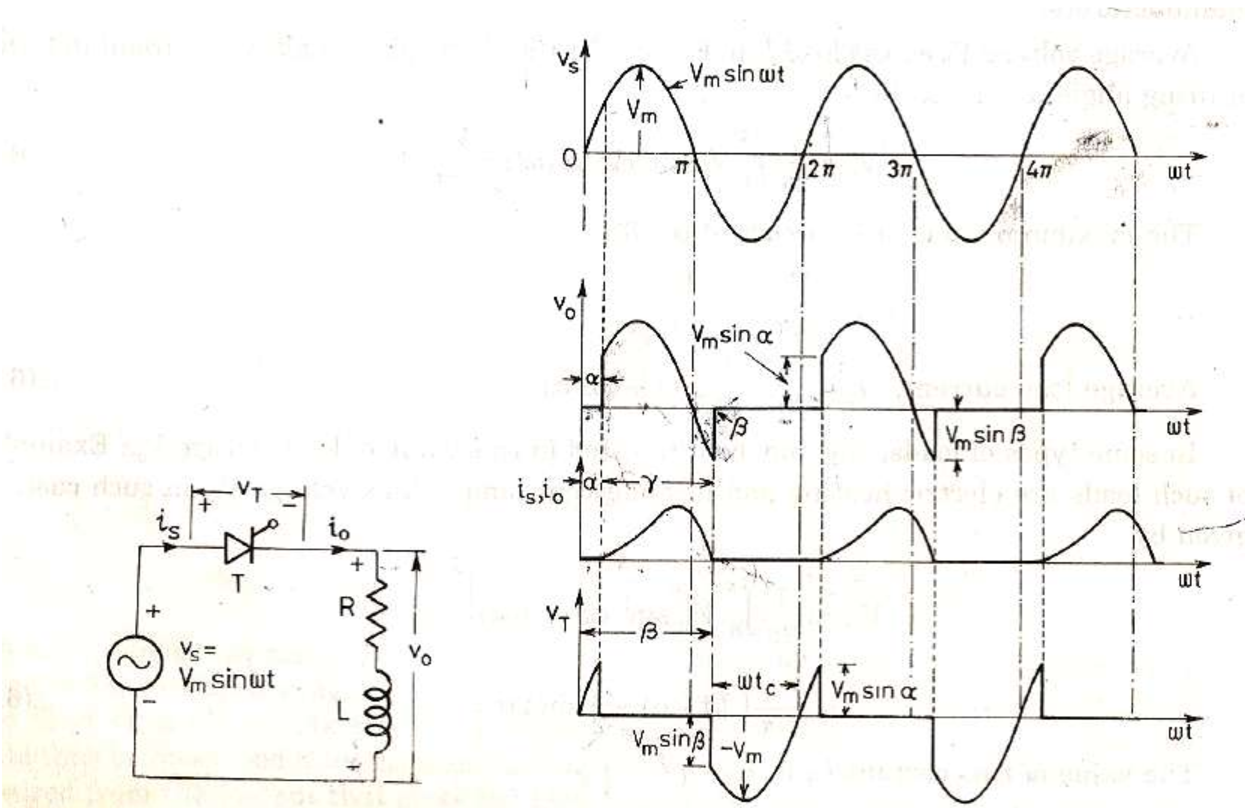


Fig. 2.2

Current develops as before. Angle β is called extinction angle.

Average load voltage is

$$V_0 = \frac{1}{2\pi} \int_{\alpha}^{\beta} V_m \sin \omega t \, d\,(\omega t) = \frac{V_m}{2\pi} (\cos \alpha - \cos \beta)$$

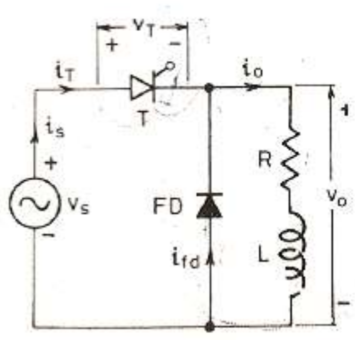
V

2.2.3 Single-phase Half-wave Circuit with RL Load and Freewheeling Diode

The waveform of load current i_0 in Fig.2.3 can be improved by connecting a freewheeling (or flywheeling) diode across load. A freewheeling diode is also called by-pass or commutating diode.

At wt = 0, source voltage is becoming positive. At some delay angle α, forward biased SCR is triggered and source voltage v_s appears across load,

At source voltage wt = Π is zero and just after this instant, freewheeling diode FD is forward biased through the conducting. SCR_ As a result, load current i_s is immediately transferred from SCR to FD. At the same time, SCR subjtcted to reverse voltage and zero current it is turned off at wt = Π



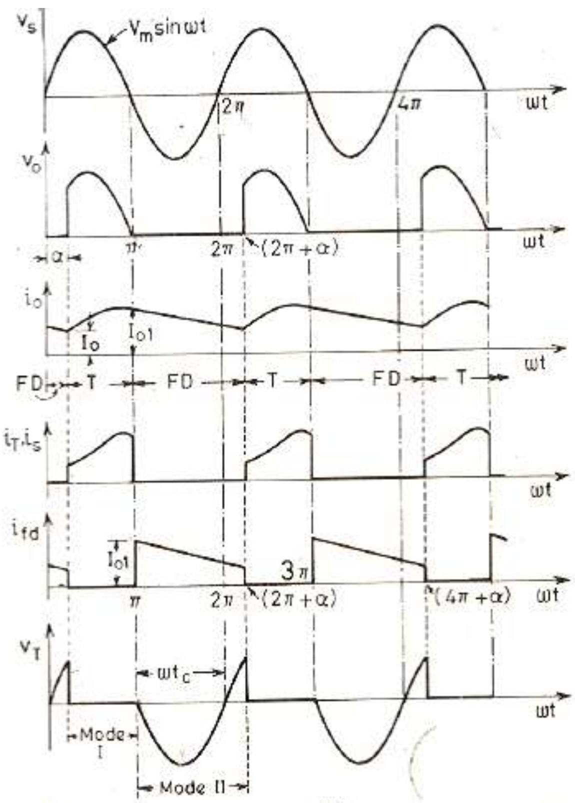


Fig.2.3

It is also seen from Figs 2.3 that load current waveform is improved with FD .Thus the advantages of using freewheeling diode are (1) input *pi* is improved

(ii) load current waveform is improved and

(iii) as a result of load performance is better.

2.3 SINGLE-PHASE FULL WAVE BRIDGE CONVERTERS

Phase controlled single phase or three phase, full-wave converters are primarily of three types; namely (1) uncontrolled converters,

(2) half controlled converters and

(3) fully-converters.

An uncontrolled converter or rectifier uses only diodes and the level of dc output voltage cannot be controlled. A half-controlled converter or semi-converter uses a mixture of diodes and thyristors and there is a limited control over the level of dc output voltage.A fully-controlled converter or full converter uses thyristors only and there is a wider control over the level of dc output voltage.

A semiconverter is one-quadrant converter. A one-quadrant converter has one polarity of dc output voltage and current at its output terminals as shown in figure 2.4

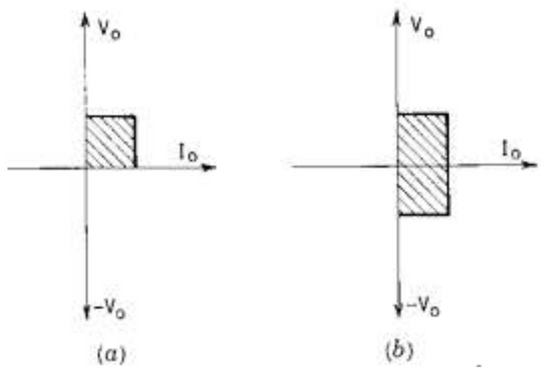


Fig 2.4

(a) One quadrant converter (b) two quadrant converter

A two-quadrant converter is one in which voltage polarity can reverse but current direction cannot reverse because of the unidirectional nature of thyristors fig(b) shown above

2.3.1 Single phase full wave bridge converters (B-2 Connection) with R load

A single phase full converter bridge using four SCRs is shown in figure 2.5

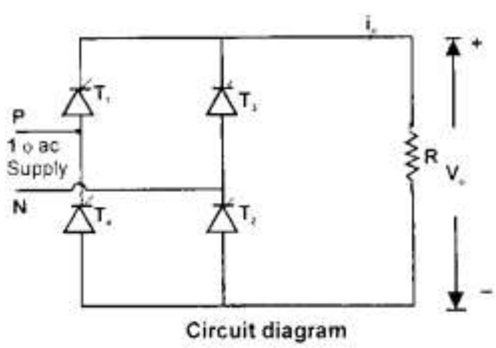


Fig 2.5

Single phase full wave controlled bridge rectifier with R load

Figure 2.5 hows a single phase fully controlled (i.e both half cycles are phase controlled) bridge converter, supplying a resistive load. During the +ve half cycle thyristors T1 and T2 are forward biased. When T1 & T2 are triggered at ωt = α, they start conducting and supplying the load current. At ωt=Π, current is zero, the supply voltage reverses and T1,T2 are turned off by natural commutation. In the –ve half cycle T3 & T4 conduct from ωt =Π+α toωt =2Π. At ωt =2Π, current is zero, the supply voltage reverses and T3 &T4 are turned off by natural commutation. The above sequence of events is repeated in each cycle. The wave forms of input, firing pulse, output voltage and load currents are also shown below Fig 2.6

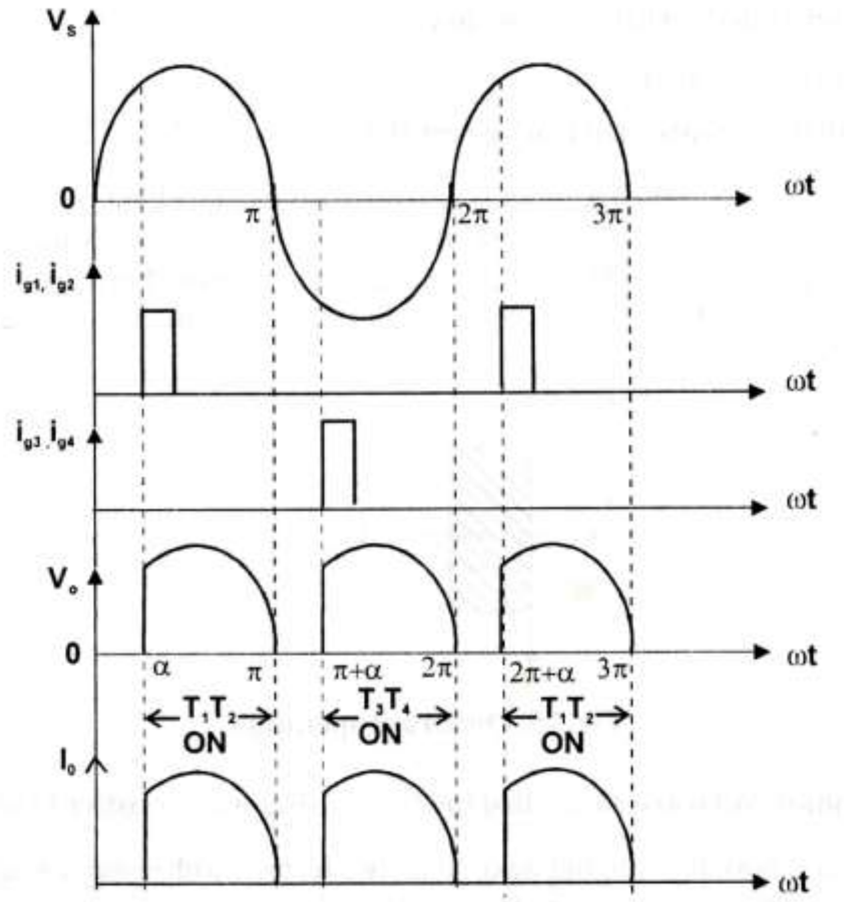


Fig 2.6

Voltage and current waveform for single phase full-wave controlled rectifier

The expressions for V_o, $I_o$$V_{rms}$ are same as that of given in M -2 connection.

2.3.2 Single phase Fully controlled Bridge Circuit with R-L Load:

The single phasefully controlledbridge circuit with R-L load is shown in figure 2.7. Conduction doesnot take place unitl the thyristors are fired and in order for current to flow, thyristors T1 and T2 must be fired together, as must T3 and T4 in the next half cycle. Inductance L is used in the circuit to reduce the ripple. A large value of L will result in a continuous steady current in the load. A small value of L will produce a discontinuous load current for large firing angles. The wave forms are given in figure 2.8

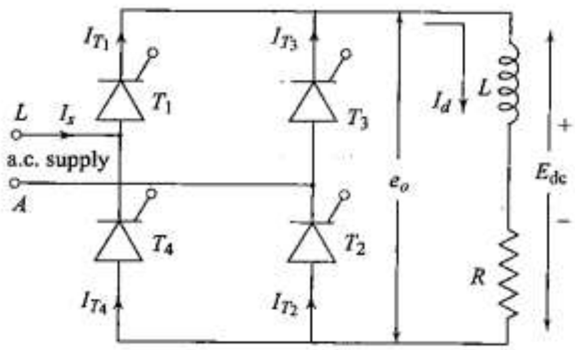


Fig 2.7

Fully controlled single phase bridge with R-L load

The voltage waveform at the dc terminals comprises a steady d.c component on to which is superimposed an a.c ripple component, having a fundamental frequency equal to twice that of a.c supply.

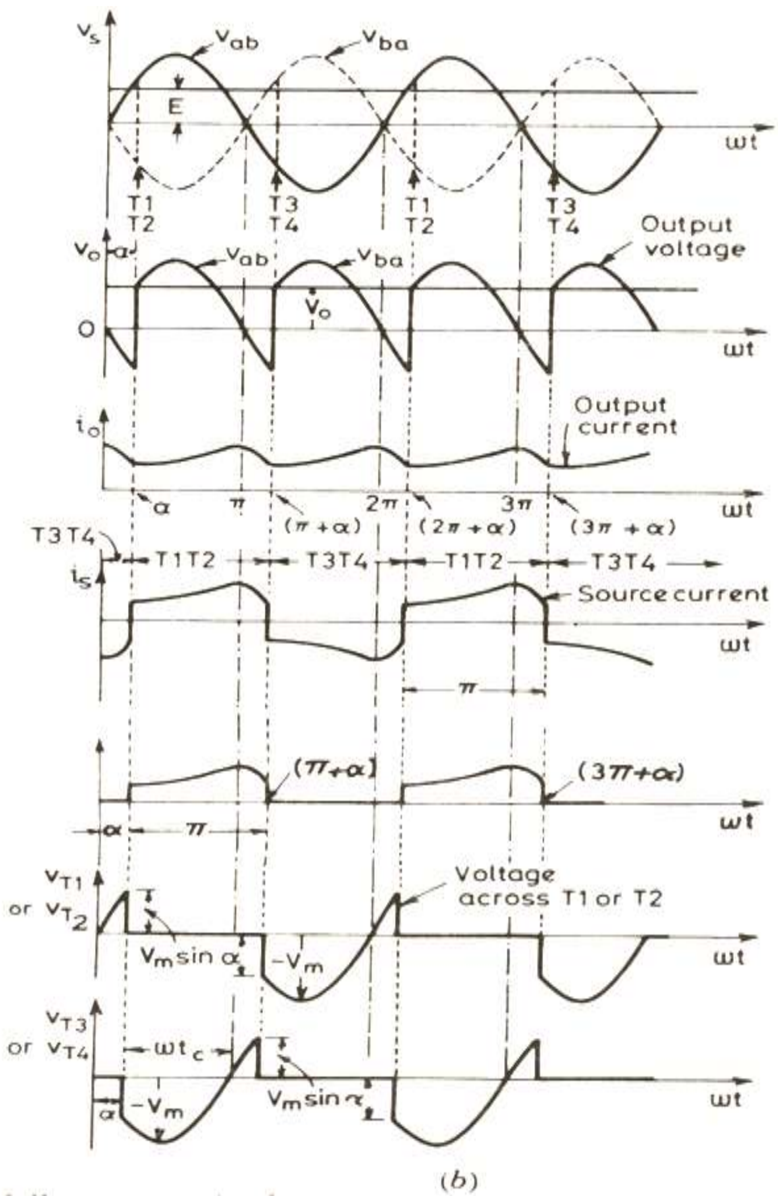


Fig 2.8

Load current i_o is assumed continuous over the working range.i.e load is alaways connected to the ac voltage source through the thyristors. $0<\alpha<\omega t$, T1,T2 are forward biased through the already conducting SCRs T3,T4 and block the forward voltage. For continuous current, T3,T4 conduct after $\omega t = 0$ eventhough these are reverse biased. When forward biased SCRs T1,T2 are triggered at $\omega t = \alpha$, they get turned on. As a result, supply voltage $V_m \sin\alpha$ immediately appears across thyristors T3,T4 as a reverse bias, these are therefore turned off by natural, or line commutation.at the same time load current i_o flowing through T3,T4 is transferred to T1,T2 at $\omega t = \alpha$. **When T1,T2 are gated at $\omega t = \alpha$, these SCRs will get turned on only if $V_m \sin\alpha > E$**. SCR T1,T2 conduct from $\omega t = \alpha$ to $\Pi + \alpha$. At $\omega t = \Pi + \alpha$,

forward biased SCRs T3,T4 are triggered. The supply voltage turns off T1, T2 by natural commutation and the load current is transferred from T1,T2 to T3,T4.

Voltage across T1,T2 is shown as $v_{T1}, v_{T2,}$ and that across T3,T4 as $v_{T3}, v_{T4.}$

Source current $i_s$is taken as +ve in the arrow direction. Hence source current is shown +ve when T1,T2 are conducting and –ve when T3,T4 are conducting.

During α to Π, both v_s and i_s are +ve, power flows from source to load. During Π to $\Pi + \alpha$, v_s is –ve but i_s +ve, hence load returns some of its energy to the supply system. But the net power flow is from ac source to dc load because $(\Pi - \alpha) > \alpha$.

The average value of output voltage $V_o$is given by

$$V_0 = \frac{1}{\Pi} \int_{\alpha}^{\Pi+\alpha} V_m \sin \omega t . d(\omega t) = \frac{2V_m}{\Pi} \cos\alpha \qquad \textbf{(1)}$$

RMS value of output voltage for single phase M-2 or B-2 controlled converter can be obtained as below.

$$V_{or} = \left[\frac{1}{\Pi} \int_{\alpha}^{\Pi+\alpha} V_m^{\ 2} \sin^2 \omega t . d(\omega t) \right]^{1/2}$$

$$= \mathrm{V_m}^2 / 2 = V_s$$

$$V_{or} = V_s$$

Equation (1) shows that if $\alpha > 90^o$, V_o is –ve. This is illustrated in fig 2.9, where α is shown greater than 90°. In this $V_{o \text{ is –ve.}}$ if the load circuit emf E is reversed, this source E will feed power back to ac supply. This operation of full converter is known as inverter operation of the converter. **The full converter with firing angle delay greater than 90º is called line commutated inverter.**Such an operation is used in the regenerative breaking mode of a dc motor in which case then E is counter emf of the dc motor.

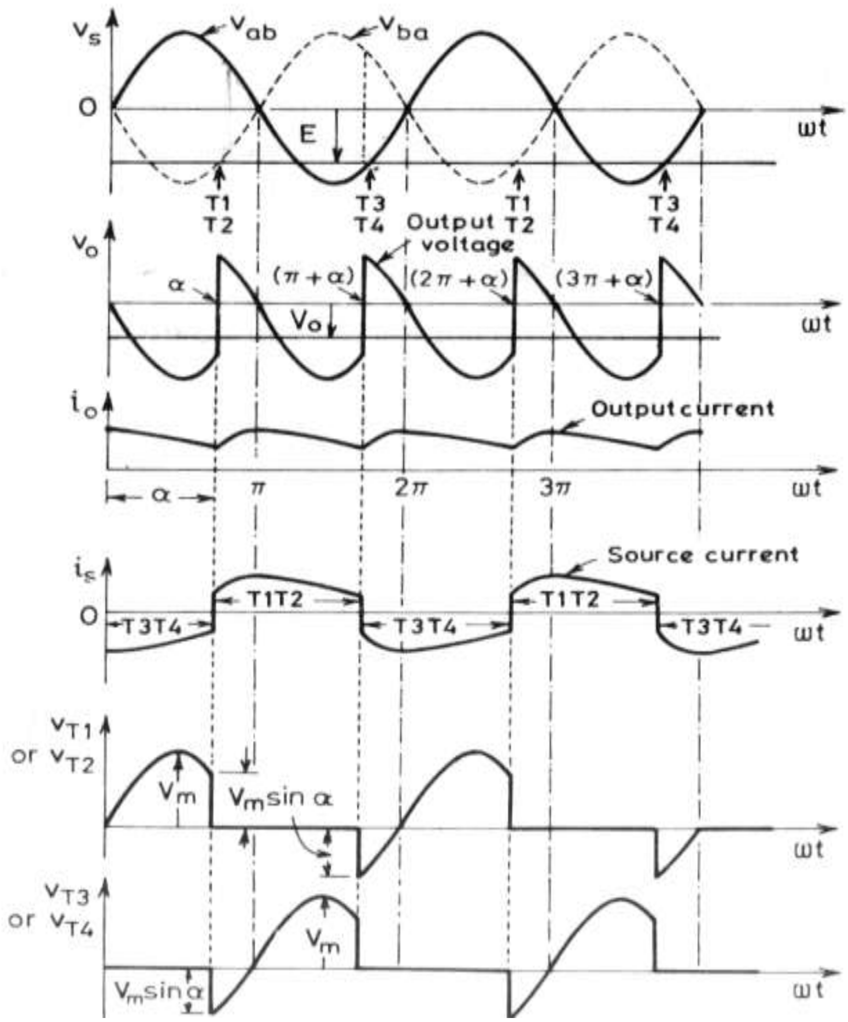


Fig 2.9

Fig (c). Voltage and current waveform for single phase full converter for $\alpha > 90°$

During 0 to α, ac source voltage $v_s$is +ve but ac source current $i_s$is –ve , power flows from dc source to ac source. From α to Π, both v_{s}& i_s are +ve hence power flows from ac source to dc source. But the net power flow is from dc to ac source because (Π-α) < α.

In converter operation, the average value of output voltage V_0 must be greater than load circuit emf E. during inverter operation, load circuit emf when inverted to ac must be more than ac supply voltage. In other words, dc source voltage E must be more than inverter voltage V_0 , only then power would flow from dc source to ac supply system. But in both converter and inverter modes, thyristors must be forward biased and current through SCRs must flow in the same direction as these are unidirectional devices. This is the reason output

Current $i_o$is shown +ve in fig 2.9. As before source current i_s +ve when T1,T2 are conducting.

The variation of voltage across thyristors T1,T2,T3 or T4 reveals that circuit turn-off time for both converter and inverter operations is given by

$$t_c = \frac{\Pi - \alpha}{\omega} \sec$$

Advantages of single phase bridge converter over mid point converter

1. SCRs are subjected to a peak inverse voltage $2V_m$ in mid point converter and Vm in bridge converter. Thus for the same voltage and current ratings of SCRs, power handled by mid point configuration is about half of that handled by bridge converter.
2. In mid point converter, each secondary should be able to supply the load power. As such the transformer rating in mid point converter is double the load rating.

From these above, we can conclude that bridge converter is preferred over mid point configuration

Average output voltage as a function of firing angle

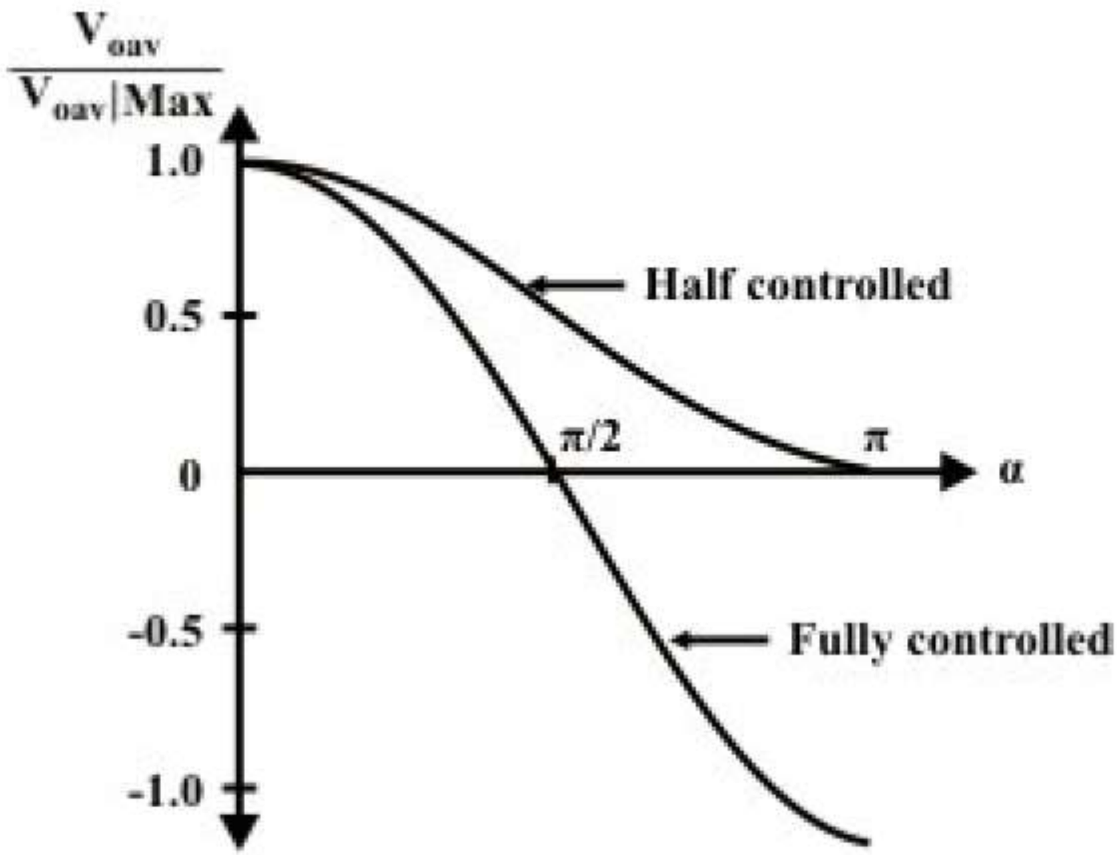


Fig 2.10

EFFECT OF SOURCE INDUCTANCE

It has been assumed that the source has no impedance. In actual practice the converter is invariably connected to ac mains through a transformer so that the voltage input to the converter can be adjusted to the desired value. The leakage impedance of the transformer (i.e source) should be taken into account for exact analysis.

The source impedance is partly resistive and partly inductive. The effect of source resistance is to reduce the input voltage by an amount equal to voltage drop across resistance. Since source resistance is small this resistance voltage drop can usually be neglected.

However the effect of source inductance must be taken into account. An important property of inductance is that current through an inductance cannot change instantaneously. This affects converter operation. In a converter, the current is transferred from one thyristor to another frequently. Because of source inductance the current in the outgoing thyristor cannot change from full value to zero instantaneously. moreover, the current through the incoming thyristor cannot increase from zero to full value instantaneously. Therefore after the triggering gate pulse is applied to a thyristor, the current of the outgoing thyristor decreases from full value to zero over a time $\omega t = \mu$. During this time interval the current through incoming thyristor rises from zero to full value. **During this period µ known as commutating period, both the outgoing and incoming thyristors are conducting. µ is also known as overlap angle.** The overlapping of currents causes a reduction in output voltage.

2.4 THYRISTOR COMMUTATION TECHNIQUES

In practice it becomes necessary to turn off a conducting thyristor. (Often thyristors are used as switches to turn on and off power to the load). The process of turning off a conducting thyristor is called commutation. The principle involved is that either the anode should be made negative with respect to cathode (voltage commutation) or the anode current should be reduced below the holding current value (current commutation).

The techniques to turn off a SCR can be broadly classified as

Natural Commutation

Forced Commutation.

2.4 .1 Natural Commutation (CLASS F)

This type of commutation takes place when supply voltage is AC, because a negative voltage will appear across the SCR in the negative half cycle of the supply voltage and the SCR turns off by itself. Hence no special circuits are required to turn off the SCR. That is the reason that this type of commutation is called Natural or Line Commutation shown fig 2.11 and fig 2.12

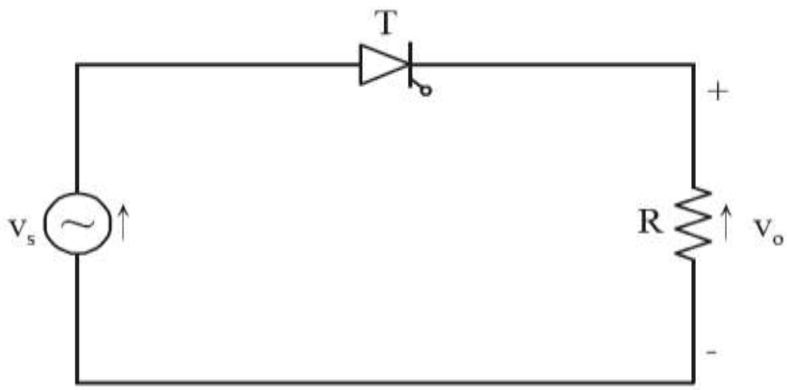


Fig 2.11

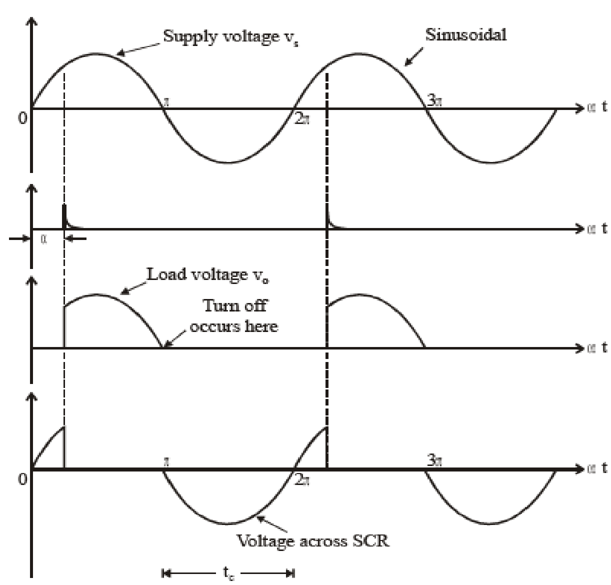


Fig 2.12

This type of commutation is applied in ac voltage controllers, phase controlled rectifiers and cyclo converters.

2.4 .2 Forced Commutation

When supply is DC, natural commutation is not possible because the polarity of the supply remains unchanged. Hence special methods must be used to reduce the SCR current below the holding value or to apply a negative voltage across the SCR for a time interval greater than the turn off time of the SCR. This technique is called FORCED COMMUTATION and is applied in all circuits where the supply voltage is DC - namely,

Choppers (fixed DC to variable DC), inverters (DC to AC). Forced commutation techniques are as follows:

- Self Commutation
- Resonant Pulse Commutation
- Complementary Commutation
- Impulse Commutation
- External Pulse Commutation.
- Load Side Commutation.
- Line Side Commutation.

2.5 THREE-PHASE CONTROLLED CONVERTERS

The converter operating from a single-phase supply produces a relatively high proportion of a.c ripple-voltage at its d.c terminals. This ripple is generally undesirable because of its heat producing effect. Therefore, a large outlay of smoothing reactor is necessary to smoothen the output voltage as well as to reduce the possibility of discontinuous operation. The need for smoothing can be minimised by increasing the number of pulses. A three phase a.c supply with a suitable transformer connection permits an increase in the pulse number. **When the number of pulses of the converter is increased, the number of segments that fabricate the output voltage also increases and consequently the ripple content decreases. Higher the pulse number, smoother is the output voltage.**

Three-phase rectifier circuits are used for large power applications. Generation of the three-phase a.c. Power is now universal and in some countries, only generation frequencies may be different. Now-a-days, 11kV, 33 kV, 66kV three-phase a.c. Supply is available to the industries. These voltages are suitably stepped down using transformers. These transformers are generally delta-connected on primary side and star-connected on the secondary side. Three-phase controlled converter circuits canbe studied under following categories :

(1) Three-pulse converters
(2) Six-pulse converters
(3) Twelve-pulse converters

THREE-PULSE CONVERTERS (M$_3$ CONNECTION)

Three pulse converters are also known as the three-phase half-wave controlled rectifier . The simplest type of phase-controlled converter operating from a three-phase supply is the three-pulse midpoint converter.

2.5.1Three-Phase Half-Wave Controlled Rectifier with Resistive Load

Figure 2.13 shows the power-diagram of a three-phase half-wave controlled rectifier with resistive load. This configuration is called as the mid-point configuration because all the phase emfs can have a common terminal which may considered as the neutral point or the mid-point.As shown in figure, the primary is connected in a delta fashion and secondary in star. The load is connected to the neutral point. For the analysis of the circuit, the leakage inductance and on state SCR drops are assumed to be zero. The wave forms are shown in figure 2.14.

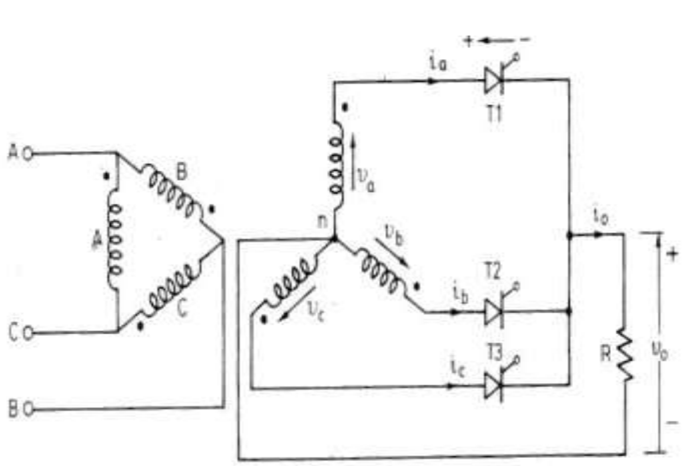


Fig 2.13

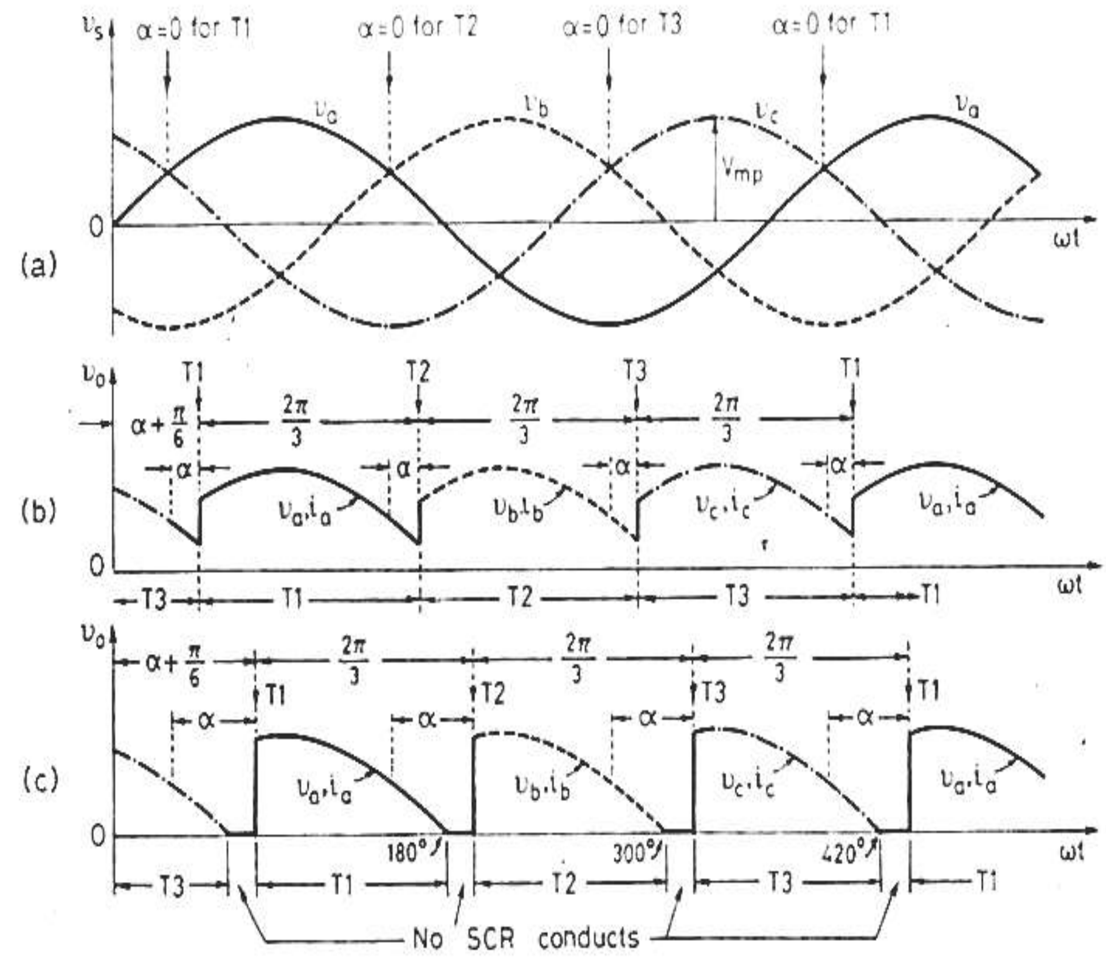


Fig 2.14

(a) line to neutral source voltage, load voltage waveform for (b) $0 < \alpha < 30°$ and (c) $\alpha > 30°$

If firing angle is zero degree, SCR T1 would begin conducting from ωt = 30º to 150º , T2 from ωt = 150º to 270º and T3 from ωt = 270º to 390º and so on. In other words firing angle for this controlled converter would be measured from ωt = 30º for T1, from ωt = 150º for T2 and from ωt = 270º for T3 as in figure 2.14 (a) . For zero degree firing angle delay, thyristor behaves as a diode.

The operation of this converter is now described for α < 30º and for α > 30º

Firing angle <30º

The output voltage waveform v_0 for firing angle <30º (say 15º) is shown in fig 2.14(b) where T1 conducts from ωt = 30º +α to ωt = 150º +α, T2 from ωt = 150º +α to ωt = 270º +α and so on. Each SCR conducts for 120º. The waveform of load current i_0 would be identical with voltage wave form v_0.

$$\textit{Average}\ \text{value output voltage}\ V_0 = \frac{3}{2\Pi}\int_{\alpha+\frac{\Pi}{6}}^{\alpha+\frac{5\Pi}{6}} V_{mp}\sin\omega t\, d(\omega t)$$

$$= \frac{3\sqrt{3}}{2\Pi}V_{mp}.\cos\alpha = \frac{3V_{ml}}{2\Pi}.\cos\alpha$$

Where V_{mp} = maximum value of phase (line to neutral) voltage

$$\text{Vml} \quad = \text{maximum value of line voltage} = \sqrt{3}.V_{mp}$$

α = firing angle delay

$$\text{average load current}\ I_0 = \frac{V_0}{R} = \frac{3V_{ml}}{2\Pi R}.\cos\alpha$$

Rms value of output , or load voltage is

$$= \frac{3V^2{}_{mp}}{4\Pi}\left[\frac{2\Pi}{3} + \frac{\sqrt{3}}{2}\cos 2\alpha\right]$$

$$or\ \ V_{or} = V_{mp}\left[\frac{1}{2} + \frac{3\sqrt{3}}{8\Pi}\cos 2\alpha\right]$$

$$= \sqrt{3}V_{mp}\left[\frac{1}{6} + \frac{\sqrt{3}}{8\Pi}\cos 2\alpha\right]^{1/2} = V_{ml}\left[\frac{1}{6} + \frac{\sqrt{3}}{8\Pi}\cos 2\alpha\right]^{1/2}$$

$$\textit{Rms load}\ \text{current} \quad I_{or} = \frac{V_{or}}{R} = \frac{V_{ml}}{R}\left[\frac{1}{6} + \frac{\sqrt{3}}{8\Pi}\cos 2\alpha\right]^{1/2}$$

Firing angle >30°

When firing angle is more than 30°, T1 would conduct from 30°+α to 180°, T2 from 150°+α to 300° and so on in fig. 2.14(b). For R load, when phase voltage v_a reaches zero at ωt=180°, current i_o =0, T1 is therefore turned off. Thus T1 would conduct from 30°+α to 180°. Same is true for other SCRs. This shows that each SCR, for firing angle >30º, conducts for (150°-α) only. This also implies that for R load, maximum possible value of firing angle is 150º. Waveform of i_o agrees with v_o waveform, fig. 2.14(c).

Average value of load voltage:

$$V_0 = \frac{3}{2\Pi}\int_{\alpha+\frac{\Pi}{6}}^{\Pi} V_{mp}\sin\omega t d(\omega t)$$

$$= \frac{3V_{mp}}{2\Pi}\left[1+\cos(\alpha+30°)\right]$$

$$\text{RMS value of output voltage Vor} = \left[\frac{3}{2\Pi}\int_{\alpha+\frac{\Pi}{6}}^{\Pi} V^2{}_{mp}\sin^2\omega t.d(\omega t)\right]^{1/2}$$

$$V_{or} = \frac{\sqrt{3}.V_{mp}}{2\sqrt{\Pi}}\left[\left(\frac{5\Pi}{6}-\alpha\right)+\frac{1}{2}\sin(2\alpha+\Pi/3)\right]^{1/2}$$

$$= \frac{V_{ml}}{2\sqrt{\Pi}}\left[\left(\frac{5\Pi}{6}-\alpha\right)+\frac{1}{2}\sin(2\alpha+\Pi/3)\right]^{1/2}$$

2.5.2 Three phase Full Converter

The figure shows a 6 pulse bridge converter.this converter is most widely used in industrial applications upto the 120kW level, where two quadrant operation is required. Shown fig 2.15

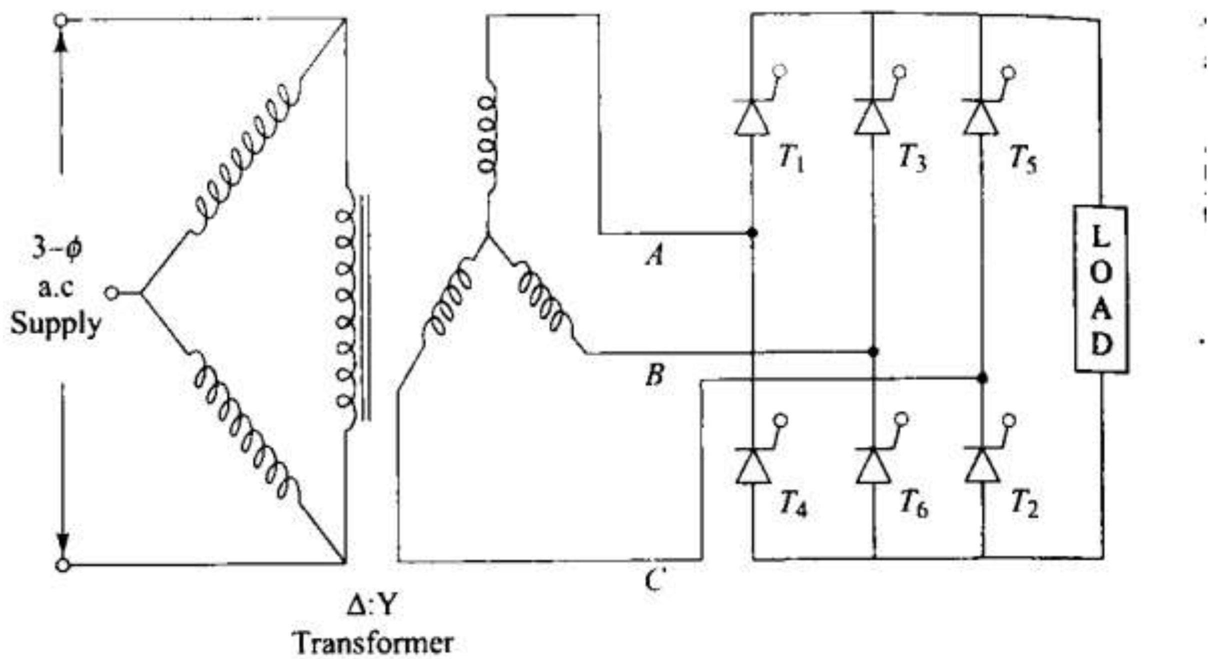


Fig 2.15

The load is fed via 3 phase half wave connection to one of the 3 supply lines, no neutral being required. Hence transformer connection is optional. **However, for isolation of output from the supply source, or for higher output requirements, the transformer is to be connected.**If transformer is used, then one winding isconnected in delta because the delta connection gives the circulating path for third harmonic current. Therefore, third harmonic current doesnot appear in line which is an advantage.

This circuit consists of two groups of SCRs, positive group and negative group. Here, SCRs T1, T3, T5 forms positive group, whereas SCRs T4,T6,T2 forms a negative group. The positive group SCRs are turned on when the supply voltages are positive and negative group SCRs are turned on when the supply voltages are negative. Inorder to start the circuit functioning, two thyristors must be fired at the same time inorder to commence current flow, one of the upper arm and one of the lower arm.

For describing the operation of the circuit, the following things to be remembered.

(i) Each device should be triggered at a desired firing angle α

(ii) Each SCR can conduct for 120º

(iii) SCR must be triggered in the sequence T1,T2,T3,T4,T5,T6

(iv) The phase shift between the triggering of the two adjacent SCR is 60º

(v) At any instant 2 SCRs can conduct and there are such 6 pairs. The 6 pairs are (T6,T1), (T1,T2), (T2,T3), (T3,T4), (T4,T5), (T5,T6).

(vi) Each SCR conducts in two pairs and each pair conducts for 60º

(vii) The incoming SCR commutates the outgoing SCR,i.e SCR T1 commutates SCR T5, SCR T2 commutates SCR T6 and so on.

(viii) When the two SCRs are conducting, i.e one from +ve (upper) group and one from –ve (lower) group, the corresponding line voltage is applied across the load.

(ix) When the upper SCR of a half bridge conducts, the current of that phase is +ve whereas when the lower SCR conducts, the current is –ve.

2.5.3 Three phase Full Converter with Resistive load

Three phase fully controlled bridge rectifier with resistive load is shown in figure 2.16

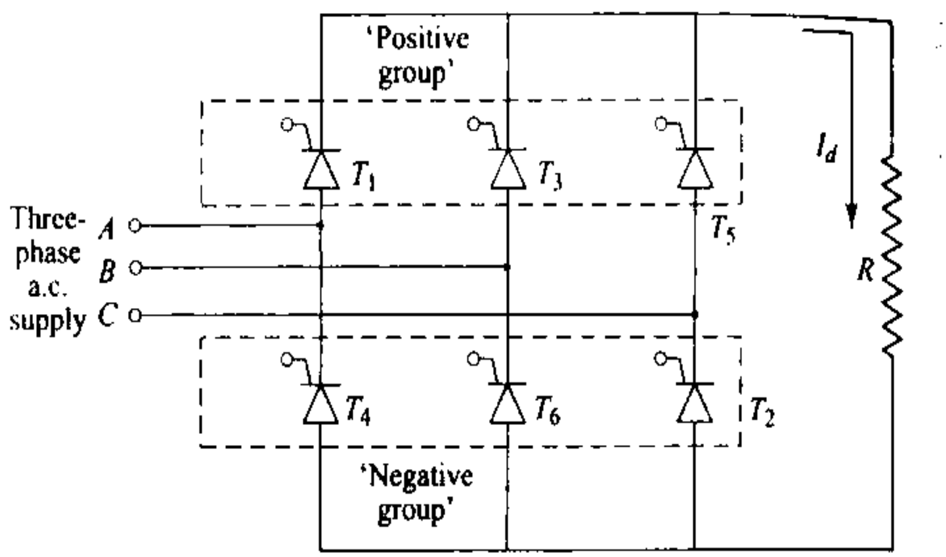


Fig 2.16

For six pulse operation, each SCR has to be fired twice in its conduction cycle, that is firing intervals should be 60º. The ouput voltage waveforms for different values of α are shown in figure 2.17

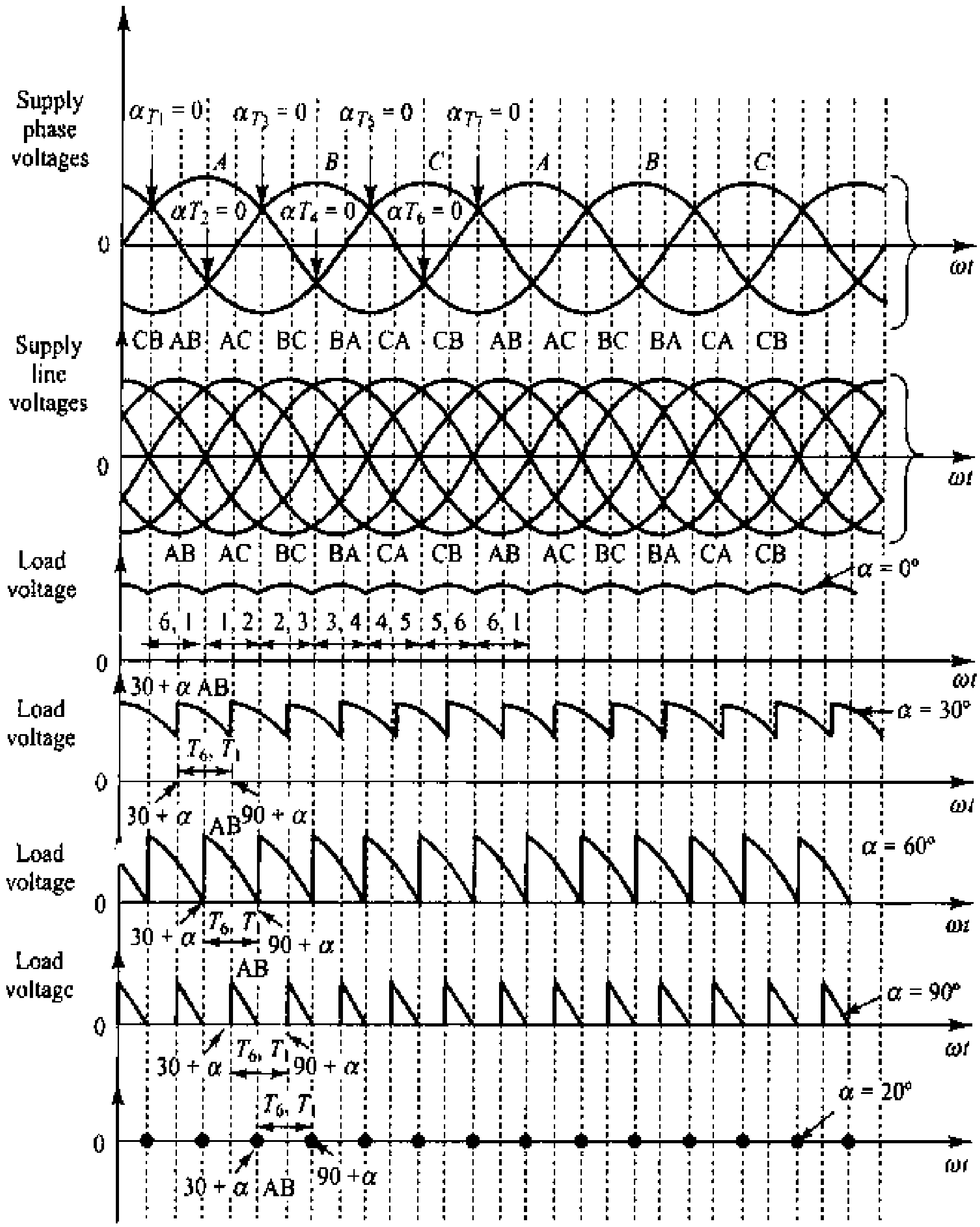


Fig 2.17

The following points can be noted:

(1) The output voltage waveform for any value of α is a 6 pulse wave with a ripple frequency of 300Hz.

(2) Continuous conduction mode ($0 \leq \alpha \leq \Pi/3$) when the phasor AB is allowed to conduct at α between 0 to Π/3, it continuous to conduct by 60º when the phasor AC is fired. The conduction is shifted from SCR T6 to T2. T6 is commutated off by the reverse voltage of phase C and B across it. The phasor AC conduct after another 60º after which it is replaced by phasor BC when phase B voltage assumes greater value than C or A. hence load current is continuous for α between 0 to Π/3.

(3) Discontinuous conduction mode : ($\Pi/3 \leq \alpha \leq 2\Pi/3$)

When $\Pi/3 \le \alpha \le 2\Pi/3$, the phasor AB conducts upto an angle Π after which both the thyristors T1 & T6 are commutated off because phase B becomes +ve w.r.to phase C and after 60º, when T2 & T1 are fired, phase AC conducts also upto angle Π, hence load current remains zero from angle Π to the next firing pulse and becomes discontinuous, therefore the fully controlled bridge circuit produces a ripple frequency of 6 times the supply frequency at all trigger angles.

(4) For $\alpha = 120^o$, the ouput voltage is zero and hence $\alpha_{max} = 120(2\Pi/3)$

(a) Continuous conduction mode: ($\alpha < 60^o$). The general equation for the average load voltage is given by

$$E_{dc} = \frac{1}{2\Pi}\int_{0}^{2\Pi} E_{dc}(\omega t).d(\omega t)$$

$$E_{dc} = 6\times\frac{1}{2\Pi}\int_{\frac{\Pi}{6}+\alpha}^{\frac{\Pi}{2}+\alpha} E_{AB}(\omega t).d(\omega t)$$

Where the line to line Voltage E_{AB} is given by

$$E_{AB} = \sqrt{3}E_m \sin(\omega t + \Pi/6)$$

$$\therefore E_{dc} = \frac{3}{\Pi}\int_{\frac{\Pi}{6}+\alpha}^{\frac{\Pi}{2}+\alpha} \sqrt{3}E_m \sin(\omega t + \Pi/6).d(\omega t) = \frac{3\sqrt{3}E_m}{\Pi}\int_{\frac{\Pi}{3}+\alpha}^{\frac{2\Pi}{3}+\alpha} \sin(\omega t).d(\omega t)$$

$$= \frac{3\sqrt{3}E_m}{\Pi}\cos\alpha$$

$$Average \text{ load current } \quad \mathrm{I_d} = \frac{3\sqrt{3}E_m}{\Pi.R}\cos\alpha$$

(b) Discontinuous conduction mode ($\alpha > 60°$)

$$E_{dc} = 6\times\frac{1}{2\Pi}\int_{\frac{\Pi}{6}+\alpha}^{\frac{5\Pi}{6}} \sqrt{3}E_m \sin(\omega t + \Pi/6)d(\omega t) = \frac{3\sqrt{3}E_m}{\Pi}\int_{\frac{\Pi}{3}+\alpha}^{\Pi} \sin(\omega t).d(\omega t$$

$$= \frac{3\sqrt{3}E_m}{\Pi}(1+\cos(\alpha+\Pi/3))$$

$$or\ \alpha_{\max,} E_{dc} = 0, \quad \therefore \frac{3\sqrt{3}E_m}{\Pi}(1+\cos(\alpha+\Pi/3)) = 0$$

$$hence\ \ \alpha_{\max} = 120^0$$

$$Average \text{ load current } \mathrm{I_d} = \frac{3\sqrt{3}E_m}{\Pi.R}(1+\cos(\alpha+\Pi/3))$$

2.6 Dual Converter

Dual converter is a combination of a rectifier and inverter in which the conversion of A.C to D.C happens and followed by D.C to A.C where load lies in between. A dual converter can be of a single phase or a three phase. A dual converter consists of two bridges consisting of thyristors in which one for rectifying purpose where alternating current is converted to direct current which can be given to load. Other bridge of thyristors is used for converting D.C to A.C

Single phase dual converter uses a single phase as source which is given to converter 1 of dual converter for rectification followed to load shown in fig 2.18

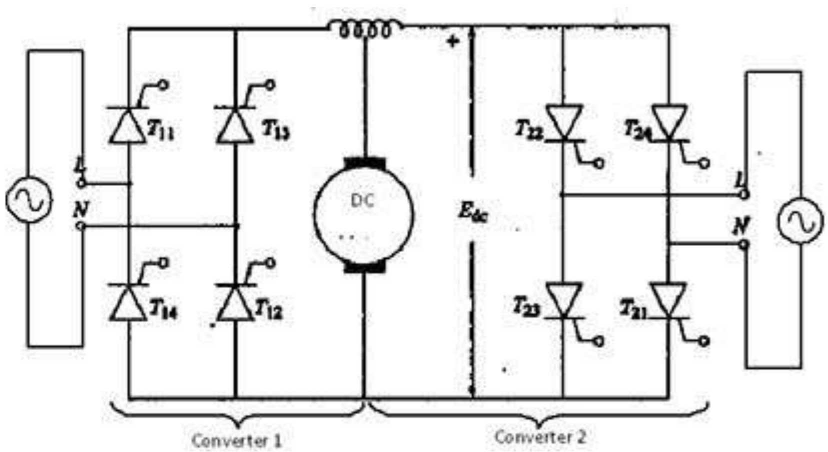


Fig 2.18

Principle of Operation:

A.C input given to converter 1 for rectification in this process positive cycle of input is given to first set of forward biased thyristors which gives a rectified D.C on positive cycle, as well negative cycle is given to set of reverse biased thyristors which gives a D.C on negative cycle completing full wave rectified output can be given to load. During this process converter 2 is blocked using an inductor. As thyristor only start conducting when current pulse is given to gate and continuous conducting until supply of current is stopped. Output of Thyristor Bridge can be as follows when it is given to different loads shown in fig 2.19

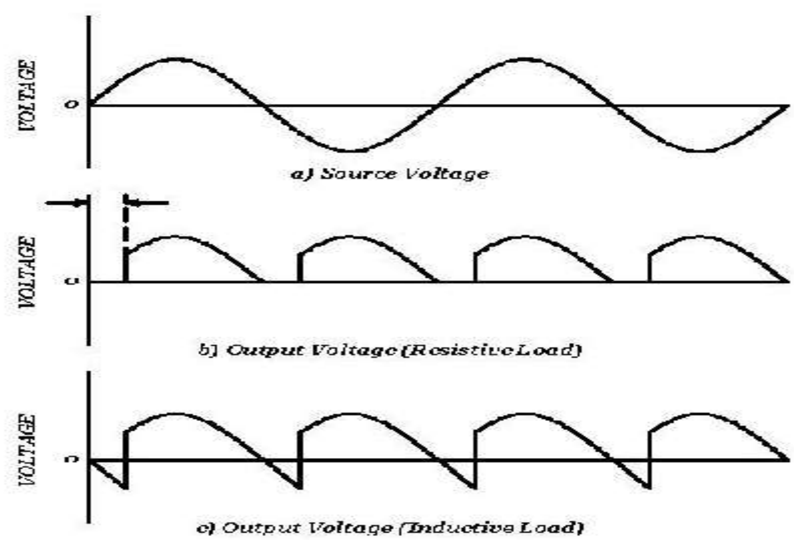


Fig 2.19

Applications of Dual Converter

- Direction and Speed control of DC motors.
- Applicable wherever, the reversible DC is required.
- Industrial variable speed DC drives

Modes of Operation of Dual Converter

There are two function modes . 1 Non Circulating Current Mode and 2. Circulating Current Mode

Non Circulating Current Mode

One converter will perform at a time . So there no circulating current between the converters.

During the converter 1 operation firing angle **(α1)** will be **0< α1<90̊ . Vdc** and I dc are positive.

During the converter 2 operation firing angle **(α2)** will be **90< α2<180̊ . Vdc** and I dc are negative

. **Circulating Current Mode**

Two converters will be in ON condition at the same time. So Circulating Current is present.

The firing angles are adjusted such that firing angle of converter 1**(α1) +** firing angle of converter 2**(α2)=**180̊**.** converter 1 performs as a controlled rectifier when firing angle will be **0< α1<90̊ and** converter 2 performs as a Inverter when firing angle will be **90< α2<180̊** In this condition **Vdc** and I dc are positive.

converter 1 performs as a Inverter when firing angle will be **90< α1<180̊ and** converter 2 performs as a controlled rectifier when firing angle will be **0< α2<90̊** In this condition **Vdc** and I dc are negative..

Model Questions

PART – A

1. What is converter? What are the types of phase controlled converter?

2. What are the advantages of phase controlled converter?

3. What is overlap angle? What are the factors affecting overlap angle?

4. What are the advantages of flywheel diode?

5. What is called inversion in converters?

6. What is meant by commutation? Mention the types of commutation.

7. What is self commutation?

8. List the types of forced commutation.

9. Mention the two modes of dual conversion.

10. Name the three configurations of dual converters.

PART – B

1. Draw the circuit diagram and waveforms of single phase half controlled bridge converter with resistive load.

2. Draw the circuit diagram and waveforms of single phase half controlled bridge converter with RL load.

3. Draw the circuit diagram and waveforms of single phase fully controlled bridge converter with resistive load.

4. Draw the circuit diagram and waveforms of single phase fully controlled bridge converter with RL load.

5. Draw the circuit diagram and waveforms of single phase half controlled bridge converter with flywheel diode.

6. Explain the effect of source inductance in converter circuit.

7. Explain natural commutation.

8. Explain forced commutation.

9. State the advantages and applications of three phase half controlled converter.

10. What is four quadrant control and mention the conditions needed to design DC motor?

11. Draw the circuit diagram of dual converter.

12. Explain non circulating current mode in dual converter.

13. Explain circulating current mode.

PART – C

1. With the necessary diagrams explain the operation of single phase half controlled bridge converter with resistive load.

2. With the necessary diagrams explain the operation of single phase half controlled bridge converter with RL load.

3. With diagram explain the importance of flywheel diode.

4. Briefly explain the operation of single phase half controlled bridge converter with flywheel diode with its waveforms.

5. With the diagram explain the operation of single phase fully controlled bridge converter with resistive load.

6. With the diagram explain the operation of single phase half controlled bridge converter with RL load.

7. With proper circuit diagrams explain the effect of discontinuous current operation in converter.

8. Explain the effect of overlap angles in single phase fully controlled converter.

9. Explain line commutation in converters.

10. With suitable diagrams explain three phase half controlled bridge converter.

11. With suitable diagrams explain three phase fully controlled bridge converter.

12. Explain the different modes of dual converter

%%%%%%%%%%%%%%%%%%%%%%%

III UNIT

CHOPPERS

3.1 INTRODUCTION Modern electronic systems require high quality, small, lightweight, reliable, and efficient power supplies. Linear power regulators, whose principle of operation is based on a voltage or current divider, are inefficient. They are limited to output voltages smaller than the input voltage. Also,their power density is low because they require low-frequency (50 or 60 Hz) line transformers and filters. Linear regulators can, however, provide a very high quality output voltage. Their main area of application is at low power levels as low drop-out voltage (LDO) regulators..

At higher power levels, switching regulators are used. Switching regulators use power electronic semiconductor switches in *on* and *off* states. Since there is a small power loss in those states (low voltage across a switch in the *on* state, zero current through a switch in the *off* state), switching regulators can achieve high energy conversion efficiencies.

Modern power electronic switches can operate at high frequencies. The higher the operating frequency, the smaller and lighter the transformers, filter inductors, and capacitors. In addition, dynamic characteristics of converters improve with increasing operating frequencies. The bandwidth of a control loop is usually determined by the corner frequency of the output filter. Therefore, high operating frequencies allow for achieving a faster dynamic response to rapid changes in the load current and/or the input voltage. High-frequency electronic power processors are used in dc–dc power conversion. The functions of dc–dc converters are: to convert

1. a dc input voltage *VS* into a dc output voltage *VO*;
2. to regulate the dc output voltage against load and line variations;
3. to reduce the ac voltage ripple on the dc output voltage below the required level;
4. to provide isolation between the input source and the load (isolation is not always required);
5. to protect the supplied system and the input source from electromagnetic interference (EMI);
6. to satisfy various international and national safety standards.

The process of convert from fixed d c to variable d c is called CHOPPER

3.2 Principle of operation

The circuit of the buck converter (dc-dc) or step-down chopper using thyristor, with inductive (R-L) and battery (or back emf = E) load, is shown in Fig.3.1 The output (load) voltage and current waveforms for both (a) discontinuous, and (b) continuous conduction are shown in Fig. 3.2.(a) and (b)

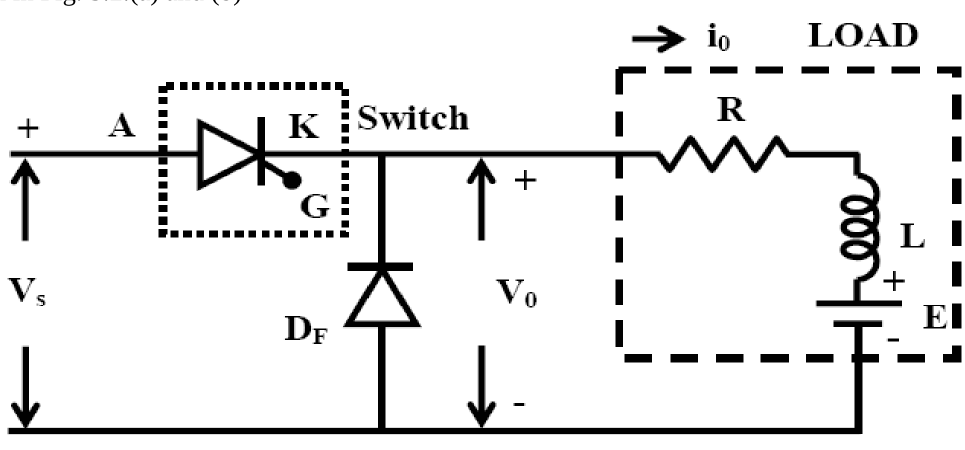


Fig 3.1

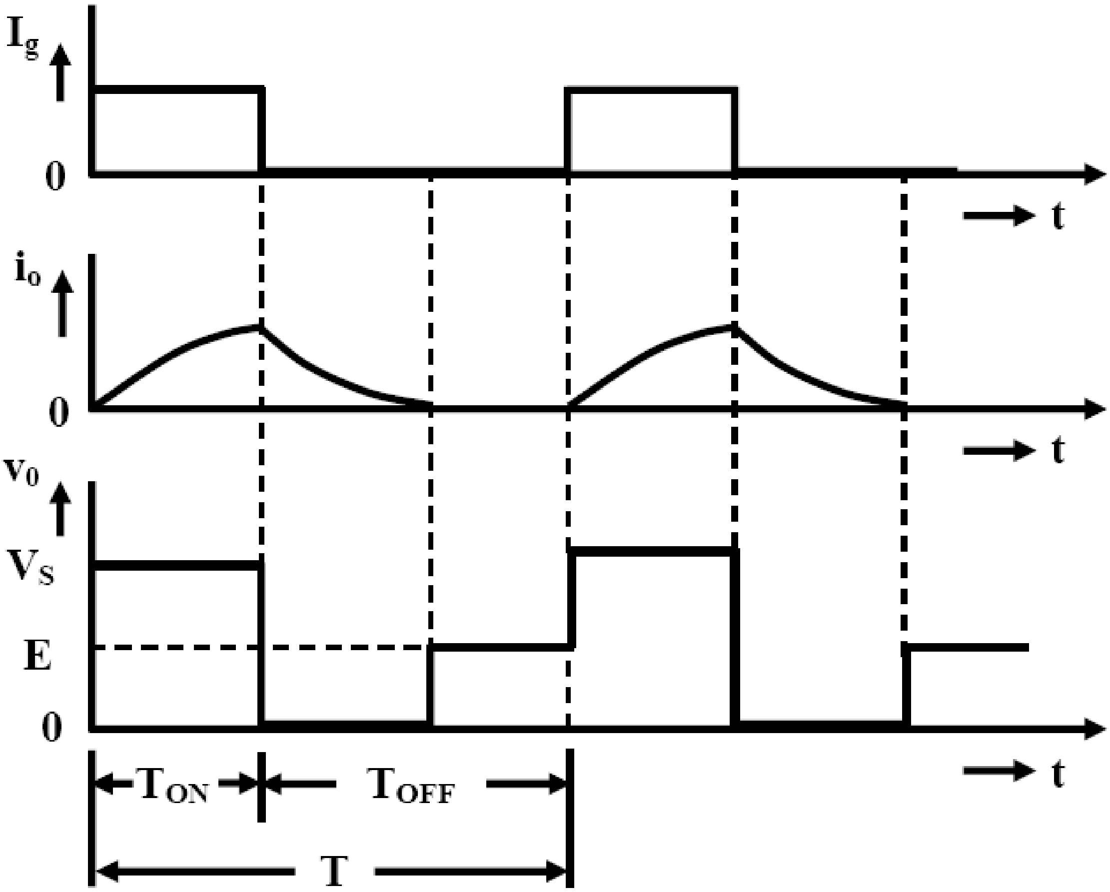


Fig 3.2 (a) **Discontinuous load current**

3.3 Control Strategies

In all cases, it is shown that the average value of the output voltage can be varied. The two types of control strategies (schemes) are employed in all cases. These are:

(a) Time-ratio control, and

(b) Current limit control.

Time-ratio Control In the time ratio control the value of the duty ratio, *k =ON*/T is varied. There are two ways, which are constant frequency operation, and variable frequency operation.

Constant Frequency Operation In this control strategy, the ON time, is varied, keeping the frequency (or time period constant. This is also called as *pulse width modulation control* (PWM) shown in fig 3.3

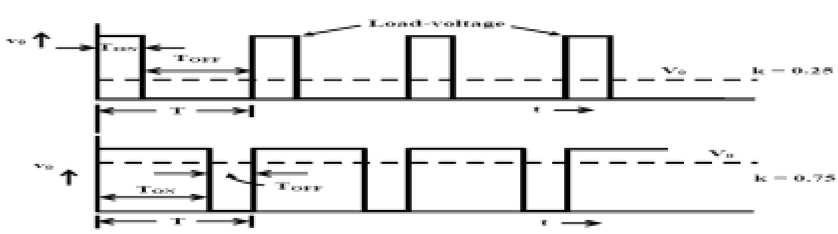


Fig 3.3

Variable Frequency Operation In this control strategy, the frequency (f = 1/ T), or time period *T* is varied, keeping either (a) the ON time, constant, or (b) the OFF time, constant. This is also called as *frequency modulation control*. Two cases with (a) the ON time, constant, and (b) the OFF time, constant, with variable frequency or time period shown in Fig.3.4. The output voltage can be varied in both cases, with the change in duty ratio

k = Ton / T

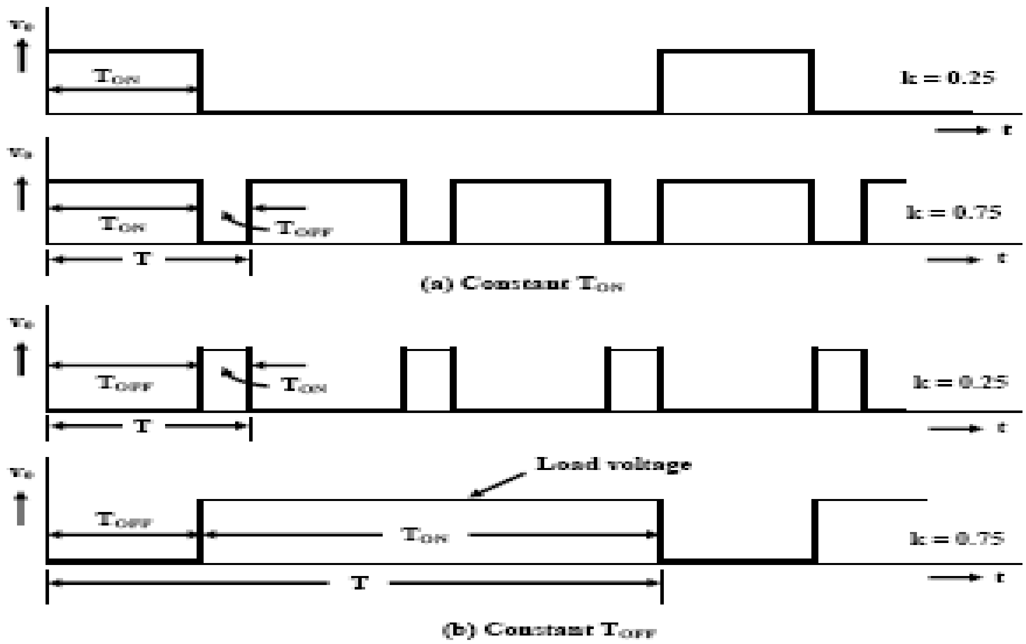


Fig.3.4

There are major disadvantages in this control strategy. These are:

(a) The frequency has to be varied over a wide range for the control of output voltage in frequency modulation. Filter design for such wide frequency variation is, therefore, quite difficult.

(b) For the control of a duty ratio, frequency variation would be wide. As such, there is a possibly of interference with systems using certain frequencies, such as signaling and telephone line, in frequency modulation technique.

(c) The large OFF time in frequency modulation technique, may make the load current discontinuous, which is undesirable.

Thus, the constant frequency system using PWM is the preferred scheme for dc-dc converters (choppers).

Current Limit Control

As can be observed from the current waveforms for the types of dc-dc converters described earlier, the current changes between the maximum and minimum values, if it (current) is continuous. In the current limit control strategy, the switch in dc-dc converter (chopper) is turned ON and OFF, so that the current is maintained between two (upper and lower) limits. When the current exceed upper (maximum) limit, the switch is turned OFF. During OFF period, the current freewheels in say, buck converter (dc-dc) through the diode, , and decreases exponentially. When it reaches lower (minimum) limit, the switch is turned ON. This type of control is possible, either with constant frequency, or constant ON time, . This is used only, when the load has energy storage elements, i.e. inductance, L. The reference values are load current or load voltage. This is shown in Fig.3.5. In this case, the current is continuous, varying between and , which decides the frequency used for switching. The ripple in the load current can be reduced, if the difference between the upper and lower limits is reduced, thereby making it minimum. This in turn increases the frequency, thereby increasing the switching losses.

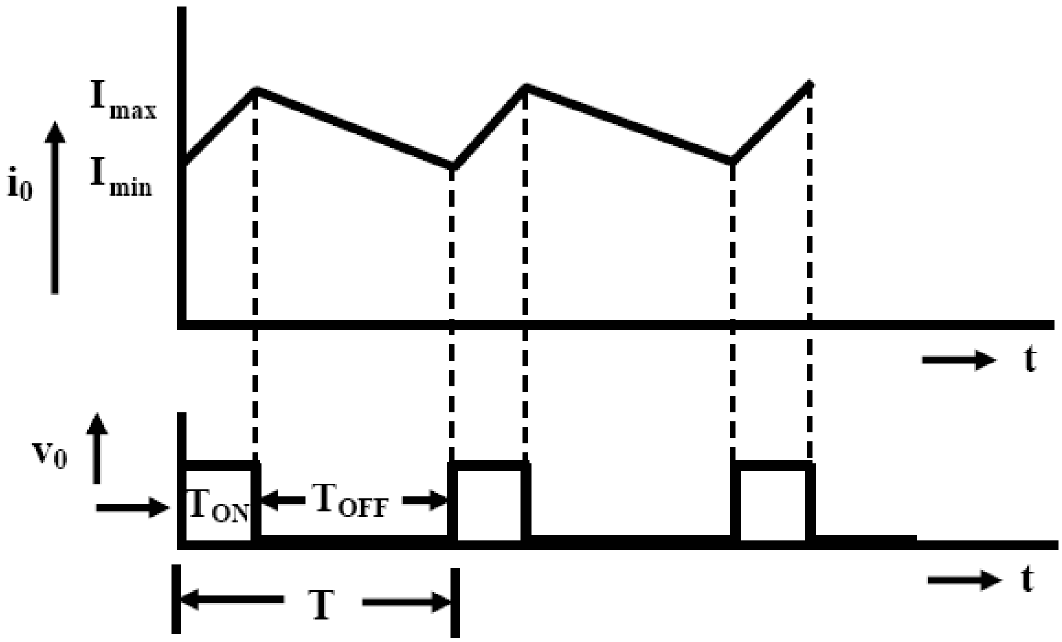


Fig.3.5

3.4 Types of Chopper

Requirements A thyristor can be turned ON by applying a positive voltage of about a volt or a current of a few tens of milliamps at the gate-cathode terminals. However, the amplifying gain of this regenerative device being in the order of the 10^8, the SCR cannot be turned OFF via the gate terminal. It will turn-off only after the anode current is annulled either naturally or using forced commutation techniques. These methods of turn-off do not refer to those cases where the anode current is gradually reduced below Holding Current level manually or through a slow process. Once the SCR is turned ON, it remains ON even after removal of the gate signal, as long as a minimum current, the Holding Current, I_h, is maintained in the main or rectifier circuit.

In all practical cases, a negative current flows through the device. This current returns to zero only after the reverse recovery time t_{rr}, when the SCR is said to have regained its reverse blocking capability.

SCRs have turn-off times rated between 8 - 50 μsecs. The faster ones are popularly known as 'Inverter grade' and the slower ones as 'Converter grade' SCRs.

3.4. TYPES OF CHOPPER CIRCUITS

Power semiconductor devices used in chopper circuits are unidirectional devices, polarities of output voltage V_o and the direction of output I_o are, therefore, restricted.

A chopper can, however, operate in any of the four quadrants by an appropriate arrangement of semiconductor devices. This characteristic of their operation in any of the four quadrants forms the basis of their classification as type-A chopper, type-B chopper etc. Some authors describe this chopper classification as class A, class B, ... in place of type-A, type-B, ... respectively.

In the chopper-circuit configurations drawn henceforth, the current directions and voltages polarities marked in the power circuit would be treated as positive. In case current directions and voltage polarities turn out to be opposite to those shown in the circuit, these currents and voltages must be treated as negative.

In this section, the classification of various chopper configurations is discussed

3.4.1. First-quadrant, or Type-A, Chopper

This type of chopper is shown in Fig.3.6 (a).), When CH1 is off, $V_o = V_s$ and current i_o flows in the arrow direction shown. When CH1 is off, $V_o = 0$ but i_o in the load continues flowing in the same direction through freewheeling diode FD. It is thus seen that average values of both load voltage and current, i.e. V_o and i_o are always positive : this fact is shown by the hatched area in the first quadrant of V_o - I_o plane in Fig. 3.6 (b).

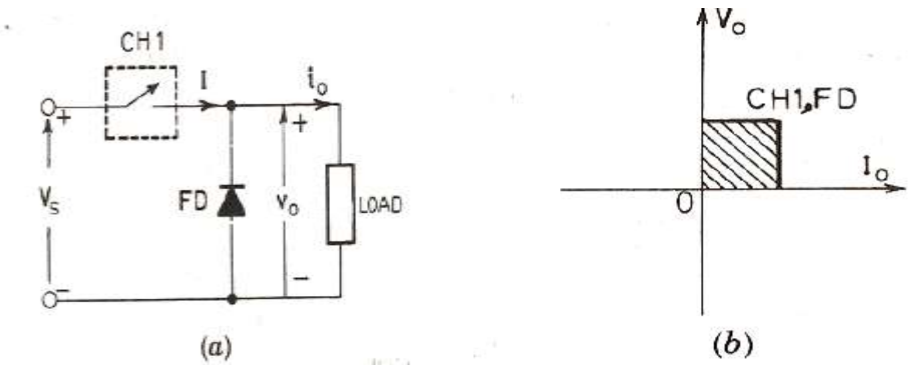


Fig.3.6

The power flow in type-A chopper is always from source to load. This chopper is also called step-down chopper as average output voltage V_o is always less than the input dc voltage V_s.

3.4.2. Second-quadrant, or Type-B, Chopper

Power circuit for this type of chopper is shown in Fig.3.7 (a). Note that load must contain a dc source E, like a battery (or a dc motor) in this chopper. When CH2 is on, $V_0 = 0$ but load voltage E drives current through L and CH2. Inductance L stores energy during T_{on} (=on period) of CH2. When CH2 is off

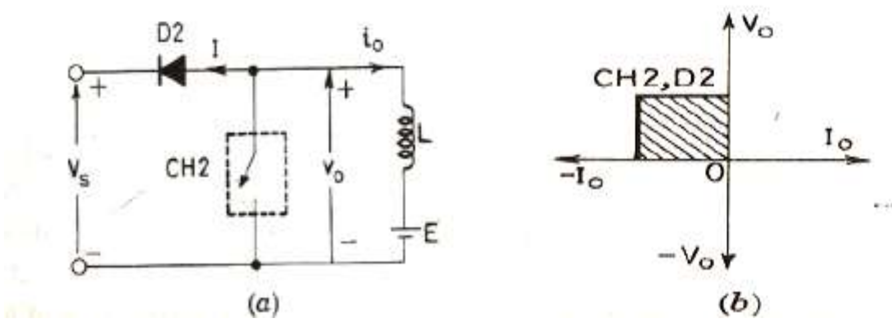


Fig.3.7

As a result, diode D2 is forward biased and begins conduction, thus allowing power to flow to the source. Chopper CH2 may be on or off, current I_o flows out of the load, current i_o us therefore treated as negative. Since V_o is always positive and I_o is negative, power flow is always from load to source.

Both type-A and type-B chopper configurations have a common negative terminal between their input and output circuits

3.4.3. Two-quadrant type-A Chopper, or Type-C Chopper

This type of chopper is obtained by connecting type-A and type-B choppers in parallel as shown in Fig. 3.8 (a).

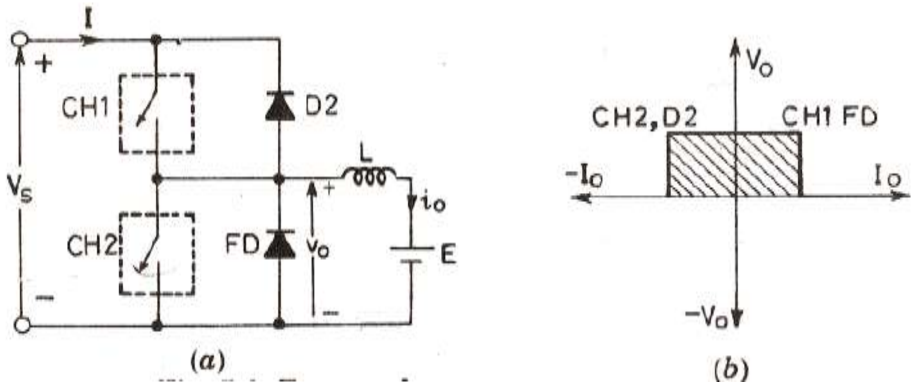


Fig. 3.8

The output voltage V_o is always positive because of the presence of freewheeling diode FD across the load. When chopper CH2 is on, or freewheeling diode FD conducts, output voltage $V_o= 0$ and in case chopper CH1 is on or diode D2 conducts, output voltage $V_o = V_s$, The load current io can, however, reverse its direction. Current i_o flows in the arrow direction marked in Fig. 3.8 (a), i.e. load current is positive when CH1 is on or FD conducts, Load current is negative if CH2 is on or D2 conducts. In other words, CH1 and FD operate together as type-A chopper in first quadrant. Likewise CH2 and D2 operate together as type-B chopper in second quadrant.

Average load voltage is always positive but average load current may be positive or negative as explained above. Therefore, power flow may be from source to load (first-quadrant operation) or from load to source (second-quadrant operation). Chopper CH1 and CH2 should not be on simultaneously as this would lead to a direct short circuit on the supply lines. This type of chopper configuration is used for motoring and regenerative braking of dc motors. The operating region of this type of chopper is shown in Fig. 3.8 (b) by hatched area in first and second quadrants.

3.4.4. Two-quadrant Type-B Chopper, or Type-D Chopper

The power circuit diagram for two-quadrant type-B Chopper, or type-D chopper, is shown in Fig. 3.9. (a). & (b)

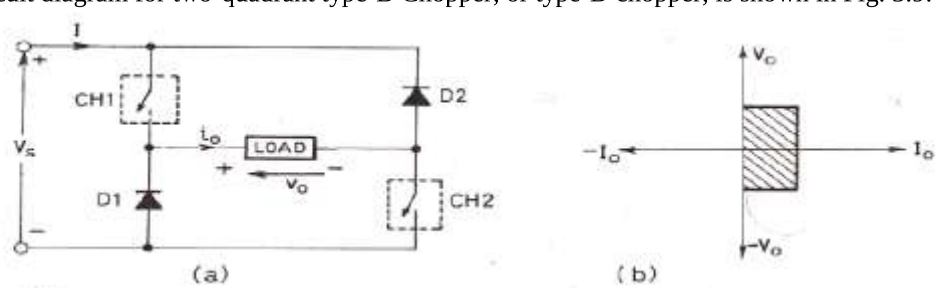
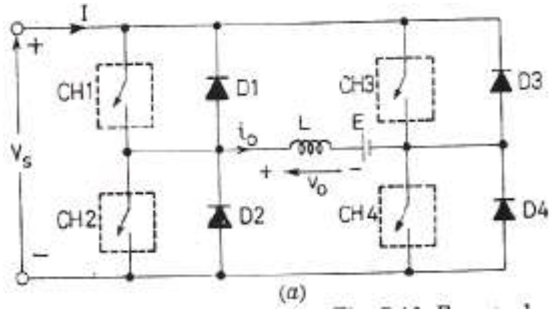


Fig. 3.9

The output voltage $V_o=V_s$ when both CH1 and CH2 are on and $V_o=-V_s$ when both choppers are off but both diodes D1 and D2 conduct. Average output voltage V_o is positive when choppers turn-on time T_{on} is more than their turn-off time T_{off} .Average output voltage V_o is negative when their $T_{on} < T_{off}$ .The direction of load current is always positive because choppers and diodes can conduct current only in the direction of arrows shown in Fig. 3.9. (a). As V_o is reversible, power flow is reversible. The operation of this type of chopper is shown by the hatched area in first and fourth quadrants in Fig. 3.9. (b).

3.4.5. Four-quadrant Chopper, or Type-E Chopper

The power circuit diagram for a four- quadrant chopper is shown in Fig. 3.10 & 3.11 It consists of four semiconductor switches CH1 to CH4 and four diodes D1 to D4 in antiparallel.



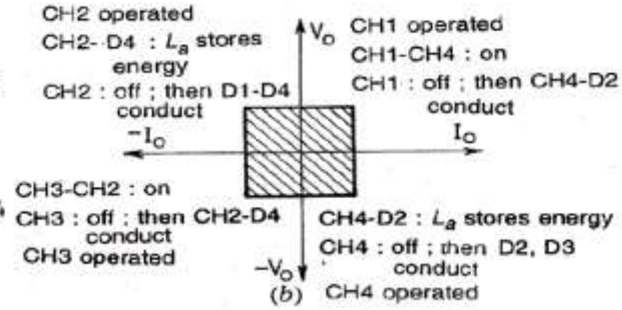


Fig. 3.10 Fig. 3.11

First quadrant : For first-quadrant operation of Fig. 3.10 (a), CH4 is kept on, CH3 is kept off and CH1 is operated. With CH1, CH4 on, load voltage $V_o = V_s$ (source voltage) and load current i_o begins to flow. Here both V_o and i_o are positive giving first quadrant operation. When CH1 is turned off, positive current freewheels through CH4, D2. In this manner, both V_o,I_o can be controlled in the first quadrant.

Second quadrant : Here CH2 is operated and CH1, CH3 and CH4 are kept off. With CH on, reverse (or negative) current flows through L, CH2, D4 and E. Inductance L stores energy during the time CH2 is on. When CH2 is turned off, current is fed back to source through diodes D1,D4. Note that here $V_o = \left[E + L\frac{di}{dt}\right]$ is more than the source voltage V_s. As load voltage V_o is positive and I_o is negative, it is second quadrant operation of chopper. Also, power is fed back from load to source.

3.5 Step Up Chopper

A boost converter (dc-dc) is shown in Fig.3.12. Only a switch is shown, for which a device belonging to transistor family is generally used. Also, a diode is used in series with the load. The load is of the same type as given earlier. The inductance of the load is small. An inductance, L is assumed in series with the input supply. The position of the switch and diode in this circuit may be noted, as compared to their position in the buck converter .

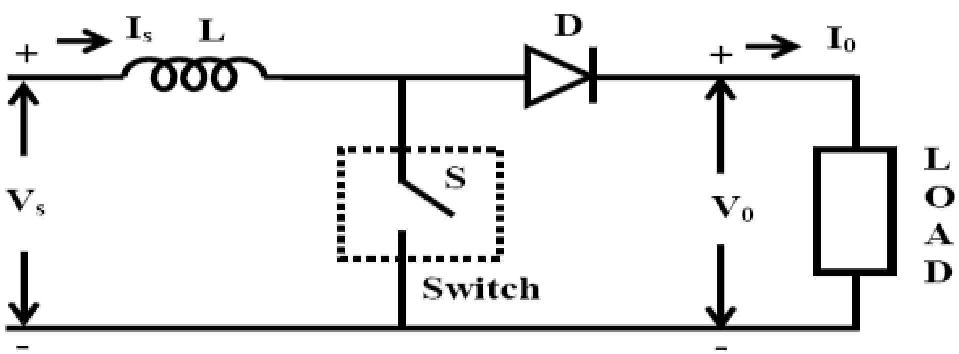


Fig.3.12

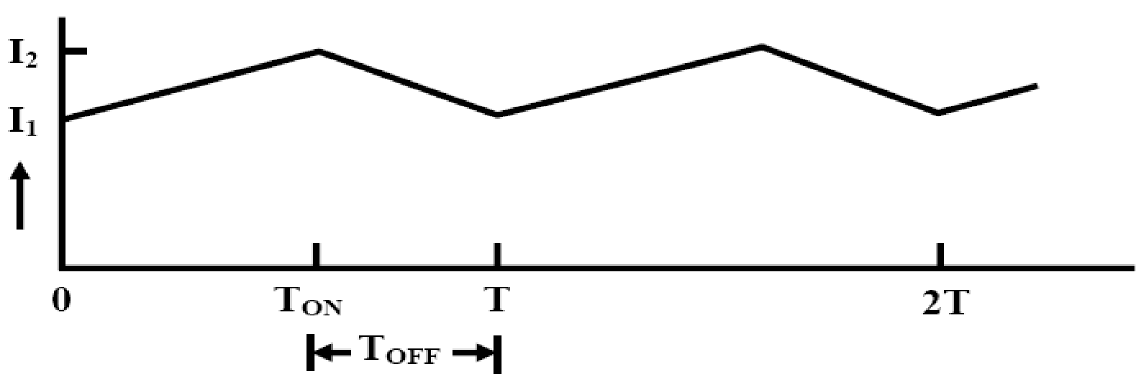


Fig.3.13

The operation of the circuit is explained. Firstly, the switch, S (i.e., the device) is put ON (or turned ON) during the period, , the ON period being . The output voltage is zero (), if no battery (back emf) is connected in series with the load, and also as stated earlier, the load inductance is small. The current from the source () flows in the inductance L.. As the current through L increases, the polarity of the induced emf is taken as say, positive, the left hand side of L being +ve.

3.6 Jones Chopper

Jones chopper is an example of class D commutation in which a charged capacitor is switched by an auxilary SCR to commutate the main SCR. In this circuit SCR1 is the main switch and SCR2 is the auxilary switch which is of lower capacity than SCR1 and is used to commutate SCR1 by a reverse voltage developed across the capacitor C. "The special feature of the circuit is the tapped autotransformer T through a portion of which the load currentflows".

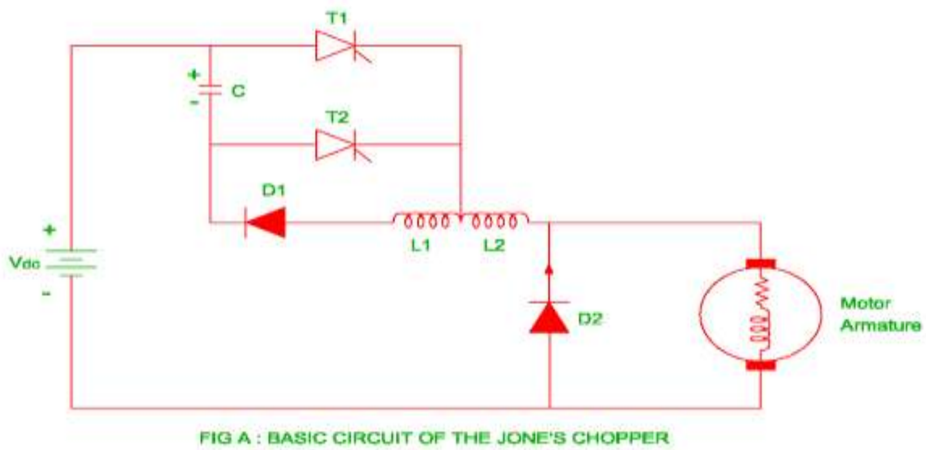


Fig3.14

Working

Shown Fig 3.14 When T1 is ON, capacitor C discharges resonantly through T1, L1, D1 . This discharge current doesnot flow through L2 and back to the battery because of transformer action of T. The load current is picked up by T1 and the freewheel diode D1 is reverse biased. As the capacitor voltage swings negative, the reverse bias on diode D2 decreases. This continues upto a time pi(L1C)^1/2.

When T2 is on the negative voltage on capacitar C is applied across T1 and it becomes OFF.The load current which is normally constant starts to flow in T2 and capacitor C. The capacitor C charged positively at first upto a voltage equal to supply voltage Vdc.The freewheel diode become forward bias and begins to pickup load current. And capacitor current starts to reduce. After this the energy 1/2LI^2 is the inductance L2 is forced in to the capacitor C.Charging is positively to 1/2CV^2 the capacitor current continues to decrease as a result current through T2 decreases gradually become OFF. The cycle repeat when T1 is again turnedON.

Advantage

The main advantage of JONES chopper over other the circuit is that

* It allows the use of higher voltage and lower microfarad commutating capacitor. This is because the trapped energy of inductor L2 can be forced in to the commutating capacitor rather than simply charging the capacitor by supply voltage.

* In this circuit there is no starting problem and anyone of the SCR can be turned on initialy there is great flexibility in condrol also.

3.7 Morgan Chopper

Figure 3.15 shows the power-circuit of Morgan chopper. In this circuit, T_1 is the main thyristor, whereas capacitor C, saturable reactor *SR* and diode D_1 forms the commutating circuit. The exciting current of the saturable reactor is assumed to be negligible small. When the saturable reactor is saturated, it has very low inductance. The voltage and current waveforms of the Morgan-chopper is shown in Fig.3.15.

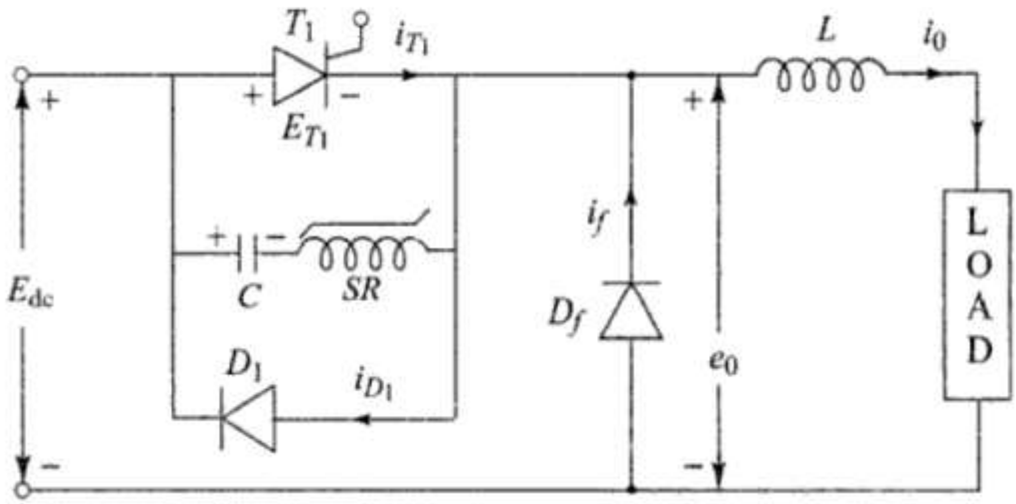


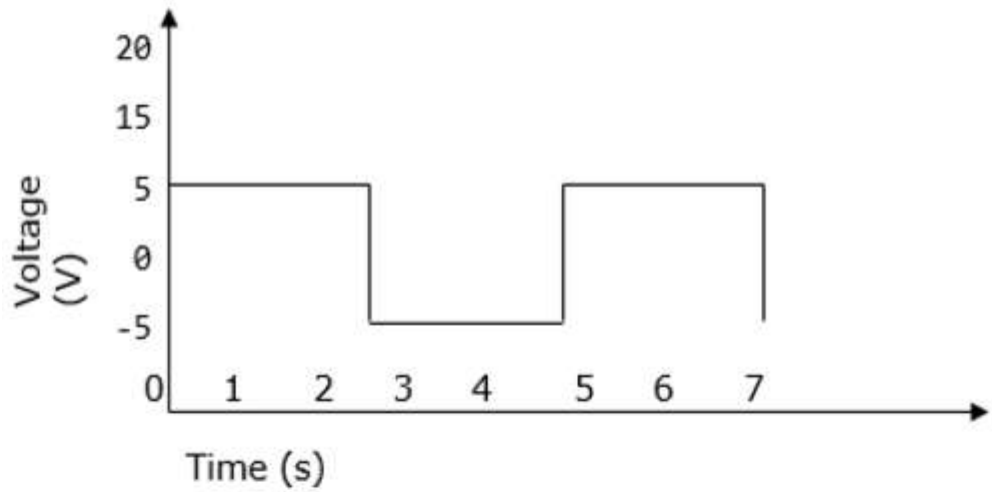
Fig.3.15.

When the main SCR T_1 is OFF, capacitor C_8 will charge to the supply voltage Ede with the polarity as shown in Fig. 8.34 and the saturable reactor is placed in the positive saturation condition. The capacitor charging path is *Ede*+ -*C* -*SR* – Load -Ede-· As shown in Fig. 8.35, thyristor T_1 is triggered at time *t* :: t_1• When thyristor T_1 is turned-on, the capacitor voltage appears across the saturable reactor and the core flux is driven from the positive saturation towards negative saturation. The capacitor voltage remains essentially constant with the samepolarity,till the negative saturation point is reached. This is due to the negligible exciting current of the *SR*. When the core flux reaches the negative saturation, the capac;tor discharges through the SCR T_1 and the post-saturation inductance of *SR*. This forms a resonant circuit with a discharging time of *1CJ L C* seconds, where *Ls* is the post-saturation inductance of the reactor. Thus, the discharging time of the capacitor is comparatively small and the reversal of tbe polarity of the capacitor takes. place very quickly. After this, the capacitor voltage which is now -Ede is impressed on the saturable reactor in the reverse direction and the core i s driven from negative saturation towards positive saturation

After a fixed interval of time, the core flux reaches the positive saturation after which the capacitor discharges very quickly through SCR T_1 in the reverse direction and the post-saturation inductance as before. The discharge current first passes through SCR T_1, turning it OFF and then through diode D_1 When SCR T_1 is turned-off the load current flows through the freewheeling diode D_1 Since the volt-time integral to saturate the core is constant, the ON period of SCR T_1 is fixed. The ON period is a function of *Ls C* and the average output voltage can be altered only by varying the operating frequency. Output voltage is lowered by lowering the frequency and increases by increasing the frequency. The ON period, however, can be controlled by varying the volt time product of the saturable reactor by means of d.c. controlled current through it. Also, the total ON time of SCR T_1 is determined by the time required for the saturable reactor to move from positive saturation to negative saturation and back to positive saturation again. Hence, the use of saturable reactor in place of linear reactor is advantageous in two ways: At the time of tum-off and charging of the capacitor, the inductance (saturated) is low and for on-time, it is high (unsaturated). The circuit cost is low due to the use of only one thyristor.

3.8 Pulse Width Modulation

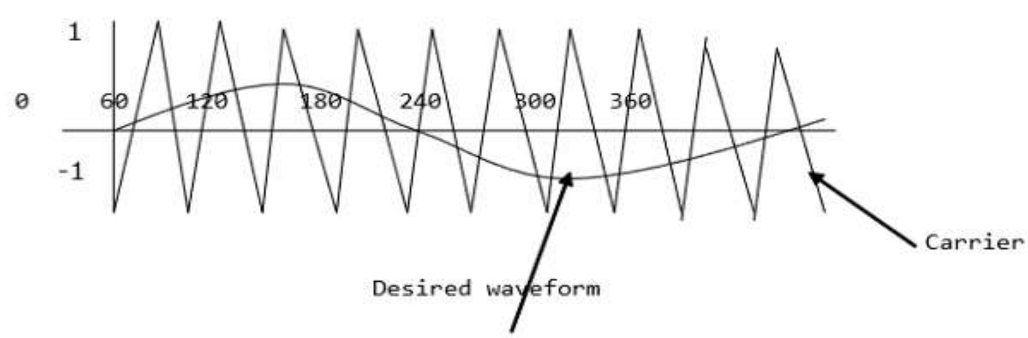
PWM is a technique that is used to reduce the overall harmonic distortion (THD) in a load current. It uses a pulse wave in rectangular/square form that results in a variable average waveform value f(t), after its pulse width has been modulated. The time period for modulation is given by T. Therefore, waveform average value is given by



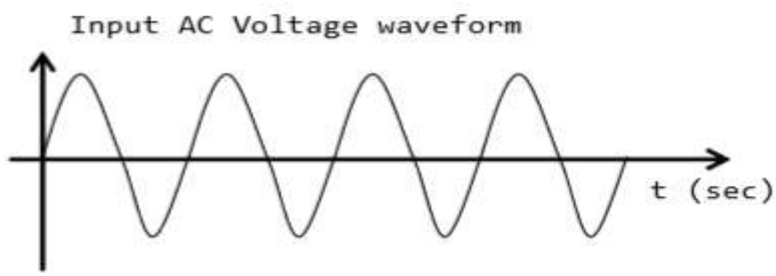
3.9 Sinusoidal Pulse Width Modulation

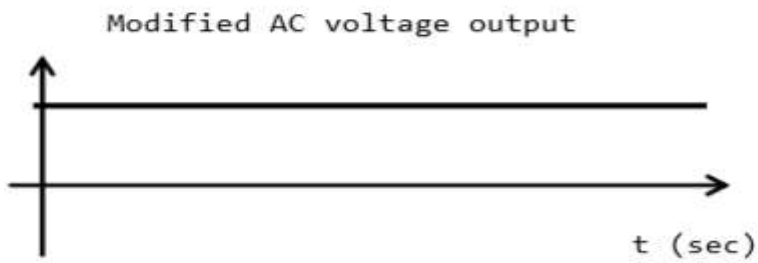
In a simple source voltage inverter, the switches can be turned ON and OFF as needed. During each cycle, the switch is turned on or off once. This results in a square waveform. However, if the switch is turned on for a number of times, a harmonic profile that is improved waveform is obtained.

The sinusoidal PWM waveform is obtained by comparing the desired modulated waveform with a triangular waveform of high frequency. Regardless of whether the voltage of the signal is smaller or larger than that of the carrier waveform, the resulting output voltage of the DC bus is either negative or positive.

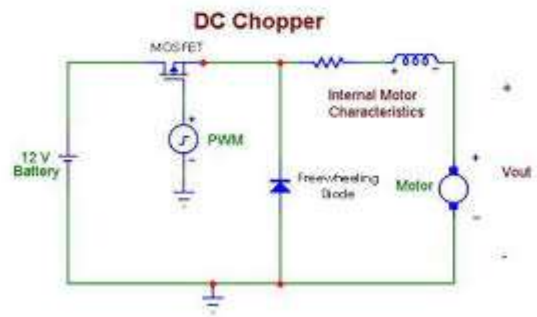


The sinusoidal amplitude is given as A_m and that of the carrier triangle is give as A_c. For sinusoidal PWM, the modulating index m is given by A_m/A_c.





3.10 PWM control circuit for driving MOSFET in chopper



Advantages and Disadvantages of HVDC Transmission

The advantages lies in the fact HVDC links are able to connect to two asynchronous network, a typical example is a 60Hz and 50Hz power system network. For long distance transmission the HVDC links are less expensive and do not suffer a lot of electrical losses. For underground transmission system HVDC is much better because it avoids the heavy currents that are required to charge and discharge the cable due the capacitance effect of the cable. Because the power flow can be controlled independently of the phase angle between the source and the load, it has the capability to stabilize a network if there is any disturbance due to any changes in power demand. Also it has the capability of connecting remote generation to a distribution grid.

Other advantages are the ability to transmit large amount of power over long distance. There is lower capital cost since the number of lines is fewer and a reduction in the profile configuration in the number of pylons required and fewer conductors.

Come with the great advantages, there are also disadvantages and that include a high capital cost for the converters and the converters generate a lot of harmonics and characteristics harmonics and also requires a lot of reactive power consumptions which warrants the installation of harmonic filters to eliminate the harmonics and also to provide the reactive power requirement at fundamental frequency. For a multi-terminal HVDC, it is so complex and requires complex and costly communication system. They also have an overload capability limitation. Also for certain type of HVDC configuration, a close in AC fault on the AC side can affect the DC side. Also the radio noise generated can affect communication system that is close by.

Model Questions

PART – A

1. Define chopper.

2. Mention the applications of chopper.

3. Mention the types of chopper.

4. Why class B chopper is called step up chopper?

5. Mention the two different modes of operation of class D choppers.

6. What is energy recovery diode? Why it is called so?

7. Mention the control strategies used in chopper.

8. Define duty cycle and chopper frequency.

9. What is meant by step up chopper?

10. Mention the advantages of DC transmission.

11. List the drawbacks of DC transmission.

12. State the principle of DC transmission.

13. Mention the different types of DC transmission.

PART – B

1. Explain constant frequency control in DC chopper.

2. Draw the circuit diagram and waveforms of class B chopper.

3. Explain the operation of class A chopper with neat sketch.

4. Explain mode 1 operation in class D chopper.

5. Explain mode2 operation in class D chopper.

6. Draw the circuit and waveforms of Morgan chopper.

7. Draw the circuit diagram of chopper using MOSFET.

8. Explain the principle of DC transmission.

PART – C

1. Explain in detail the different control techniques used in chopper.

2. Explain the operation of class C chopper in detail with necessary diagrams.

3. Explain the operation of class D chopper in detail with necessary diagrams.

4. Explain the operation of class E chopper in detail with necessary diagrams.

5. Explain the operation of Jones chopper in detail with necessary diagrams.

6. Explain the operation of Morgan chopper in detail with necessary diagrams.

7. Draw and explain the circuit diagram of PWM control circuit for driving MOSFET in chopper.

8. Draw and explain chopper circuit using MOSFET.

9. With neat block diagram explain DC transmission and mention its advantages.

%%%%%%%%%%%%%%%%%%%%%%

IV UNIT

INVERTERS

4.1 INTRODUCTION Definition It is a circuit which converts DC in to AC.

Requirement One of the most important thing that you must know before buying an **inverter** is your "power **requirement**". In simple words- what all electrical appliances (like CFL, tube lights, fan, television, computer, refrigerator etc.) you will run at the time of power cut.

Some Industrial applications are adjustable speed drives stand by air craft power supply UPS for computers , hvdc transmission lines etc…

4.2 SINGLE-PHASE VOLTAGE SOURCE INVERTERS OPERATING PRJNCIPLE

Single-phase bridge inverters are of two types, namely (1) single-phase half-bridge inverters and (14) single-phase full-bridge inverters, Basic principles of operation of these two types are presented here

Power circuit diagrams of the two configurations of single-phase bridge inverter, as stated above, are shown in Fig. 4.1 (a) for half-bridge inverter and in Fig, 4.1 (a) for full-bridge inverter, In these diagrams, the circuitry for turning-on or turning-off of the thyristors is not shown for simplicity. The gating signals for the thyristors and the resulting output voltage waveforms are shown in Figs, 4.1 (b) and 4.1 *(b)* for half-bridge and full-bridge inverters respectively. These voltage waveforms are drawn on the assumption that each thyristor conducts for the duration its gate pulse is present and is commutated as soon as this pulse is removed. In Figs, 4.1 *(b)* and 4.1 *(b)*, i_{g4} are gate signals applied respectively to thyristors T1-T4

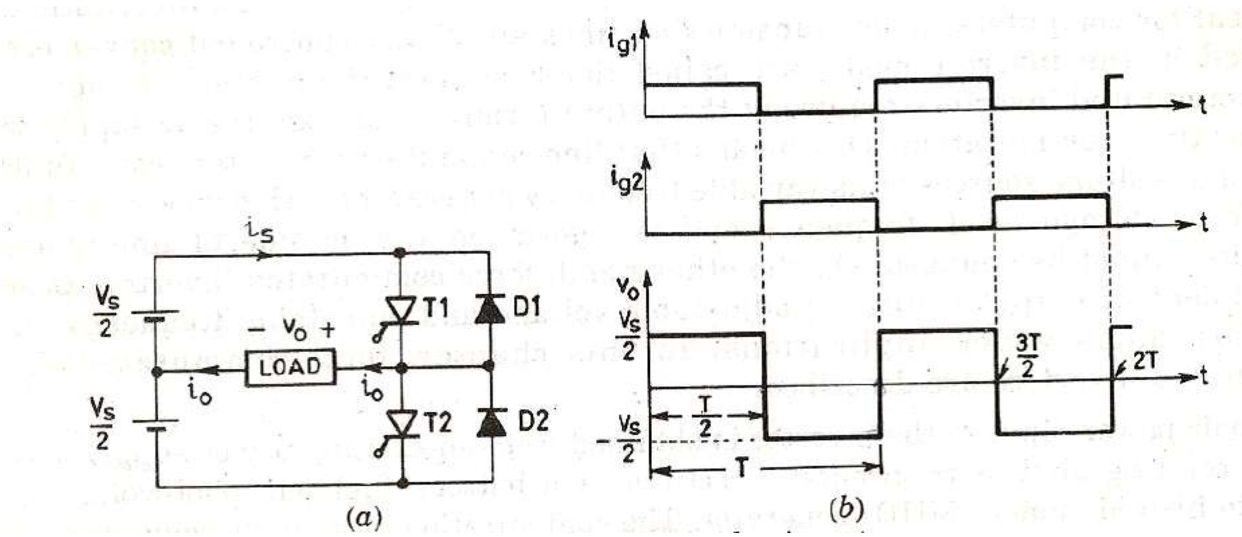
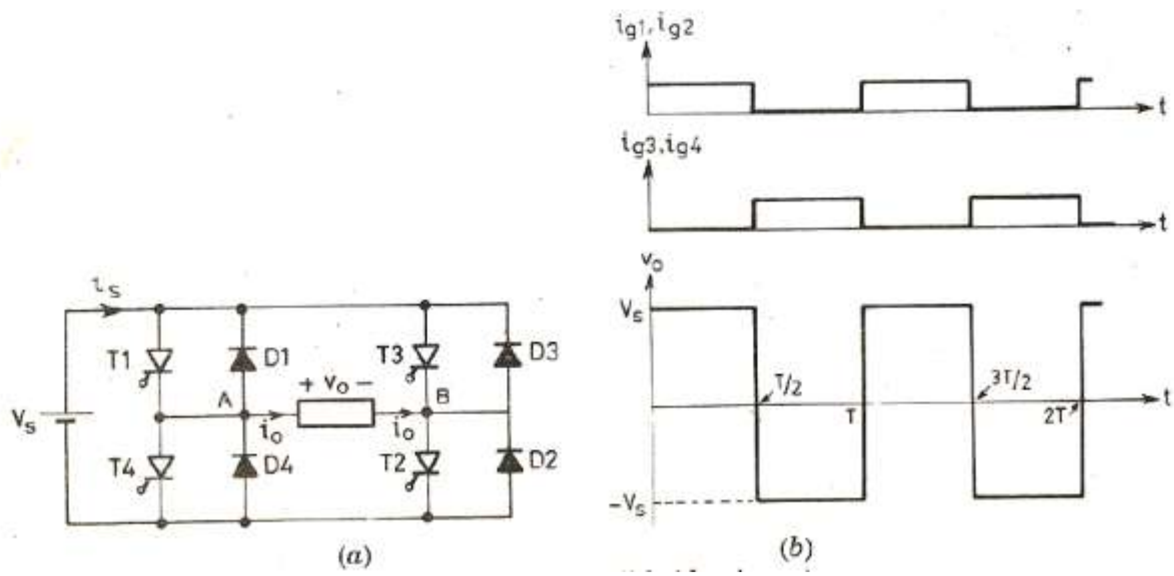


Fig. 4.1

Single-phase half bridge inverter, as shown in Fig. 4.1 (a), consists of two SCRs, two diodes and three-wire supply. It is seen from Fig. 4.1. (b) that. far 0 < K T/2, thyristor T1 12,.tg2 conducts and the load is subjected to a voltage V/2 due to the upper voltage source V/2., At t = T/2, thyristor T1 is commutated and T2 is gated or uring the period T/2 < *T*, thyristor T2 conducts and the load is subjected to a voltage {— V./2) due to the lower voltage source V_1/2. It is seen from Fig. 81 *(b)* that lead voltage is an alternating voltage waveform of amplitude V/2 and of frequency 1/T H2. Frequency of the inverter output voltage can be changed by controlling T.

The main drawback of half-bridge inverter is that it requires 3-wire do supply. This difficulty can, however, be overcome by the use of a full-bridge inverter shown in Fig. 4,2 (a). It consists of four SCRs and four diodes. In this inverter, number of thyristors and diodes is twice of that in a half bridge inverter, This, however, does not go against full inverter because the amplitude of output voltage as well as its output power is doubled in this inverter as compared to their values in the half-bridge inverter. This is evident from Figs. 4.2 *(6)* and 4.2 *(6).*



Figs. 4.2

For full-bridge inverter, when T1, T2 conduct, load voltage is V, and when T3, T4 conduct load voltage is — Y_1 as shown in Fig. 4.2 *(b).* Frequency of output voltage can be controlled by varying the periodic time T.

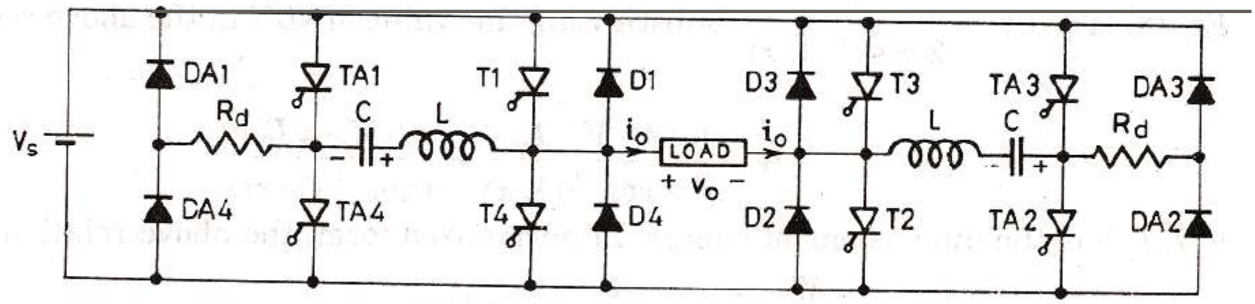
In Fig. 4.1 (a), thyristors TI, T2 are in series across the source ; in Fig. 4.2 (a) thyristors TI, T4 or T3, T2 are also in series across the source. During inverter operation, it should be ensured that two SCRs in the same branch, such as T1, T2 in Fig, 4.1 (ez), do not conduct simultaneously as this would lead to a direct short circuit of the source.

For a resistive load, two SCRs in Fig. 4.1 (a) and four SCRs in Fig. 4.2 (a) would suffice, because load current i_o and load voltage [t_o would always be in phase with each other.

This, however, is not the case when the load is other than resistive, For such types of loads, current i_t will not be in phase with voltage u_o and diodes connected in anti parallel with thyristors will allow the current to flow when 'the main thyristors are turned off. These diodes are called feedback *diodes*

4.3 Modified McMurray full-bridge inverter

A single-phase modified McMurray full-bridge inverter is shown in Fig, 4.3, The number of thyristors, diodes and other components in full-bridge inverter is double of those in half-bridge inverter. The operation of this inverter during commutation process is similar to that described in the previous section for a single-phase half-bridge inverter. For example, for mode 1, thyristors Ti. T2 are conducting and the load current completes its path through source V,,, T1, load, T2 and back to source. For mode 11, TA1 and TA2 are triggered together for commutating main SCRs T1 and T2. For mode 111, commutating current i_s in both the circuits goes beyond load current 4 so that T1 and T2 are turned of and so on.



Fig, 4.3

Power circuit diagram of a modified McMurray Bedford half-bridge inverter is Fig. 4.3. It uses less number of thyristors and diodes as compared to modified McMurray half-bridge inverter, The number of capacitors and inductors is, however, large. This inverter, Fig. 8.15. consists of main thyristors T1, T2 and feedback diodes D1, D2. Commutation circuitry consists of two capacitors Cl, C and magnetically coupled inductors -Li, L2. Actually L1 and L2 constitute one inductor with a centre tap so that LI =. L2 = L.

In a branch consisting of two tightly coupled inductors in series with two thyristors, if one thyristor is turned on, the other conducting thyristor gets turned of this type of commutation is called .complementary commutation.

The simplifying assumptions are the same as for the inverter discussed in previous section.

The *working* of this inverter can be explained in different modes as follows

Mode I

In this mode, thyristor T_l is conducting and upper dc source supplies load current 1_0 to the load, Fig, 8.16 (a). As the load current is almost constant, voltage drops across across L_l and T_i. Voltage across C_1. is zero and voltage across C_2. Is zero because point g is effectively connected to point .13 through L_l and T_1 and lower plate of C_2 is connected to point f. The equivalent circuit for this anode is as shown in Fig. 8.16 (a). In this figure, voltage of node g with respect to point f is K. The potential of points d and c i.e the same as that of pointing with respect to f. In other words, the potential of all the three nodes g, d, c with respect to point f V this is shown in Fig, 4.3.

Mode II.

When t = 0 thyristor T_2 is triggered to initiate the -commutation of T_i. With the turning-on of T_2, point d gets connected to e *f*, i.e. to the negative supply terminal. Voltage across 01 acid C_2 cannot change instantaneously, therefore a voltage V. appears across L_2. As L_l and L_2 are magnetically coupled, an equal voIta.ge is induced across L_l with terminal 42 positive. Voltage o_n across terminals of thyristor T_i can he found by traversing the loop *b a fe el e*, Fig. 4.3 ;

$$v_{T1} = v_{bc} = -\frac{V_s}{2} - \frac{V_s}{2} + V_s + V_s = V_s$$

This shows that point *c is* positive with respect to b by V volts, *i.e,* Ti is subjected to a reverse voltage of - V ; it is therefore turned off at t = 0 + . Load current 4 flowing through 1'1 and LI. io at once transferred to 12 anti T2 so *as to* maintain constant (proportional to Li, _TO in the centre tapped inductor as per the constant flux linkage theorem. Current directions for i", are shown in Fig. 4.3 (c). KVL for the loop consisting of CI, 02 and the source V for this figure gives

Mode III.

At t_1. capacitor Cl is charged to supply voltage V. and therefore no current can flow through Cl. *i.e.* i_d = 0. After one-fourth of a cycle from t = 0. i.e. att1,0. Just after t_i, (1_0 + .1,,,)/2 through C2 tends to charge it with bottom plate positive. As a result, diode D2 gets forward biased at t_l. Thus, now entire current (I_D +.1) is transferred to D2 so that both i.,$_1$= i_a= 0 just. after t_i but 4_{12} t_0 + f_r,, ; this is shown in the equivalent circuit of Fig. 4.3. (e), Diode current i_{D2} =1_0 + I_m.

The energy stored in inductor L. at f_1 is dissipated in the closed circuit made up of L2, T2 and D2. At time t_2, this energy is entirely dissipated, therefore current i_n decays to zero and as a result.. T2 is turned off at t_2, Fig. 8.17. Sometimes, a small resistance is included in series with the diode to speed up the dissipation of stored energy in 142. As *in* decays from 4, at t_i to zero at t_2, $/_{D2}$ also decays from 1_0+ *.1,, at* t_i to *422 = io = cab at* t_9

Mode IV.

When the current. i_n through L2 and T2 has decayed to zero the equivalent eirc-uit is as shown in Fig_ 8,16 *(f)*. A load current i_{ci} = I_{D2} still continues flowing through the diode D2 as f_{in} during (t_a - t_a) interval, fig_ 4.3

Mode V

Finally, load current t_o through the diode 1)2 and load decays to zero at t_a and is then reversed_ As soon as i_c, equal to *iD2*, tends to reverse, 1)2 is blocked. The reverse bias across D2, due to voltage drop in V2 no longer exists. Therefore, thyriator T2 already gated during the interval t_a - $_t$ gets turned on to carry the load current in the reversed direction. The capacitor Cl, now charged to the source voltage V_a, Fig. 4.3 (e), is ready for commutating the main thyristor T2.

4.4 THREE PHASE BRIDGE INVERTERS

For providing adjustable-frequency power to industrial applications, three-phase inverters are more common than single-phase inverters. Three-phase inverters, like single-phase inverters, take their dc supply frOm a battery or mare usually from a rectifier_

A basic three-phase inverter is a six-step bridge inverter. It uses a minimum of six thyristors. hi inverter terminology, a step is defined as a change in the firing from one thyristor to the next thyristor in proper sequence, For one cycle of 360', each step would be of 60' interval for a six-step inverter_ This means that thyristors would be gated at regular intervals of 60° in proper sequence so that a 3-phase ac voltage is synthesized at the output terminals of a six-step inverter.

Fig. 4.4 shows the power circuit of a three-phase bridge inverter using six thyristors and six diodes As stated earlier, the transistor family of devices is now very widely used in inverter circuits. Presently, the use of 'Galls in single-phase and three-phase inverters is on the rise. The basic circuit configuration of inverter, A large capacitor connected at the input terminals tends to make the input do voltage constant. This capacitor also suppresses the harmonics fed back to the source.

There are two possible patterns of gating the thyristors. In one pattern, each thyristor conducts for 180' and in the other, each thyristor conducts for 120^{O}. But in both these patterns,

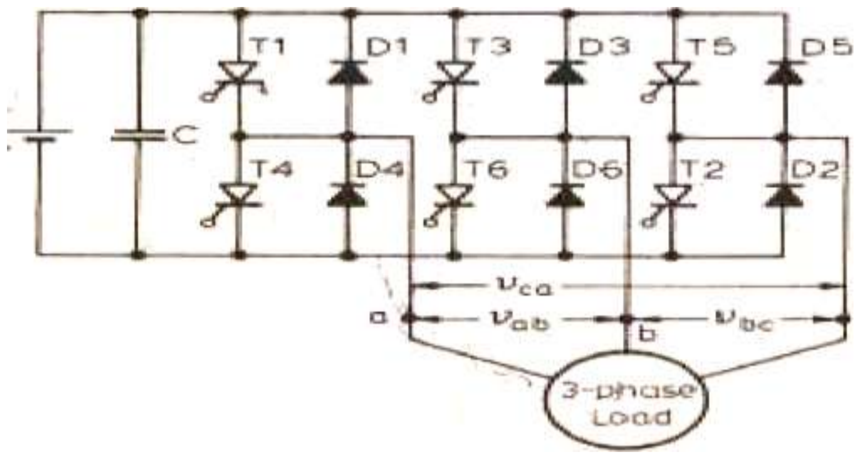


Fig 4.4

Gating signals are applied removed at 60° intervals of the output voltage waveforms

4.4.1 Three-phase 120 Degree Mode

Power circuit diagram of this inverter is the same as that shown in Fig.4.4. For the 120 degree mode each thyristor conducts for 120° of a cycle. Like 180° mode, 120° mode inverter also requires six steps, each of 60° duration, for completing one cycle of the output ac voltage.

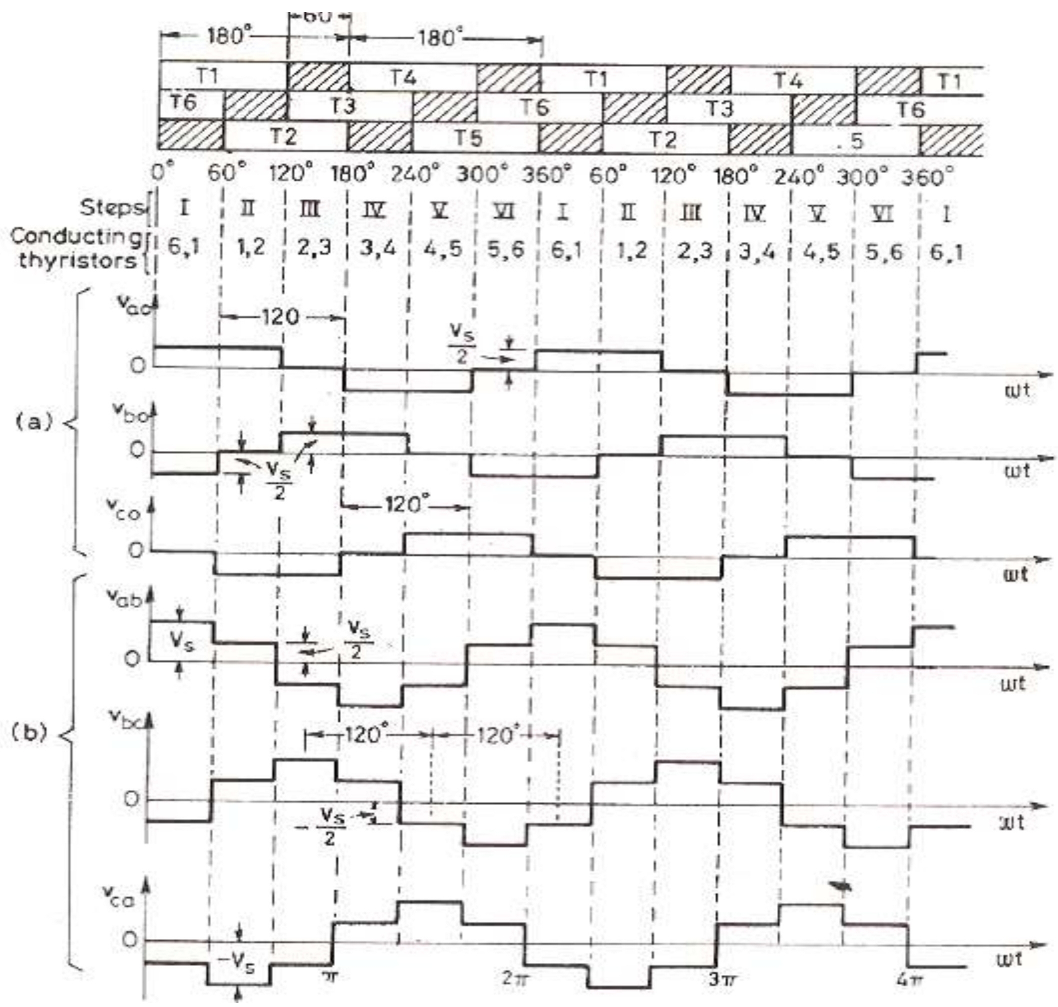
A table giving the sequence of firing the six thyristors is prepared as shown in the top of Fig.8.22.Jn Thls table, first rows shows that Tl conducts for 120° and for the next 60•, neither Tl nor T4 conducts. Now T4 turned on at wt = 180 and further conducts for 120°, *1.e.* from wt >*t* = 180° to w*t.* =3000. This means that for so interval from w*t* = 120° to wt = 180°. series connected SCRs do not conduct. At wt = 300°, T4 is turned off, then so interval elapses before Tl is turned on again at wt = 360".In the second row, T3 is turned on at wt = 180° mode inverter. Now T3 conducts for 120°, then 60° interval elapses during which neither T3 nor T6 conducts. At wt = 300', TS is turned on, it conducts for 120' and then S0° interval elapses after which T3 is turned on again. The third row is also completed similarly. This table shows that T6, Tl should be gated for step l; Tl, T2 for step ll ; T2, T3 for step 11I and so on. The sequence of firing the six thyristors is the same as for the 180° mode inverter. During each step, only two thyristors conduct for this inverter -one from the upper group and one from the lower group ; but in 180° mode inverter, three thyristor conduct in each step.

The circuit models for steps are shown I n Fig., where load is assumed to be resistive and star connected. During step I, thyristors 6, 1 are conducting and a such load terminal a is connected to the p.os1tive bus of de source whereas terminal *b* is connected to negative bus of de source, Fig. 8.23 (a). Load terminal *c* is not connected to de bus. The line to nutral voltages, from Fig. are

$$v_{ao} = \frac{V_s}{2}, \quad v_{ob} = \frac{V_s}{2}$$

$$v_{bo} = -\frac{V_s}{2}$$

$$v_{co} = 0$$



Merits and Demerits

(i) In the 180° mode inverter, when gate signal i_{61} is cut-off to turn off Tl at *oot* = 180°, gating signal i_{14} is simultaneously applied to tum on T4 in the same leg. In practice, a commutation interval must exist between the removal of 111 and application of i_{114}, because otherwise de source would experience a direct short-circuit through SCRs Tl and T4 in the same leg.

This difficulty is overcome considerably in 120-degree mode inverter. In this inverter, there is a 60° interval between the turning off of Tl and turning on of T4. During this 60° interval, Tl can be commutated safely. In general, this angular interval of 60° exists between the turning-off of one device and turning-on of the complementary device in the same leg. .This 60° period provides sufficient time for the outgoing thyristor to regain forward blocking capability.

ii) In the 120° mode inverter, the potentials of only two output terminals connected t.o the de source are defined at any time of the cycle.

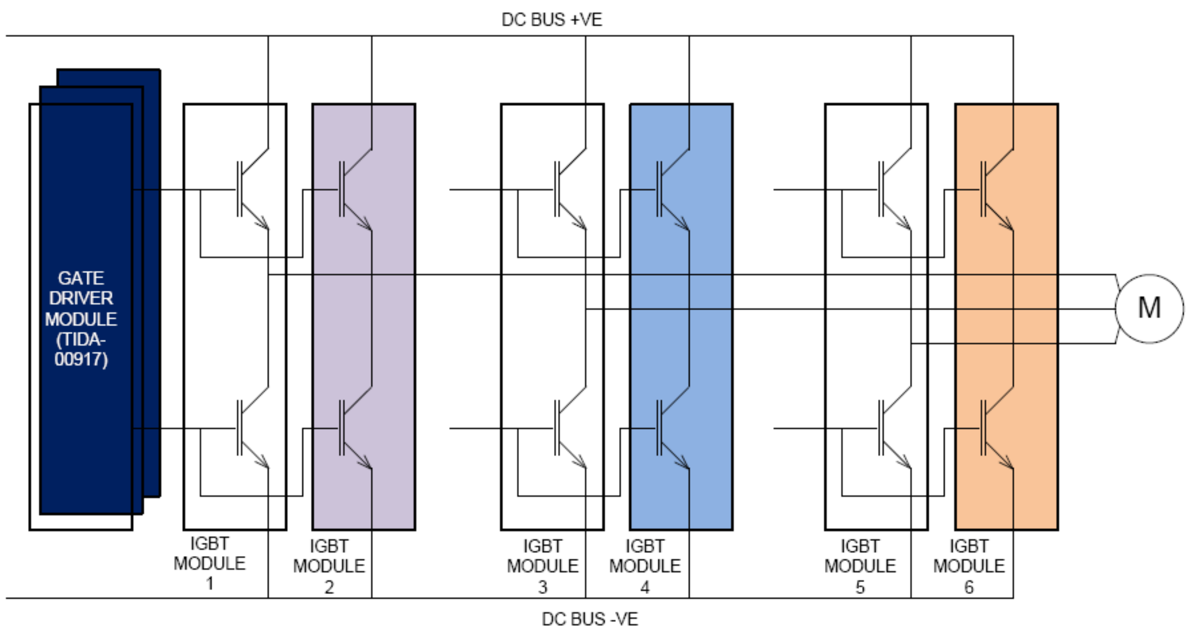
4.5 Parallel inverter using IGBT.

Paralleling IGBTs become necessary for power conversion equipment with higher output power ratings, where a single IGBT cannot provide the required load current. This TI Design implements a reinforced isolated IGBT gate control module to drive parallel IGBTs in half-bridge configuration. Paralleling IGBTs introduces challenges at both the gate driver (insufficient drive strength) as well as at system level in maintaining equal current distribution in both the IGBTs while ensuring faster turnon and turnoff.

System Description

Insulated gate bipolar transistors (IGBTs) are considerably used in three-phase inverters that have numerous applications like variable-frequency drives that control the speed of AC motors, uninterruptible

power supplies (UPS), solar inverters, and other similar inverter applications. IGBTs have the advantages of high-input impedance as the gate is insulated, has a rapid response ability, good thermal stability, simple driving circuit, good ability to withstand high voltage, snubber-less operation, and controllability of switching behavior providing reliable short-circuit protection. The IGBT is a voltage controlled device, which gives it the ability to turn on and off very quickly. Paralleling IGBT modules becomes necessary when the output current requirement cannot be provided by a single IGBT module. A single module of an IGBT is capable of handling currents up to 600 A in the dual onfiguration. Higher currents in the range of kilo amperes are required in case of high power rated equipments. Higher currents can be obtained either by paralleling inverters or by paralleling the IGBT modules inside the inverter as shown in Figure 1. An advantage of paralleling includes distributing heat sources so that higher levels of power loss can be dissipated.



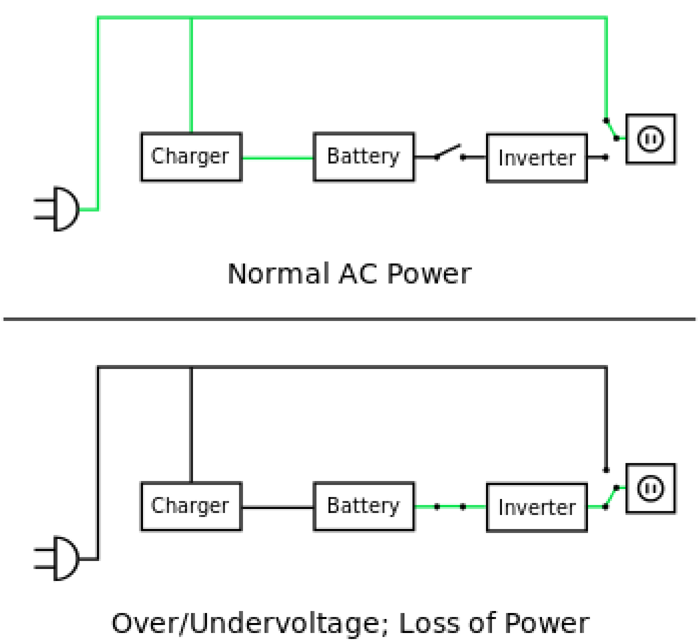
This isolated gate driver circuit is designed for low voltages and medium power drives, operating from a three-phase AC supply up to 480 VAC. Medium power drives rated for greater than 100 kW can have IGBT modules with gate charges up to 10 µC, necessitating high peak currents to turn on and off the IGBT. Gate driver ICs have a limited peak current capability; typical values are 2.5 A for source and 5 A for sink.

4.6 UPS

An **uninterruptible power supply**, also **uninterruptible power source**, **UPS** or **battery/flywheel backup**, is an electrical apparatus that provides emergency power to a load when the input power source or mains power fails. A UPS differs from an auxiliary or emergency power system or standby generator in that it will provide near-instantaneous protection from input power interruptions, by supplying energy stored in batteries, super capacitors, or flywheels. The on-battery runtime of most uninterruptible power sources is relatively short (only a few minutes) but sufficient to start a standby power source or properly shut down the protected equipment.

A UPS is typically used to protect hardware such as computers, data centers, telecommunication equipment or other electrical equipment where an unexpected power disruption could cause injuries, fatalities, serious business disruption or data loss. UPS units range in size from units designed to protect a single computer without a video monitor (around 200 volt-ampere rating) to large units powering entire data centers or buildings. The world's largest

Offline/standby



Offline/Standby UPS: The green line illustrates the flow of electric power. Typical protection time: 0–20 minutes. Capacity expansion: Usually not available

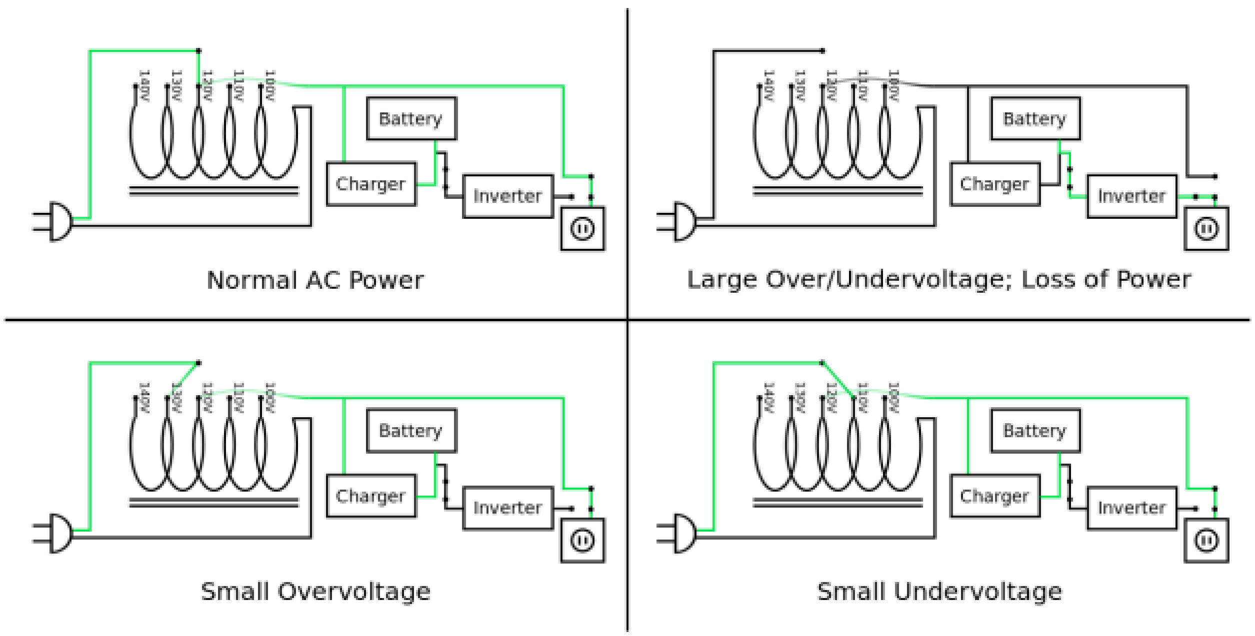
The offline/standby UPS (SPS) offers only the most basic features, providing surge protection and battery backup. The protected equipment is normally connected directly to incoming utility power. When the incoming voltage falls below or rises above a predetermined level the SPS turns on its internal DC-AC inverter circuitry, which is powered from an internal storage battery. The UPS then mechanically switches the connected equipment on to its DC-AC inverter output. The switchover time can be as long as 25 milliseconds depending on the amount of time it takes the standby UPS to detect the lost utility voltage. The UPS will be designed to power certain equipment, such as a personal computer, without any objectionable dip or brownout to that device.

Online/double-conversion

In an online UPS, the batteries are always connected to the inverter, so that no power transfer switches are necessary. When power loss occurs, the rectifier simply drops out of the circuit and the batteries keep the power steady and unchanged. When power is restored, the rectifier resumes carrying most of the load and begins charging the batteries, though the charging current may be limited to prevent the high-power rectifier from overheating the batteries and boiling off the electrolyte. The main advantage of an on-line UPS is its ability to provide an "electrical firewall" between the incoming utility power and sensitive electronic equipment.

The online UPS is ideal for environments where electrical isolation is necessary or for equipment that is very sensitive to power fluctuations. Although it was at one time reserved for very large installations of 10 kW or more, advances in technology have now permitted it to be available as a common consumer device, supplying 500 W or less. The initial cost of the online UPS may be higher, but its total cost of ownership is generally lower due to longer battery life. The online UPS may be necessary when the power environment is "noisy", when utility power sags, outages and other anomalies are frequent, when protection of sensitive IT equipment loads is required, or when operation from an extended-run backup generator is necessary.

The basic technology of the online UPS is the same as in a standby or line-interactive UPS. However it typically costs much more, due to it having a much greater current AC-to-DC battery-charger/rectifier, and with the rectifier and inverter designed to run continuously with improved cooling systems. It is called a *double-conversion* UPS due to the rectifier directly driving the inverter, even when powered from normal AC current.



Need for UPS

An Uninterruptible Power Supply (**UPS**) is used to protect critical loads from mains supply problems, including spikes, voltage dips, and fluctuations and complete power failures using a dedicated battery. A **UPS** system can also be used to 'bridge the gap' whilst a standby generator is started and synchronized.

Comparison Chart

Here is a comparison chart of Online and Offline UPS mentioning advantages (+) and disadvantages (-)

Topology	Reliability	Cost	Input	Output
Offline	+ Fewer parts lower operating temperature	+ Lower initial cost (fewer parts) Lower operating cost (less electricity)	- Extreme voltage distortion can require frequent battery usage	+/- Output frequency varies within a configurable range
Online	- Many parts higher operating temperature	- Higher initial cost (more parts) Higher operating cost (more electricity)	+ Accepts extreme voltage distortion without going to battery	+ Output fixed to a configurable frequency

Model Questions

PART - A

1. What is inverter?

2. What are the requirements of inverter?

3. What are the methods used to obtain sine wave output from an inverter?

4. What are the advantages of McMurray inverter?

5. Define UPS.

6. What is the need for UPS?

7. What are the types of UPS?

8. Mention the applications of inverters.

9. State the different modes of three phase inverter.

10. Mention the advantages of online UPS.

PART – B

1. Draw the circuit diagram and waveforms of single phase inverter with resistive load.

2. Draw the circuit diagram and waveforms of single phase inverter with RL load.

3. What are the methods used for reducing harmonics at the output of inverters?

4. Explain PWM in inverters.

5. Draw the circuit diagram of through pass inverter.

6. Draw the circuit diagram and waveforms of parallel inverter using IGBT.

7. Draw the block diagram of OFF line UPS.

8. Draw the block diagram of ON line UPS.

9. Compare ON line and OFF line UPS.

PART – C

1. With suitable diagrams explain the operation of single phase inverter with resistive load.

2. With suitable diagrams explain the operation of single phase inverter with RL load.

3. Briefly explain the output voltage control in inverters.

4. Briefly explain the various methods of obtaining sinewave output from an inverter.

5. Explain in detail about McMurray inverter.

6. Explain in detail about Through pass inverter.

7. Explain in detail about three phase inverter.

8. Explain in detail about parallel inverter using IGBT.

9. With necessary diagrams explain ON line UPS.

10. Explain in detail about OFF line UPS

%%%%%%%%%%%%%%%%%%%%%%

V UNIT

NUMERICALLY CONTROLLED SYSTEMS

Definition

A numerical control system is defined by the Electronics Industries Association EIA as “A system in which actions are controlled by the direct insertion of numerical data at some point. The system must automatically interpret at least some portion of the data.”

5.1 Basic Concepts of Numerical Control

Numerical control is the controlling of a machine tool by means of prepared program which consists of blocks or series of numbers. These numbers define the required position of each slide, its feeds, cutting speeds, etc. The numbers are defined from the dimensions of the part that are taken from the drawing of the machined product. In the manufacturing of complicated parts, additional data points are calculated by the system using an interpolator.

Input format of the numerical data in N/C system

In a numerical control system the numerical data required to produce a part is maintained on a punchedtape. The data is arranged in the form of blocks of information, where each block contains the numerical data information required to produce one segment of the work piece. The block contain sin coded form the information need for processing a segment of workpiece ,such as the segment length, the feed, the cutting speed ,etc.

The dimensional information like the length, breath radii of the circles and the contour form like linear or circular are taken from the drawing. Dimensions are given separately for each(X, Y, etc.) axis of motion. cutting speed, feed and auxiliary functions like coolant ON/OFF, spindle directions, clamp, gear changes are programmed according to the surface finish and tolerance requirements.

The preparation of the data requires a parts programmer .The parts programmer must have knowledge and experience in the mechanical engineering fields. He should have the knowledge of tools , cutting fluids, fixture design techniques, use of machinability data and process engineering. He should be familiar of the functions of the N/C processes. The programmer writes the sequence of the optimal operations as a program either in manual or in a computer language called APT .The program is punched on a tape using a flexowriter.

5.2 Block diagram of a numerical control system

A N/C machine tool system consists of the Machine Control Unit (MCU) and the machine tool The MCU consists of two main units. The Data Processing Unit (DPU) and the Control Loops Unit (CLU).

The DPU consists of the data input device, data reading circuits the parity checking logic, decoding circuits and an interpolator. The DPU reads the punched tape using a tape reader. The coded information from the tape reader passes to the decoding circuits.

The data contains the required new position of each axis, its direction of motion, feed and auxiliary function control signals .The decoding circuits distribute the data among the controlled axes. The interpolator supplies current velocity commands between two different points from the drawing .This data is then sent to the control loops unit.

The CLU operates the driving devices of the machine lead screws and receives the feedback signals about the position and velocity of each of the axes. Each lead screw under each axis of control has a separate driving device and a separate feedback device.

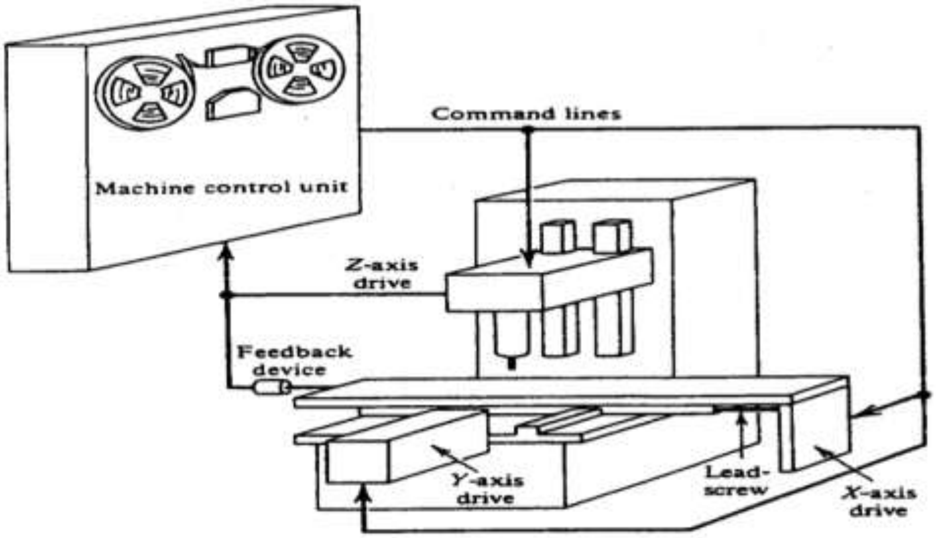


Fig 5.1 Block diagram of a Numeric Control system

The driving device can be a dc motor, a stepper motor or a hydraulic system The feedback devices are the measuring devices such as the encoders, digitizers, resolvers, inductosyn, tachometers and digital to analog converters. The CLU has position control loops, velocity control loops, decelerating and backlash take-up circuits and auxiliary function control.

5.2.1 Advantages of a N/C system

1. A full flexibility in the production of a new part.
2. Accuracy through all range of speeds and feeds.
3. A shorter production time.
4. Possibility of manufacturing part of any contour
5. An easy adjustment of the machine.
6. The need for highly skilled and experienced operator is avoided.
7. The operator can also see the other machine operations.
8. The part production is economical

5.2.2 Disadvantages of a N/C system

1. The price is costly.
2. Complicated maintenance required.
3. A highly skilled parts programmeris required.

5.2.3 Applications

The applications of an N/C system are

1. Sequence control
2. Drilling machine
3. Boring machine
4. Punching
5. Turning
6. Flame welding
7. Filament winding
8. Wire processing
9. Knitting and textile cutting
10. Spark erosion machine
11. Lathe / Turning Centre
12. Milling / Machining Centre
13. Turret Press and Punching Machine
14. Wire cut Electro Discharge Machine (EDM)
15. Grinding Machine
16. Laser Cutting Machine
17. Water Jet Cutting Machine
18. Electro Discharge Machine
19. Coordinate Measuring Machine
20. Industrial Robot

5.3 Driving devices

5.3.1 Hydraulic systems

They are used to drive the machine tools. They can deliver high powers in the range of hundreds of horse power with a relatively small size and can be easily adapted for electrical control. The hydraulics system has higher maximum angular acceleration and smooth operation of the machine tool slides. The disadvantages are oil leakages at the transmission systems and components. The oil should be kept free from contamination. Dynamic lags may introduce undesirable changes in control actions.

The hydraulic system consists of the

1. A hydraulic power supply
2. Servo valve

3. Sump
4. Hydraulic motor

The hydraulic power supply is a source of high pressure oil for the hydraulic motor, servo valves and the auxiliary components. The main components of the hydraulic power supply are

1. The pump which supplies the pressurised oil.
2. The pump is driven by a three phase induction motor.
3. A check valve to restrict reverse flow of the oil to the pump.
4. The supply has a fine filter and a coarse filter to remove dirt and prevent contamination to the oil.
5. A pressure controlling valve to control the supply pressure to the servo systems.
6. An accumulator for storing the hydraulic energy.

The electro hydraulic servo valve controls the flow of the pressurised oil. The motion of the servo valve is controlled by an amplified electrical signal. The input voltage to the valve is proportional to the velocity of the hydraulic motor.

The sump receives the used oil through the return line. The oil is feedback to the hydraulic power supply.

The prime mover is the hydraulic motor for rotary motion or the hydraulic cylinder for linear motion. The hydraulic motor operates at high speeds and is geared to the lead screw which drives the table.

5.3.2 Stepper motor

The stepper motor translates an input pulse sequence into proportional angular movements, rotating one angular increment or step angle for each input pulse. The stepper motor has 'm' phase stator windings and a rotor with no windings. The specifications of the stepper motor are

(1) The phases equal to the number of the stator windings

(2) The number of poles of the stator and the rotor.

The number of steps per revolution of the stepper motor is determined by the number of phases and poles of the stator and the rotor. The shaft is connected to therotor. The shaft position is determined by the number of pulses and the velocity of the motor is given by the pulse frequency. The shaft speed in steps per second is equal to the incoming frequency of the pulses per second.

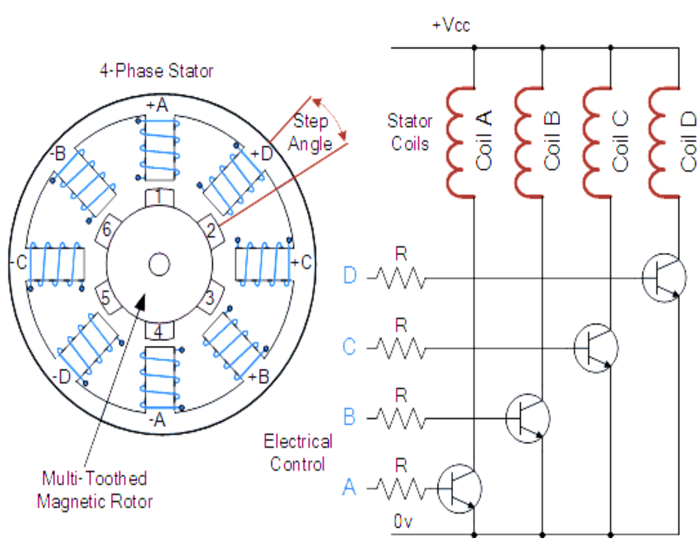


Fig 5.2 Stepper motor as a driving device

The stator windings are excited by the successive switching of the voltage supplied to the phase windings in a particular sequence using the driving circuit .The driving circuit consists of a steering circuit or a logic circuit which converts the incoming pulses into the correct switching sequence needed to step the motor and a power amplifier.

The stepper motor can be constructed for unidirectional or bi-directional rotation. The stepper motor is designed for small N/C systems with open loop control. The limitation of the stepper motor is the small torque output. They cover a wide range of performance.

5.4 Data Processing Unit

The data processing unit connects the punched tape with the control loops unit.The DPU consists of the tape reader, data storing registers, distribution circuits, decoders and the converters to convert the data into a form acceptable by the CLU. In contouring control systems the DPU consists of the interpolator.

The DPU consists of the digital circuits for storing, translation and distribution of the information .It has the relays to initiate the auxiliarycommands. The interpolator has the DDA units and additional digital circuits.

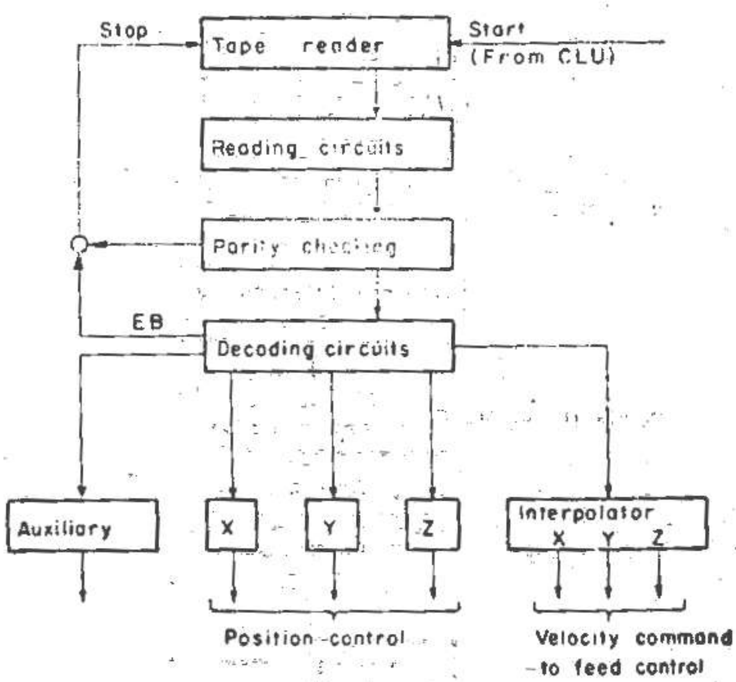


Fig 5.3 Block diagram of a Data processing unit

Data reading:

The tape readers are classified as the mechanical readers and the photoelectric readers. The operation of the mechanical reader senses the pins that make or break the electrical contacts by the presence or absence of the tape holes. The photoelectric reader has determines the presence or absence of the holes based on light sensing.The photoelectric reader can read 300 to 600 characters per second.

The reading circuit:

The reading circuit

1. Supplies the actuating control signals to start or stop the tape reader
2. Stores the read data temporarily
3. Provides a parity check for each character.
4. Identifies the End of Character and the minus sign.

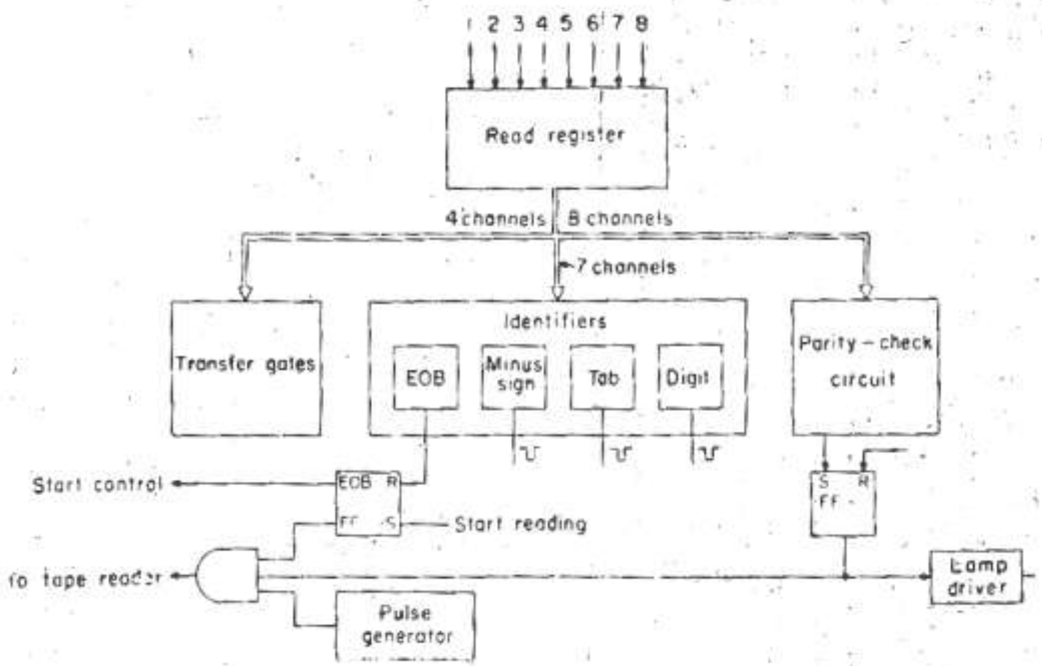


Fig 5.4 Tape reading circuit

Each character is read from a row on the punched tape and is temporarily stored in the read register. To avoid the possibility of errors in the punched code or in the reading of the tape, EIA code makes each character code combination to have odd number of holes.

Whenever a parity error is detected the machine and the reading process are stopped and the parity light is illuminated. Whena End of Block character is read, it is identified and stops the reading process and halts the pulse generator. At the same time a start control is sent to the CLU which begins to perform the instructions. The identifier is a combinational circuit that identifies the digits, Tab and the Minus sign based on conditions in the tape format.

The tape format is an agreed order in which the various types of words will appear within the block. The purpose of the words are identified based on the tape format and the data is distributed to the appropriate locations using the digital circuits that are designed to do it. The data is decoded and sent to the CLU.

Contouring system are equipped with an interpolator. The interpolators in a N/C systems are of three types, linear, circular and parabolic.

5.5 Part Programming of N/C systems

Part programming for N/C production includes all data required to produce the part, the calculations of the tool path along which the machine operations will be performed, the arrangement of the given and calculated data in the standard format, which should be converted into an acceptable form for a particular MCU.

The necessary data for producing a part are

1. Data directly taken from the drawing:
   i. Dimensions like length, width height, radius etc.
   ii. Segment shape: Linear ,circular or parabolic
   iii. Diameters of holes to be drilled.

iv. The tool path can be calculated from these information.

2. Data established according to surface quality, required tolerance, type of work piece and cutting tools: Feeds, cutting speeds and auxiliary functions like turn ON or OFF the coolant.
3. Data determined by the programmer such as direction of cutting a circle, toolchange. etc..
4. The part programmer must establish the optimal sequence of operations which are required to produce a part. He must be familiar with the N/C processes and the characteristics of that particular N/C systems. Information depends on the particular N/C system and is varied with any MCU and CLU combinations.

All data fed to the N/C system is in the form that can be read and processed by the DPU .The punched tape is used as the control medium .

The two types of data processing techniques employed to produce the punched tape are

1. Manual

In manual programming the data required for machining a part is written in a standard format on a manuscript.The manuscript is a planning chart or list of instructions which describe the operations to produce the part. The manuscript is typed using a flexowriter .and the punched tape is produced.

2. Computer assisted preparation of the tape

The computer allows the programming of the tool cutter path of complexparts that could not be manually programmed. The computer performs mathematical calculations quickly and accurately. They are also reliable. The computer languages were developed and APT (Automatic ProgrammedTools) system is a comprehensive language for part programming. Thelanguage has English like words and mathematical notations and is simple to use. Computations that

Each N/C system and machine tool combination has a post processer program that will receive the APT output as an input and makes additional computations that are necessary to ensure that the specific machine tool/control unit combination will produce the part of the prescribed tolerance, at the desired feed rate, etc. The post processor generates as output either the control tape or information that can be translated on a punched tape by using a standard equipment.

5.5 .1 Post Processor

The post processor is an additional computer program which accepts as input the partially and generally processed data and generates as output either the control punched tape for a particular machine tool/control unit combination or information suitable for preparing the tape.

The post processor output must be able to produce a part in the specified tolerance, at programmed feed s and control dynamic effects as overshoot or undershoot. The post processor has to take into account the dynamic and geometric constraints of the machine tool.

There is an individual post processor for each type of machine tool/control unit combination. Any number of post processor programs can be associated with a single part programming APT system.

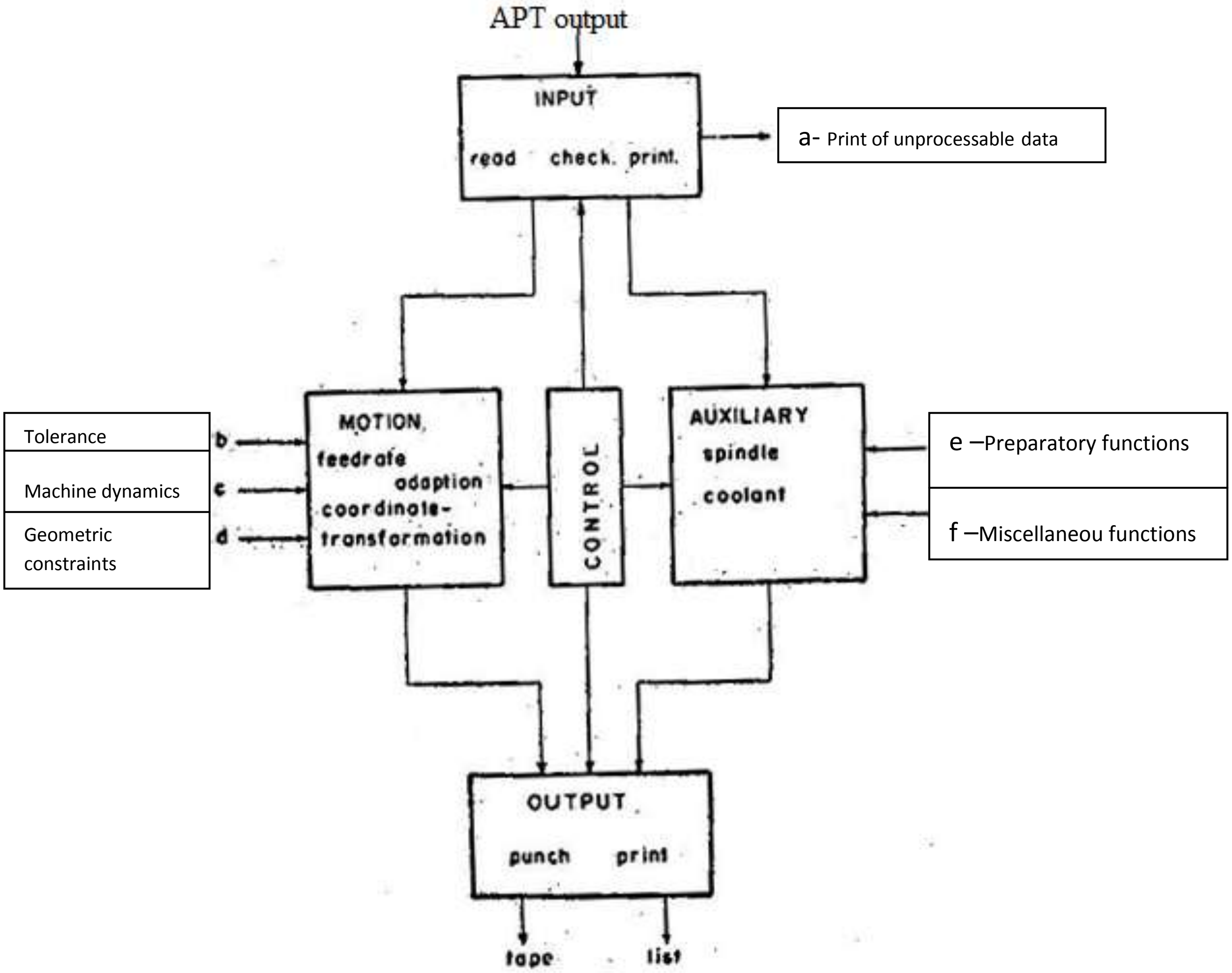


Fig 5.5 Post processor elements

The post processor elements are the input, motion, auxiliary, output and control.

1 .The input element reads the information which is the APT output. Reading may be performed directly with punched cards, punched tape or the magnetic tape.

2. The motion element performs all the instructions concerned with the tool movement. The motion element includes two functions denoted as the dynamic and geometric portion of the package.

3. The auxiliary element is fed by the preparatory and miscellaneous functions that can be performed by the machine tool /control unit combination and accepts from the input element all data concerning these functions.

4. The output element receives the output data from the motion and auxiliary elements. The data is converted into the format acceptable by the MCU.

5. The control element generates the timing of the post processor and adapts all elements and permits program flow. It also controls the flow of data to the external output.

5.5.2 Programming systems

The part programming systems for the N/C systems are

1. ADAPT -Adaptation of APT
2. EXAPT -EXtended subset of APT
3. AUTOSPOT –AUTOmatic System POsitioning Tools
4. AUTOPROMPT
5. SPLIT

5.6 Basic Concepts of CNC, DNC and AC systems

5.6.1 CNC-Computer Numeric Control

The EIA definition of computer numerical control (CNC): A numerical control system wherein a dedicated, stored program computer is used to perform some or all of the basic numerical control functions in accordance with control programs stored in the read-write memory of the computer

It consists of a Machine Control Unit (MCU) and machine tool itself. MCU is a computer and is the brain of a CNC machine. It reads the part programs and controls the machine tools operations. Then it decodes the part program to provide commands and instructions to the various control loops of the machine axes of motion.

CNC part program contains a combination of machine tool code and machine-specific instructions. It consists of

(a) Information about part geometry

(b) Motion statements to move the cutting tool

(c) Cutting speed and (d) Feed

(e) Auxiliary functions such as coolant on and off, spindle direction

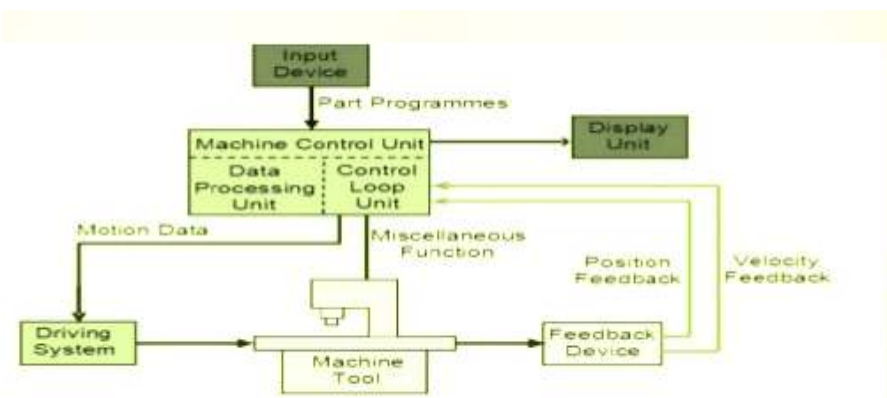


Fig 5.6 Block diagram of a CNC system

5.6.2 DNC –Direct Numeric Control

The DNC system operates the N/C systems in time shared mode.

The EIA definition of DNC:A system connecting a set of numerically controlled machines to a common memory for part program or machine program storage with provision for on-demand distribution of data to machines.

It consists of a central computer to which a group of CNC machine tools are connected via a communication network. The communication is usually carried out using a standard protocol such as TCP/IP or MAP. DNC system can be centrally monitored which is helpful when dealing with different operators, in different shifts, working on different machines.

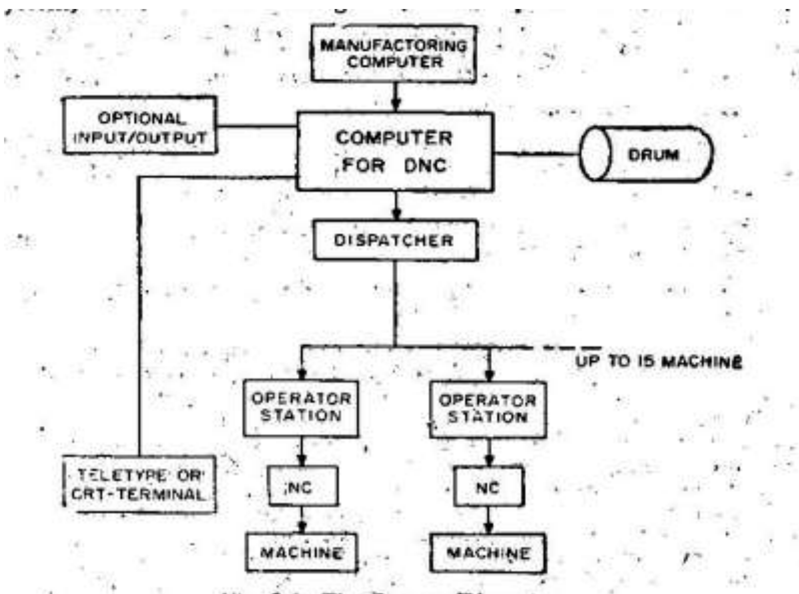


Fig 5.7 Block diagram of a DNC system

A common drawback of the CNC systems is that their machining control variables, such as speeds or feed rates, arc prescribed by a part programmer and consequently depend on his or her experience and knowledge

5.6.3 Adaptive Control

The availability of a dedicated computer in the control system and the need for higher productivity has greatly accelerated the development of adaptive control (AC) systems for metal cutting. These systems are based on real-time control of the cutting variables with reference to measurements of the machining process state-variables. The adaptive control is basically a feedback system that treats the CNC as an internal unit and in which the machining variables automatically adapt themselves to the actual conditions of the machining process.

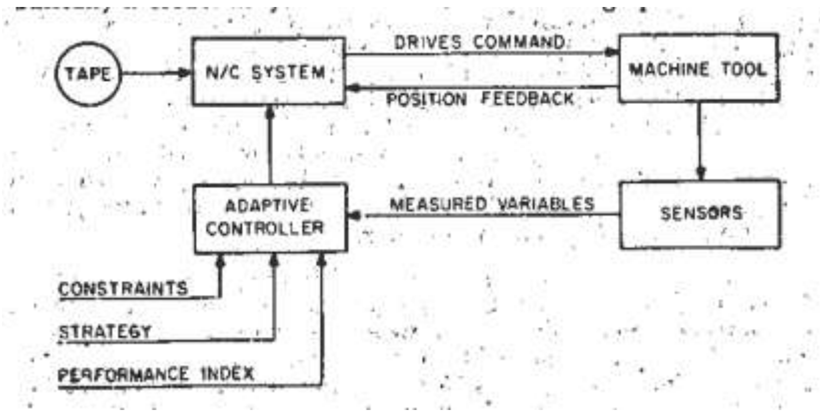


Fig 5.8 Adaptive control

AC systems for machine tools can be classified into two types

(1) Adaptive control with optimization (ACO),

(2) Adaptive control with constraints (ACC),

ACO refers to systems in which a given performance index (usually an economic function) is optimized subject to process and system constraints.

With ACC, the machining variables are maximized within the region bounded by theprocess and system constraints, such as maximum force or power. ACC systems do not utilize a performance index and are based on maximizing a machining variable (e.g., feed rate) subject to process and machine constraints (e.g., allowable cutting force on the tool, or maximum power of the machine).

5.6.4 Adaptive Control with Optimization

The block diagram of the Bendix system is shown. The system consists of a milling machine, NC controller, sensors unit and adaptive controller. The sensors measure the cutting torque, tool temperature, and machine vibration. These measurements are used by the adaptive controller to obtain the optimal feed rate and spindle speed values.

The adaptive controller contains a data reduction subsystem (DRS) fed by the sensor measurements as well as by the calculated feed rate and spindle speed and a set of constraints. The DRS produces two signals: a metal removal rate (MMR) and a tool wear rate (TWR).

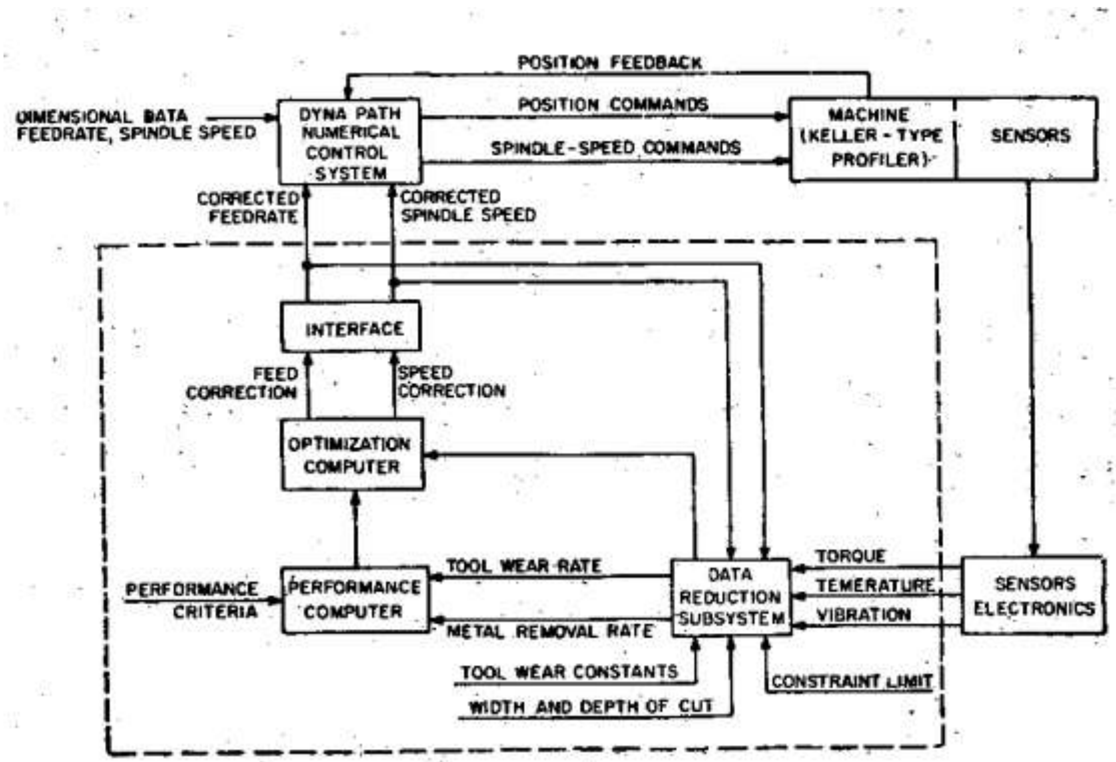


Fig 5.9 Adaptive Control with Optimization

The user needs to perform off-line experiments to determine the values of these constants for every combination of tool and work piece material. The time and effort needed for these experiments may override the economic benefits of the ACO system.

5.6.5 Adaptive Control with Constraints

The objective of ACC type of system is to increase the MRR (Metal Removal Rate) during rough cutting operations. This is achieved by maximizing one or more machining variables within a prescribed region bounded by process and system constraints. One example, is to maximize the machining feed rate while maintaining a constant load on the cutter, despite variations in width and depth of cut.

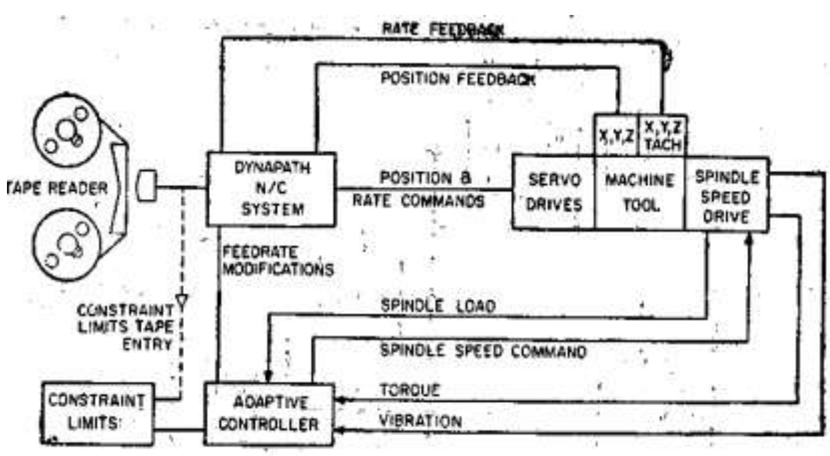


Fig 5.10 Adaptive control with constraints

With the ACC system, the maximum allowable load (e.g., cutting force) on the cutter is programmed. As a result, when the width or depth of cut are small the feed rate is high; when either the width or depth of cut (or both) are increased, the feed rate is automatically reduced, and consequently the allowable load on the cutter is not exceeded. The result is, the average feed with ACC is much larger than a CNC system.

The ACC system guarantees maximum productivity while minimizing the probability of cutting tool breakage. The most commonly used constraints in ACC systems are the cutting force, the machining power, and the cutting torque.

5.7 A Typical CNC system

A typical CNC system for a three axis machine tool with adaptive control is shown in the diagram. It includes

1. The machine tool with DC servo motors as feed drives and resolvers as feedback devices. The transducer is added for adaptive control.

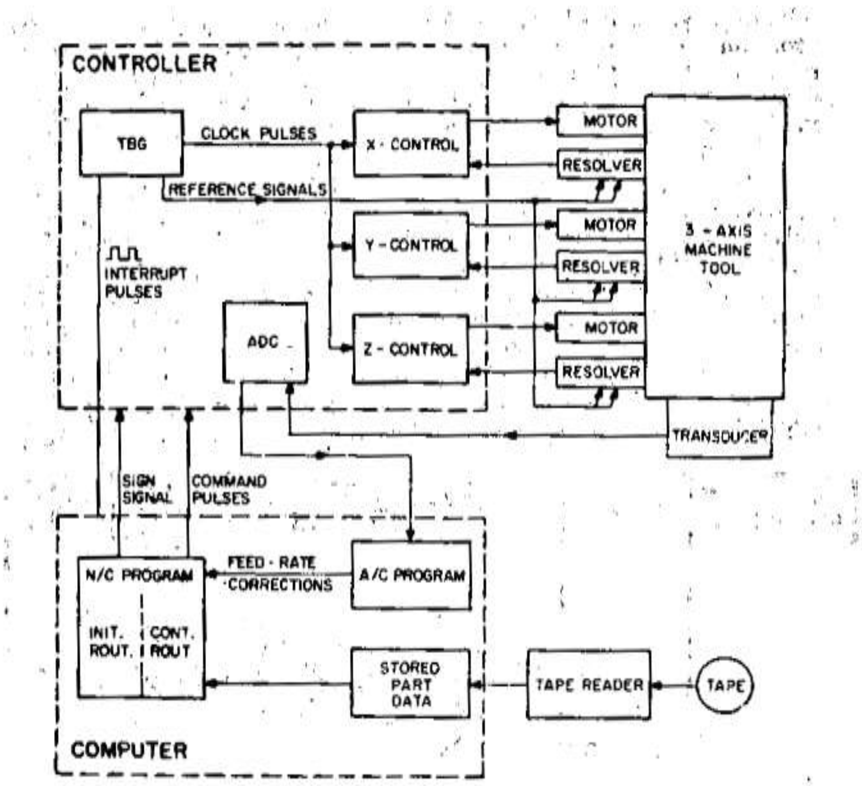


Fig **5.11 Block diagram of a typical CNC system**

2. The computer can control the machine drives through the auxiliary controller .It contains a TBG(Time Base Generator)and analog to digital converters. The TBG includes the main clock of the system, 2.5 KHz pulse generator. The three functions performed by the TBG are the direct feeding of the control loops, producing interrupt pulses and generating reference signals for the stators of the resolvers.

3. There is a computer for storing the data and performing the N/C and A/C programs. The interrupt system of the computer takes care on the running of both programs.

4. Tape reader reads the two programs and the N/C data.

The CNC system can be operated in both closed loop and open loop modes. The position control and velocity control are carried out in the closed loop mode. In open loop mode the axis control in N/C system is done using the stepper motors.

5.8 Comparison of NC and CNC systems.

A. Numeric Control System

1. Numerical control (NC) is a form of flexible (programmable) automation in which the process is controlled by numbers, letters, and symbols.
2. In a **n**umerical **c**ontrol machine, the program is fed to the machine through magnetic tapes or other such media.
3. The original NC machines are essentially basic machine tools which were modified to have motors for movement along the axes.
4. In a NC machine, for a variation in the output there is a change made in the program in the tape and then fed to the machine again

B. Computer Numeric Control

1. In a **c**omputer **n**umerical **c**ontrolled machine, the machines are interfaced with computers.
2. The CNC uses a dedicated microprocessor to perform the MCU function. This makes them more versatile, suppose a change in dimension of a part is required in a CNC machine, just change a variable in the computer program.
3. Subroutine macros can be stored in memory and called by the part-program to execute frequently-used cutting sequence.
4. Metric conversions, sophisticated interpolation functions (such as cubic interpolation) can be easily accomplished in CNC.
    a. Absolute or incremental positioning (the coordinate systems used in locating the tool relative to the work piece) as well as PTP or contouring mode can be selected.
    b. The part-program can be edited (correction or optimization of tool path, speeds, and feeds) at the machine site.
    c. Tool and fixture offsets can be computed and stored.
5. Tool path can be verified using graphic display
6. Diagnostics are available to assist maintenance and repair.

Model Questions

PART – A

1. Define CNC.

2. Mention the different units of numerical control system.

3. State the disadvantages of numerical control system.

4. Name the different types of driving devices.

5. Mention the different units in hydraulic system.

6. What is stepper motor?

7. Mention the names of programming systems.

8. State the types of data processing techniques.

9. List the different elements of post processor.

10. What is APT language?

11. Mention the types of AC system.

12. What are the advantages of CNC system?

13. What are the types of numerical control system?

PART – B

1. Draw the block diagram of basic concepts of numerical control system.

2. Explain DPU in NC system.

3. Explain CLU in NC system.

4. Mention the advantages and applications of NC system.

5. Draw the structure of hydraulic system.

6. What are the different types of stepper motor? Mention its applications.

7. Explain computer programming.

8. Draw the structure of post processor.

9. Draw the block diagram of SCO.

10. Compare NC and CNC.

11. Draw the block diagram of ACC.

12. Draw the block diagram of CNC.

PART – C

1. Explain the basic concepts of numerical control.

2. Draw and explain the block diagram of NC system in detail.

3. With diagrams explain hydraulic system.

4. With necessary diagrams explain the principle of operation of stepper motor.

5. Explain the steps for part programming.

6. Explain manual programming.

7. With diagram explain post processor system.

8. Briefly explain APT language.

9. Briefly explain the characteristics of numerical control system.

10. With block diagram explain CNC typical system.

11. With relevant diagram explain CNC programming.

12. With block diagram explain ACO.

13. With block diagram explain ACC.

14. With block diagram explain direct numerical control.