PNS SCHOOL OF ENGINEERING & TECHNOLOGY

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LECTURER'S NOTE

ON

POWER ELECTRONICS & PLC

(THEORY – 5)

FOR

5TH SEMESTER, ELECTRICAL ENGINEERING

(AS PER SCTE&VT SYLLABUS)

PREPARED BY

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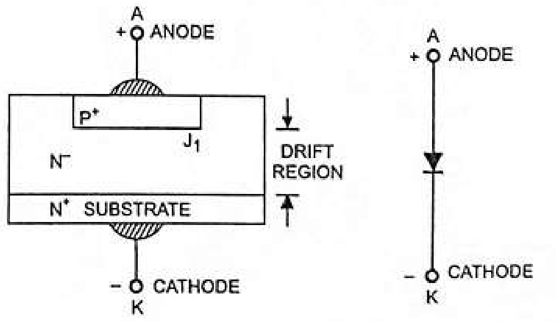
HOD ELECTRICAL

CHAPTER1: UNDERSTAND THE CONSTRUCTION AND WORKING OF POWER ELECTRONIC DEVICES.

POWER DIODE:

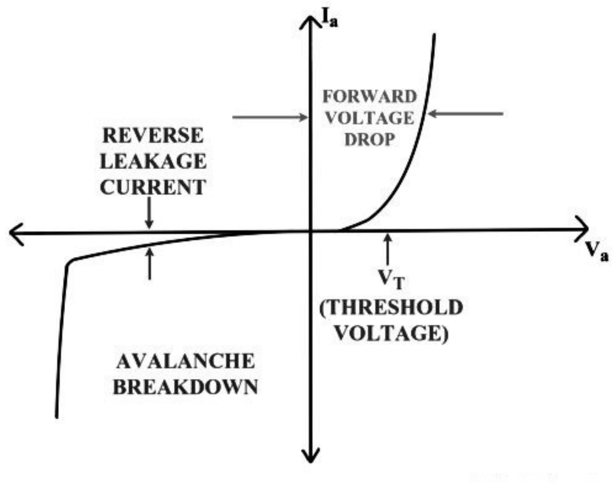
CONSTRUCTION:



Power diodes differ in structure from signal diodes. A signal diode constitutes a simple p-n junction. But a power diode constitutes a heavily doped n^+ substrate. On this substrate, a lightly doped n^- layer is epitaxially grown. Then a heavily doped p^+ layer is diffused into n^- layer to form the anode of power diode. So n^- layer is the basic structural feature not found in signal diode.

The function of n^- layer is to absorb the depletion layer of the reversed bias p^+-n^- junction J_1. The breakdown voltage needed as a power diode governs the thickness of n^- layer. The drawback of n^- layer is to add significant ohmic resistance to the diode when it is conducting a forward current. This leads to large power dissipation in the diode.

V-I CHARACTERISTICS OF POWER DIODE:



During forward bias from V_a = 0 to, V_T forward anode current is very small. Beyond Cut-in voltage or threshold voltage or turn-on voltage (V_T= 1V for power diode), anode current rises rapidly and the diode starts conducting. For signal diodes, the anode current increases first exponentially then linearly while in the case of power diode anode current rises linearly.

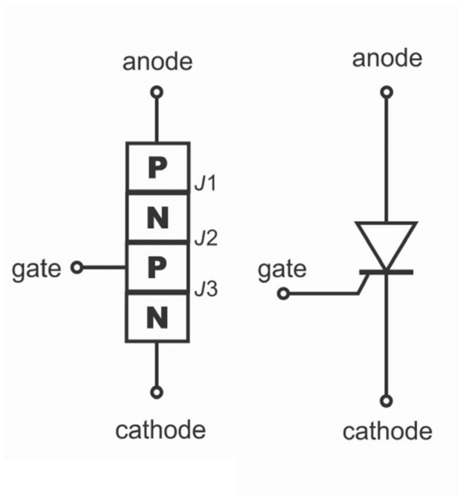
During reverse bias, small reverse anode current flow called leakage current up to breakdown voltage (V_{BR}). After V_{BR} reverse current increase abruptly. It may destroy the diode and must be avoided.

APPLICATION OF POWER DIODE:

Power Diode is used in Rectifiers Clipper Circuits, Clamping Circuits, Reverse Current Protection Circuits and In Logic Gates.

SCR:

CONSTRUCTION:



It is a four layered PNPN switching device, having three junctions J1, J2 & J_3. It has three terminals, named Anode (A), Cathode (K) and Gate (G). The anode and Cathode are connected to the main power circuit. The gate terminal carries a low level gate current in the direction of gate to cathode. The gate terminal is provided at the P layer near to cathode.

PRINCIPLE OF OPERATION:

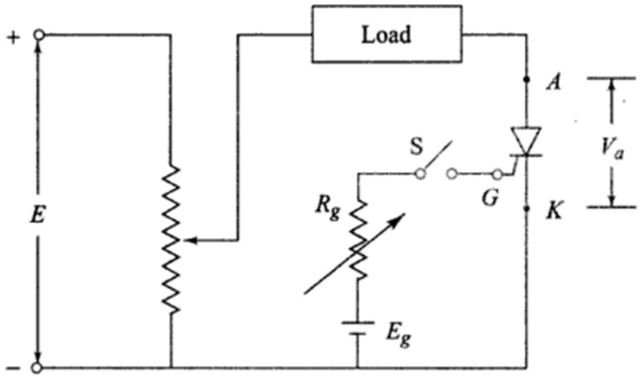
When anode is made positive with respect to Cathode, the outer two junctions J_1 and J_3 are forward bias but the middle junction J_2 becomes reversed bias. Thus the junction J_2 because of presence of depletion layer, does not allow any current to flow through the device but a very negligible leakage current flows through it. This condition is known as forwarding blocking state.

When the cathode is made positive with respect to anode, the junction J_2 becomes forward biased whereas the two junctions J_1 & J_3 become reversed bias. So junctions J_1 and J_3 do not allow the flow of current except the leakage current. This condition is known as reverse Blocking state.

In forward blocking state junction J_2 is reverse bias. But if we gradually increase the Anode - Cathode voltage, the depletion layer decreases. Then at a stage the depletion layer at junction J_2 vanishes and the junction J_2 breaks down. This phenomenon is known as Avalanche break down.

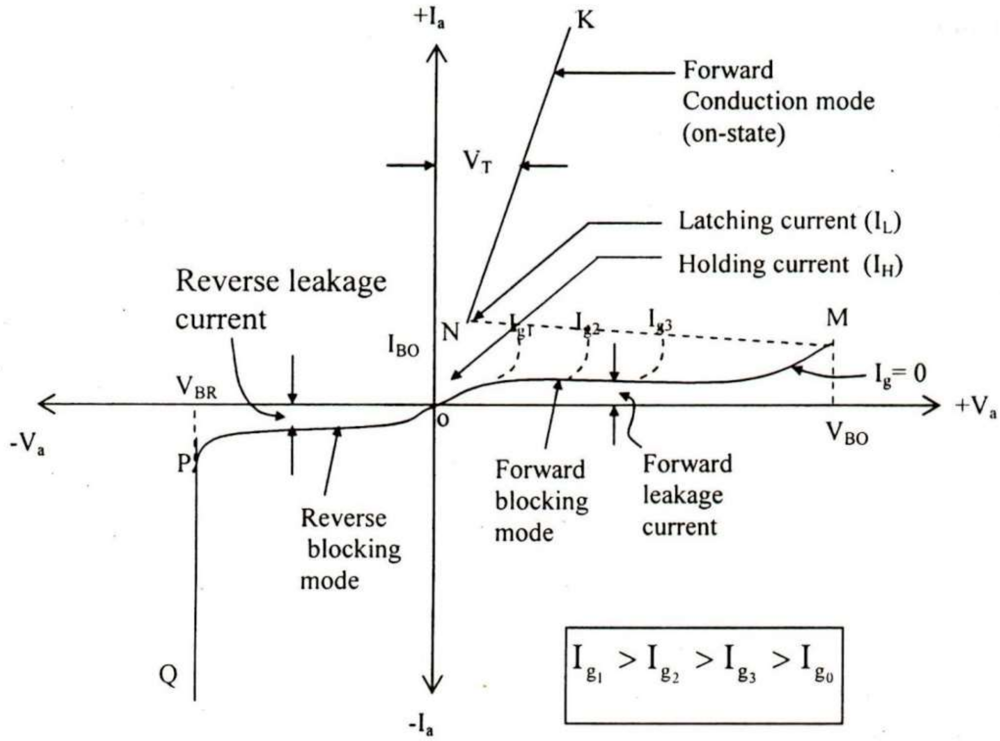
Since the two functions J_1 & J_3 are already forward biased, a large amount current starts to flow through the device. This condition is known as forward conducting mode.

STATIC V-I CHARACTERISTIC OF SCR:



REVERSE BLOCKING REGION:

When cathode is made positive with respect to anode with switch 'S' open, the SCR becomes reversed bias. In this condition junctions J_1 & J_3 are reversed bias and junction J_2 is forward biased. Therefore a small leakage Current flows in reverse direction. If the reverse voltage is increased, then at a critical breakdown level called reverse break down voltage (V_{BR}), an avalanche will occur at J_1 & J_3 increasing the current sharply in the direction of cathode to anode.



$I_{g_1} > I_{g_2} > I_{g_3} > I_{g_0}$

FORWARD BLOCKING REGION:

In this, anode is made positive with respect to cathode with switch 'S' open. Therefore junctions J_1 & $J_3$are forward bias and junction J_2 is reversed bias. Due to the reverse biasing of J_2, only small leakage current flows through the device. But the device does not conduct.

FORWARD CONDUCTION REGION:

When the anode to Cathode voltage is increased with switch 'S' open avalanche breakdown occurs at the junction J_2 at a critical break-over voltage (V_{BO}) and load current starts to flow through the device from anode to cathode. This means the SCR starts conducting.

When a gate signal is applied by closing the switch 'S', the SCR turns on before break-over voltage (V_{BO}). The forward voltage at which the device switches to conducting state depends upon the magnitude of gate current; higher the gate current, lower is the forward break-over voltage.

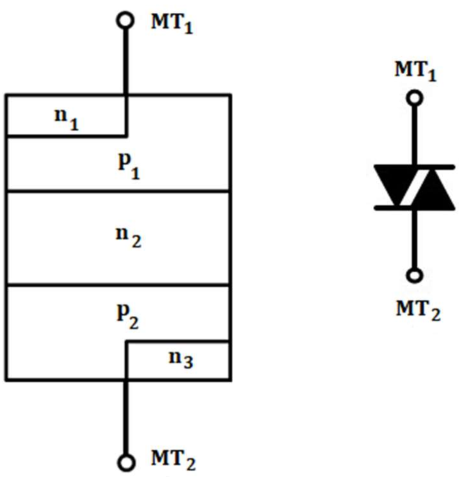
APPLICATION OF SCR:

Due to the wide variety of advantages, like ability to turn ON from OFF state in response to a low gate current and also able to switch high voltages, makes the SCR or thyristor to be used in a variety of applications.

These applications include switching, rectification, regulation, protection, etc. The SCRs are used for home appliance control include lighting, temperature control, fan speed regulation, heating, and alarm activation. For industrial applications, SCRs are used to control the motor speed, battery charging and power conversion

DIAC:

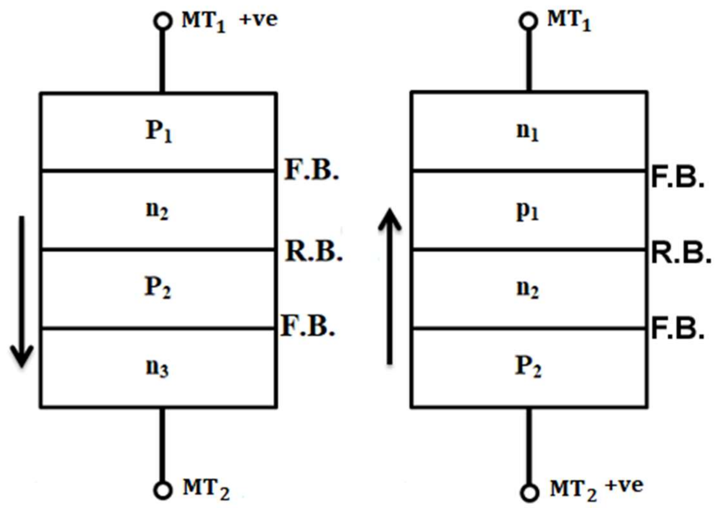
CONSTRUCTION:



It is a two terminal and five layer bidirectional semiconductor device. Five layers consist of three N layers and two P layers. The layers which are close to the terminals are made up of both N type and P type. The two terminals are named as MT_1 and MT_2. It stands for diode in 'ac'. It can be turned ON in both forward and negative direction.

WORKING OF DIAC:

When the terminal MT_1 is positive the direction of the flow of current will be in the order P_1-N_2-P_2-N_3. The junction between P_1 and N_2 is forward biased, the junction between N_2 and P_2 is reverse biased and the junction between P_2 and N_3 is forward biased.



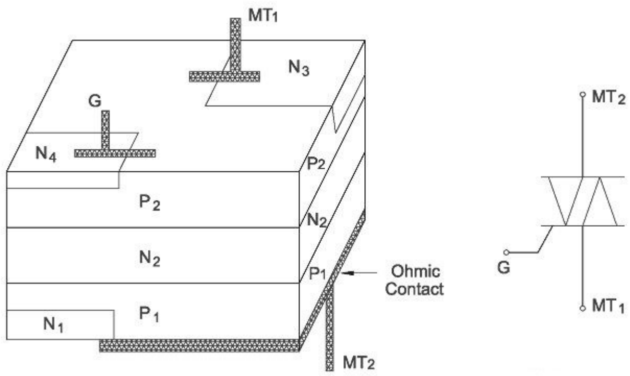
When the terminal MT_2 is positive the direction of the flow of current will be in the order N_1-P_1-N_2-P_2. The junction between N_1 and P_1 is forward biased, the junction between P_1 and N_2 is reverse biased and the junction between N_2 and P_2 is forward biased.

APPLICATION OF DIAC:

The main application of a DIAC is its use in a TRIAC triggering circuit. The DIAC is connected to the gate terminal of the TRIAC. When the voltage across the gate decreases below a predetermined value, the gate voltage will be zero and hence the TRIAC will be turned off. Some other applications of a DIAC include: It can be used in the lamp dimmer circuit, heat control circuit and speed control of a universal motor.

TRIAC:

CONSTRUCTION:

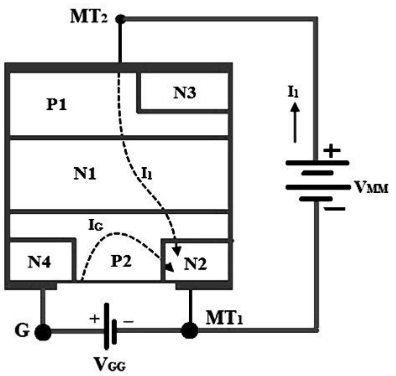


TRIAC is a four layer, six doped region and a three terminal device. Gate terminal is connected to both N_3 and P_2 so that gate triggers the device when both positive and negative voltage is applied. In the Same way MT_1 is also connected to N_2 and P_2 regions and MT_2 is connected to the P_1 and N_4 regions. So the polarity between the terminals decides the direction of the current through the layers.

WORKING OF TRIAC:

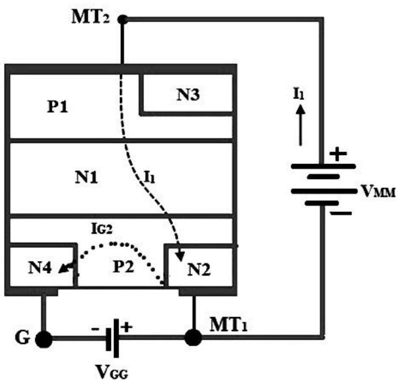
There are four possible combinations of the potentials applied to the terminals.

MODE1: MT_2 IS POSITIVE AND GATE TERMINAL IS POSITIVE:



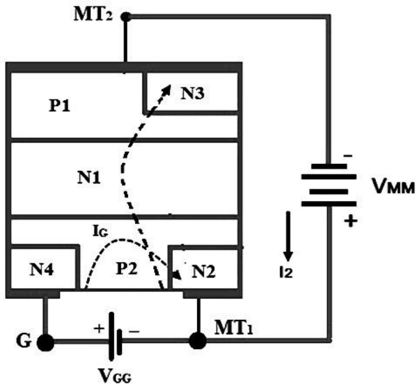
When the MT_2 terminal is made positive with respect to the terminal MT_1 and when positive voltage is applied at the gate terminal the path of the current flow from MT_2 to MT_1 will be P_1-N_1-P_2-N_2. The junction between P_1N_1 and P_2N_2 are forward biased and junction between N_1P_2 is reverse biased and breakdown occurs at this junction.

MODE2: MT_2 IS POSITIVE AND GATE TERMINAL IS NEGATIVE:



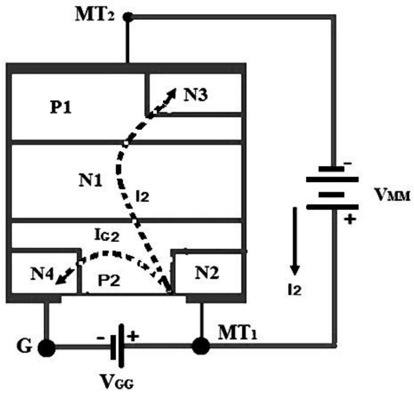
When the MT_2 terminal is made positive with respect to the terminal MT_1 and when negative voltage is applied at the gate terminal, initially the path of the current flow from MT_2 to MT_1 will be P_1-N_1-P_2-N_3. When the voltage applied at the MT_2 terminal is further increased the junction P_2N_2 is forward biased and the path of the current flow will be P_1-N_1-P_2-N_2. More Gate current is needed to turn the TRIAC.

MODE3: MT_2 IS NEGATIVE AND GATE TERMINAL IS POSITIVE:



When the MT_2 terminal is made positive with respect to the terminal MT_1 and when negative voltage is applied at the gate terminal the path of the current flow from MT_2 to MT_1 will be $P_2N_1P_1$. The Junctions P_2N_1 and P_1N_4 are forward biased and the junction N_1P_1 is reverse biased. So in this mode, TRIAC work in a negative biased region.

MODE4: MT_2 IS NEGATIVE AND GATE TERMINAL IS NEGATIVE:

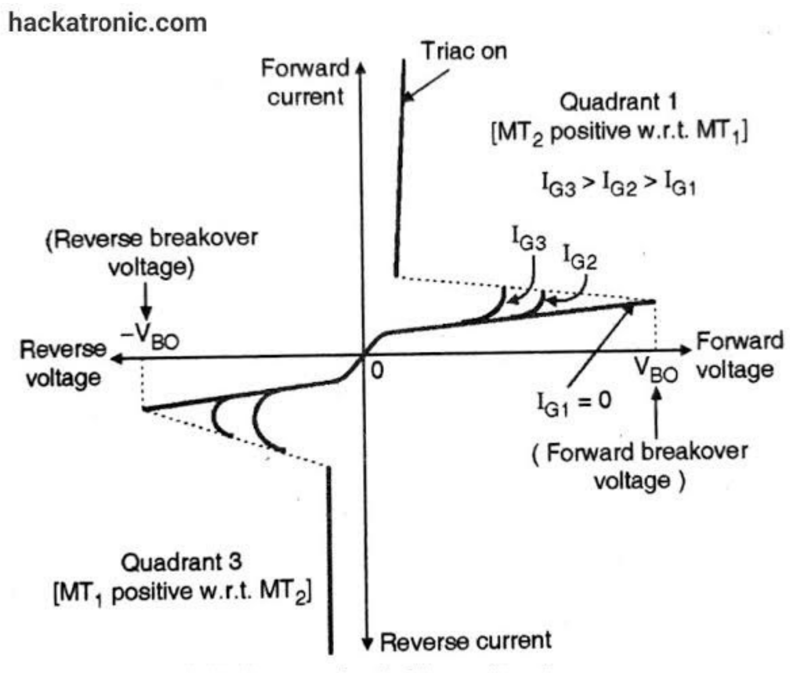


When the MT_2 terminal is made negative with respect to the terminal MT_1 and when negative voltage is applied at the gate terminal the path of the current flow from MT_2 to MT_1 will be $P_2N_1P_1N_4$.

V-I CHARACTERISTICS OF TRIAC:

The TRIAC function like a two SCRs connected in anti-parallel and hence the V-I characteristics of TRIAC in the 1st and 3rd quadrants will be similar to the V-I characteristics of a SCRs. When the terminal MT_2 is positive with respect to MT_1 terminal, the TRIAC is said to be in forward blocking mode.

A small leakage current flows through the device provided that voltage across the device is lower than the break over voltage. Once the break over voltage of the device is reached, then the TRIAC turns ON as shown in below figure.



However, it is also possible to turn ON the TRIAC below the V_{BO} by applying a gate pulse in such that the current through the device should be more than the latching current of the TRIAC.

Similarly, when the terminal MT_2 is made negative with respect to MT_1, the TRIAC is in reverse blocking mode. A small leakage current flows through the device until it is triggered by break over voltage or gate triggering method. Hence the positive or negative pulse to the gate triggers the TRIAC in both directions.

The supply voltage at which the TRIAC starts conducting depends on the gate current. If the gate is current is being greater, lesser will be the supply voltage at which the TRIAC is turned ON. Above discussed mode -1 triggering is used in the first quadrant whereas mode-3 triggering is used in 3rd quadrant.

Due to the internal structure of the TRIAC, the actual values of latching current, gate trigger current and holding current may be slightly different in different operating modes. Therefore, the ratings of the TRIACs considerably lower than the SCRs.

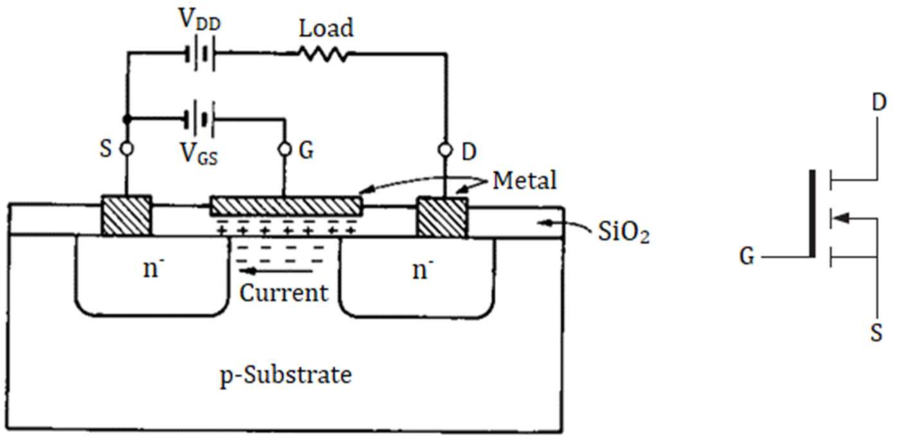
APPLICATION OF TRIAC:

TRIACs are used in numerous applications such as light dimmers, speed controls for electric fans and other electric motors and in the modern computerized control circuits of numerous household small and major appliances. They can be used both into AC and DC circuits however the original design was to replace the utilization of two SCRs in AC circuits.

POWER MOSFET (METAL OXIDE SEMICONDUCTOR FIELD EFFECT TRANSISTOR):

CONSTRUCTION:

A Power MOSFET has three terminals called Drain (D), Source (S) and Gate (G). It is a voltage control device. Its operation depends upon the flow of majority carriers only, so MOSFET is a unipolar device. It is of two types; N-charnel enhancement MOSFET and P-channel enhancement MOSFET. Out of these two types, N channel MOSFET is more common of because of higher mobility electrons. In the circuit of symbol of Power MOSFET, the arrow indicates the direction of electron flow.



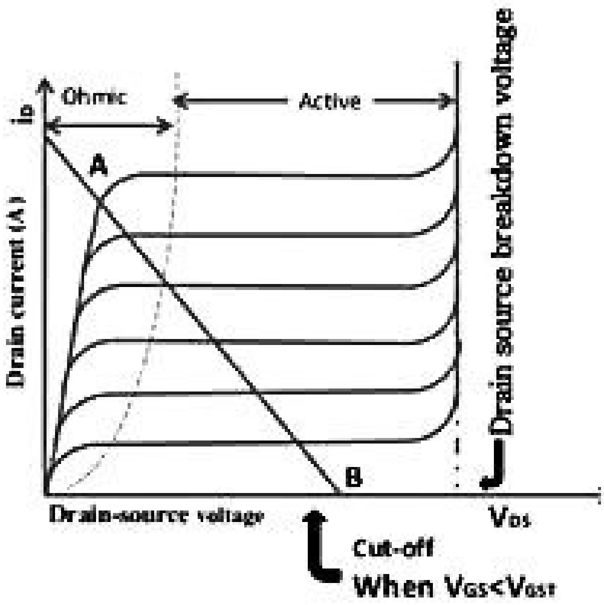
N-Channel Power MOSFET Consists of a p-substrates known as body. On p substrate two heavily doped n^+ regions are diffused. An isolating layer of silicon dioxide (SiO_2) is grown on the surface. Now this insulating layer is etched in order to embed metallic Source and Drain terminal. Note that n^+ regions make contact with Source and Drain terminal. A layer of metal is also deposited on SiO_2 layer so as to form gate of MOSFET in between Source and Drain Terminal.

When gate circuit is open, junction between n^+ regions below Drain and p substrate is reverse biased by input voltage V_{DD}. Therefore no current flows from Drain to Source and load. When gate is made positive with respect to Source, an electric field is established. Eventually, induced negative charges in the p substrate below SiO_2 layer are formed thus causing the p layer below gate to become an induced n layer. These negative charges, called electrons, form n channel between n^+ regions and current can flow from Drain to Source. If V_{GS} is made more positive, induced n-channel becomes deeper and therefore more current flows from Drain to Source. This shows that gate voltage V_{GS} enhances the drain current I_D, hence the name enhancement MOSFET.

V-I OR OUTPUT CHARACTERISTICS:

Power MOSFET output characteristics indicate the variation of drain current I_D as a function of drain-source voltage V_{DS}, with gate-source voltage V_{GS} as a parameter. For low values of V_{DS}, the graph between I_{DS}-V_{DS} is almost linear; this indicates a constant value of on-resistance $R_{DS} = \frac{V_{DS}}{I_D}$.

For given V_{GS}, if V_{DS} is increased, output characteristic is relatively flat indicating that drain current is nearly constant.



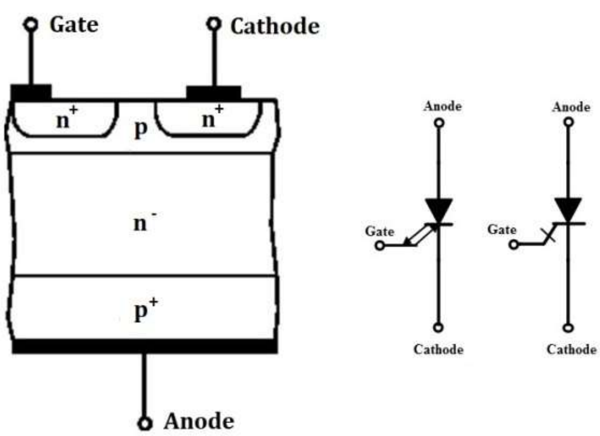
A load line intersects the output characteristics at A and B. Here A indicates fully-on condition and B fully-off state. Power MOSFET operates as a switch either at A or at B.

APPLICATIONS OF MOSFET:

MOSFET amplifiers are extensively used in radio frequency applications. It acts as a passive element like resistor, capacitor and inductor. DC motors can be regulated by power MOSFETs. High switching speed of MOSFETs makes it an ideal choice in designing chopper circuits.

GTO (GATE TURN-OFF THYRISTOR):

CONSTRUCTION:



It includes 3-junctions and 4 PNPN layers. A GTO is a three-terminal PNPN device like anode, cathode, and gate. In this kind of thyristor, the anode terminal is composed of a p^+ layer through n^+ type fingers diffused within it.

The n^+ layer of this thyristor is doped highly to get high emitter efficiency and it provides a cathode terminal. Thus, the junction like J_3 breakdown voltage is low. The p^- layer doping level must be low to maintain excellent emitter efficiency. Similarly, to have a good switch OFF properties, the region doping must be high.

WORKING OF GTO:

When the positive gate current is applied to make the anode terminal positive to the cathode terminal, the electrons can be generated from the cathode terminal to the anode. So, this induces the hole-injection with the help of an anode terminal in the base region. These electrons as well as holes-injection continuous till the GTO enters into the conduction region.

In GTO, at first, the conduction begins through switch ON the region of cathode contiguous to the gate terminal. Thus, the remaining region comes into the conduction through plasma spreading. Not like a SCR, GTO includes narrow cathode elements which are interdigitated heavily through gate terminal, thus early turned ON region is extremely large & plasma spreading is little. Therefore, the GTO comes into the conduction region very fast.

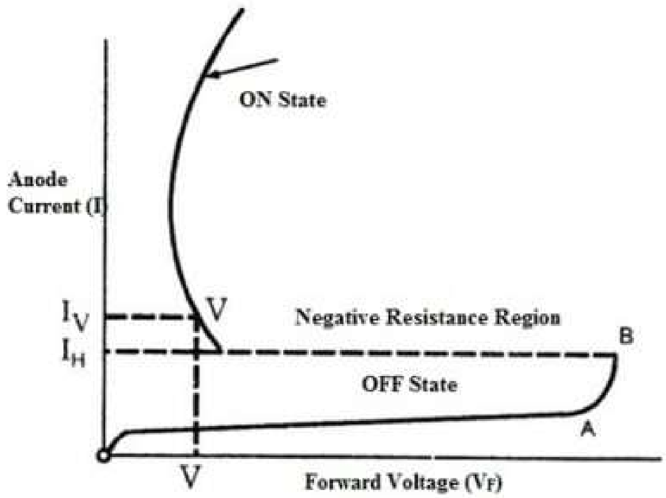
At the gate terminal, a reverse bias can be applied to switch OFF the GTO by making the gate terminal negative as compared with the cathode. In the $^{p-}$ layer, a fraction of the holes can be extracted using the gate terminal to hold back the electrons injection from the cathode terminal.

In reply to this, an extra hole current can be removed by the gate terminal which results in more control of electrons from the cathode terminal. Finally across the p-base junction, the voltage drop can cause reverse bias in the cathode junction of the gate & therefore the GTO will be deactivated.

Throughout the process of hole extraction, the area of the p^- base is slowly exhausted so that the conduction region can be squeezed. As this procedure continues, the anode current supplies in remote areas by forming filaments with high current density. So, this can cause limited hot spots which can damage the device if not these filaments are extinguished rapidly.

During the high negative gate voltage application, these filaments are extinguished quickly. Because of the stored charge in the N base region, the anode terminal to gate current flows continuously although the cathode current is stopped. So, this is known as a tail current which decomposes exponentially when the surplus charge carriers are decreased through the recombination procedure. When the tail current level is decreased to a leakage current level, then the device keeps the characteristics of forwarding blocking.

V-I CHARACTERISTICS OF GTO:



In the first mode like forwarding blocking, the voltage is applied across the GTOwithout applying the +ve gate signal. Therefore, it does not conduct in this mode. But, there is a little leakage current which is very much higher as compared to a SCR's leakage current. Actually, in this mode, the GTO works like a transistor with high voltage & low gain which means, the anode current is low. In this mode, the GTO simply blocks the rated forward voltage when the gate terminal is biased negatively to the cathode.

When a positive gate signal is given with appropriate amplitude to the GTO, then it moves into the mode of forwarding conduction. Similarly, whenever a reverse voltage is applied to the GTO, then it blocks the reverse voltage up to a limit but as soon as the reverse voltage reaches a critical value, called the reverse break over-voltage, the GTO starts conducting in the reverse direction.

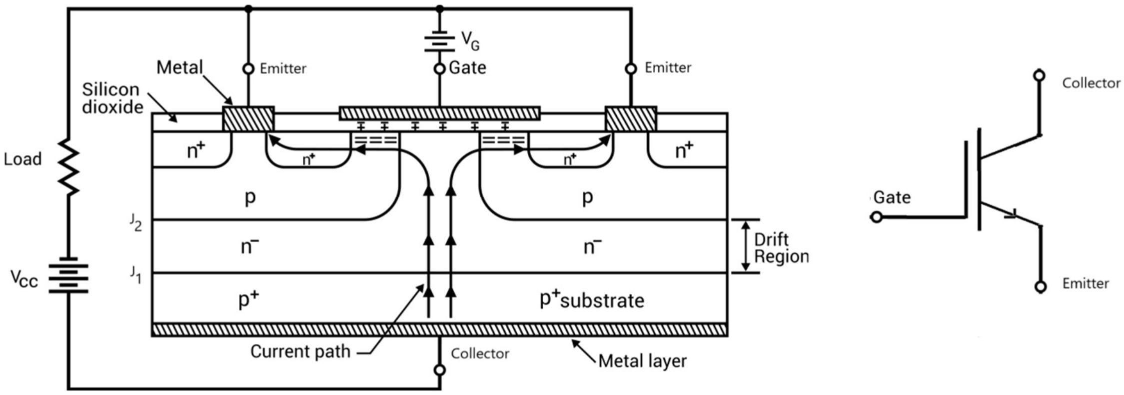
This mode of operation does not destroy the device if the gate is negatively biased and the time of this operation is small. In reverse biased condition, the blocking capacity mainly depends on the GTO type. A symmetric type includes a high reverse blocking capability whereas an asymmetric type includes a small reverse blocking capacity that ranges from 20-30 V.

APPLICATION OF GTO:

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.

IGBT (INSULATED GATE BIPOLAR TRANSISTOR):

CONSTRUCTION:



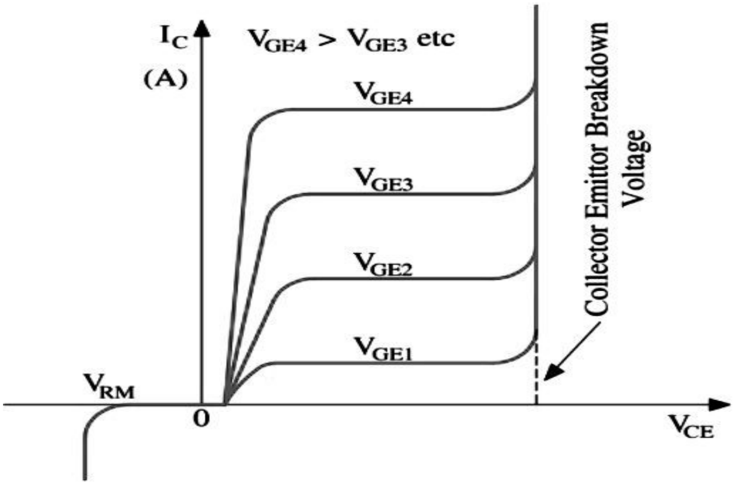
IGBT is a three terminal Semiconductor device, named Collector (C), Emitter (E) and Gate (G). It has a p^+ substrate on which a layer of n^- region is grown. The p^+ substrate is called injection layer because it injects holes in to n^- layer. The n^- layer is called drift region because n^- layer determines the voltage blocking capability of IGBT. The p layer is called the body of the IGBT in which n^+ region is diffused as shown in the figure. An insulating layer of silicon dioxide (SiO_2) is grown on the surface. This insulating layer is etched to embed metallic Emitter terminal. Some metals are also deposited at the middle of the insulating layer surface to form Gate terminal. Another layer of metal is deposited below p^+ substrate to house Collector terminal.

When Collector is made positive with respect Emitter, IGBT gets forward biased with no voltage between Gate and Emitter, two junctions between n^- region and p region (Junction J_2) are reversed bias, So no current flows from Collector to Emitter.

When Gate is made positive with respect to Emitter by voltage V_G, with Gate–Emitter voltage more than the threshold voltage V_{GET} of IGBT, an n channel is formed in the upper part of p region just beneath the gate. This n-channel short circuits the n^- region with n^+ regions. Electrons from n^+ emitter region begin to flow to n^- drift region through n-channel. As IGBT is forward biased with Collector positive and Emitter negative, p^+ Collector region injects holes into n^- drift region. So n^-drift region is flooded with electrons from p body regions and holes from p^+ Collector regions. With this, the injection carrier density in n^- drift region increases considerably and as a result, conductivity of n^- regions enhances significantly. Therefore, IGBT gets turned on and begins to conduct forward current I_C.

V-I OR OUTPUT CHARACTERISTICS OF IGBT:

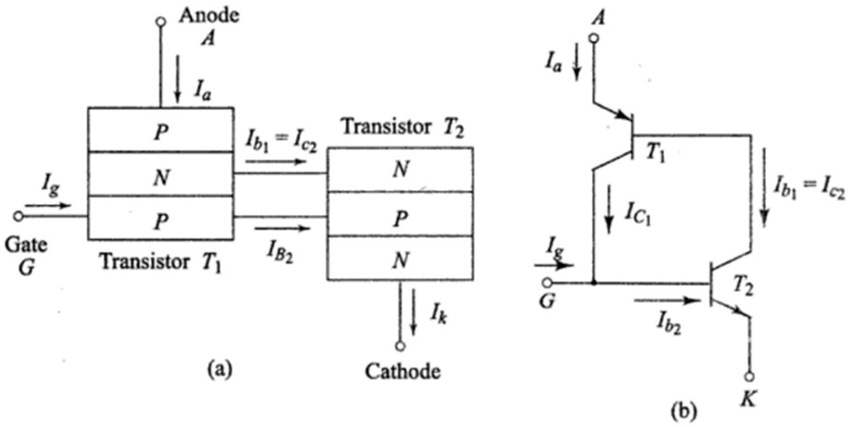
IGBT output characteristic show the plot of collector current I_C versus collector-emitter voltage V_{CE} for various values of gate-emitter voltages V_{GE1}, V_{GE2} etc. In the forward direction, the shape of the output characteristics is similar to that of BJT. But here the controlling parameter is gate-emitter voltage V_{GE} because IGBT is a voltage-controlled device. When the device is OFF, junction J_2 blocks forward voltage and in case reverse voltage appears across collector and emitter junction J_1 blocks it.



APPLICATION OF IGBT:

IGBTs are used in various applications such as AC and DC motor drives, Unregulated Power Supply (UPS), Switch Mode Power Supplies (SMPS), traction motor control and induction heating, inverters, used to combine an isolated-gate FET for the control input and a bipolar power transistor as a switch in a single device, etc.

TWO TRANSISTOR ANALOGY OF SCR:



The operation of SCR can be explained by considering it in terms of two transistors. This is known as the two transistor analogy of SCR. The SCR can be considered as an NPN and PNP transistor, where the collector of one transistor is attached to the base of the other and vice versa. This model is obtained by splitting the two middle layers of the SCR into two separate parts.

From the figure:

$I_{c1} = I_{b2}$ and $I_{b1} = I_{c2}$

Also $I_k = I_a + I_g$ ....(1)

From Transistor analysis:

$I_{b1} = I_{e1} - I_{c1}$ ....(2)

Also $I_{c1} = \alpha_1 I_{e1}$ ....(3)

From Equation (2) & (3):

$I_{b1} = I_{e1} - \alpha_1 I_{e1}$

or $I_{b1} = (1 - \alpha_1)I_{e1}$ ....(4)

From the figure it is seen that the anode current of the device is the emitter current of transistor T_1 and cathode current is the emitter current of transistor T_2.

So $I_{e1} = I_a$ and $I_{e2} = I_k$

Hence equation (4) implies

$I_{b1} = (1 - \alpha_1)I_a$ ....(5)

Again from Transistor analysis:

$I_{c2} = \alpha_2 I_{e2}$

or $I_{c2} = \alpha_2 I_k$ ....(6)

As $I_{b1} = I_{c2}$

or $I_{b1} = \alpha_2 I_k$

Equation (5) & (6) implies

or $\alpha_2 I_k = (1 - \alpha_1)I_a$ ....(7)

or $\alpha_2 I_k = I_a - \alpha_1 I_a$

Putting the value of Ik from equation (1)

or $\alpha_2(I_a + I_g) = (I_a - \alpha_1 I_a)$

or $\alpha_2 Ia + \alpha_2 I_g = I_a - \alpha_1 I_a$

or $\alpha_2 I_g = I_a - \alpha_1 I_a - \alpha_2 I_a$

or $\alpha_2 I_g = (1 - \alpha_1 - \alpha_2)I_a$

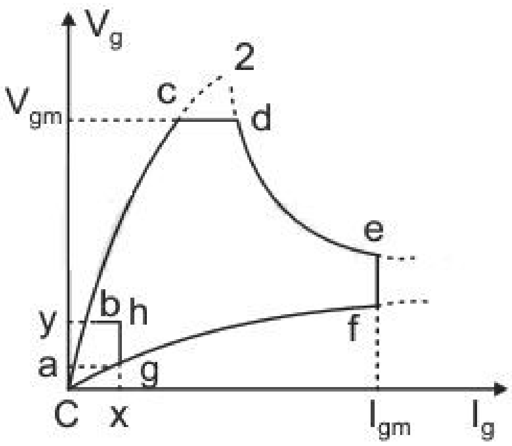
or $I_a = \dfrac{\alpha_2 I_g}{1 - \alpha_1 - \alpha_2}$

or $I_a = \dfrac{\alpha_2 I_g}{1 - (\alpha_1 + \alpha_2)}$ ....(8)

So from the above expression, it is seen that when the loop gain $\alpha_1 + \alpha_2$ approaches unity, the SCR will starts conducting. Also if we increase the gate Current, the SCR will conduct.

GATE CHARACTERISTIC OF SCR:

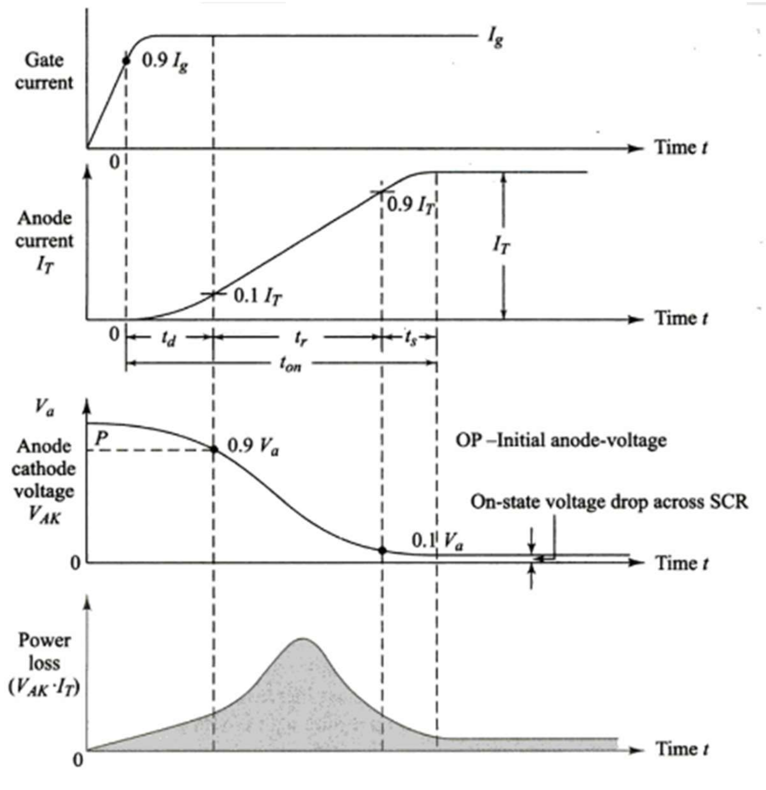
The gate characteristic of an SCR is the graph between gate voltage and gate current. Here the gate to cathode voltage V_g and gate to Cathode current Ig represent dc Value. Curve-1 represents the lowest voltage Values that must be applied to turn on the SCR. Curve-2 gives the highest possible voltage values that can be safely applied to gate circuit.



Each SCR has maximum limits as V_{gm} for gate voltage and I_{gm} for gate current. There is also rated average gate power dissipation P_{gav} specified for each SCR. These limits should not be exceeded in order to avoid permanent damage of junction J_3. There are also minimum limits for V_g and I_g for reliable turn-on, these are represented by 'oy' and 'ox' respectively. So the preferred gate drive area for an SCR is 'bcdefghb'.

SWITCHING CHARACTERISTIC OF SCR:

DURING TURN-ON:



An SCR is usually turned on by applying a positive gate voltage between gate and cathode. There is however, a transition time from forward off-state to forward on-state. This transition time is called SCR turn-on time. This can be divided into three intervals (i) Delay time, (ii) Rise time and (iii) spread time.

DELAY TIME (t_d):

The delay time t_d is the time interval between the instant at which the gate current reaches $0.9I_g$ and the instant at which anode current reaches $0.1I_a$. The delay time may also be defined as time during which anode voltage from V_a to 0.9 V_a.

RISE TIME (t_r):

The rise time t_r is the time taken by anode current to rise from $0.1I_a$ to $0.9I_a$. It may also be defined as the time duration in which the anode voltage decreases from $0.9V_a$ to $0.lV_a$.

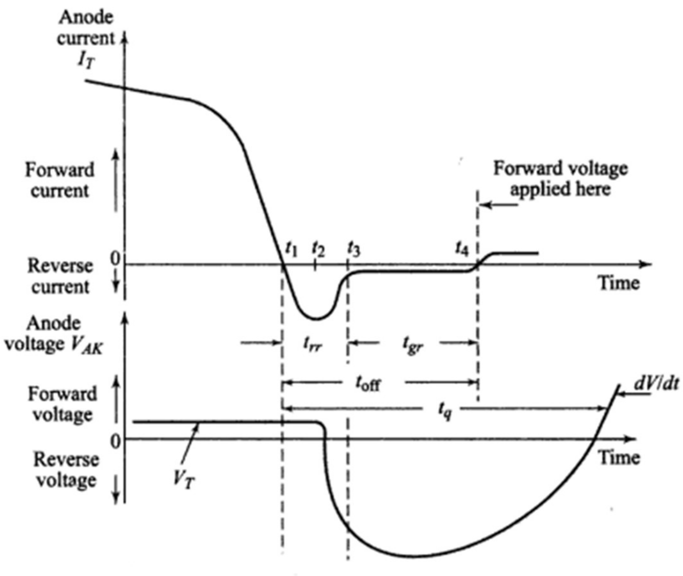
SPREAD TIME (t_p):

The spread time t_p is the time taken by the anode current to rise from $0.9I_a$ to I_a. It may be defined as the time period in which anode voltage decreases from $0.1V_a$ to on state voltage drops i.e. 1 to 1.5 volt. Note that total turn-on time of an SCR is equal to the sum of delay time, rise time and spread time.

DURING TURN-OFF:

SCR turn-off means that it has changed from on to off state and capable of blocking the forward voltage. This dynamic process of the SCR from conduction state to forward blocking state is called commutation or turn-off process.

Once the SCR is 'on', gate loses control. The SCR can be turned-off reducing the anode current below holding current. If forward voltage is applied to SCR at this moment its anode current is zero, the device will not be able to block this forward Voltage as the carriers (holes and electrons) in the four layers are still favorable for conduction. The SCR will therefore go into conduction immediately even though gate signal is not applied. In order to obviate such an occurrence, it is essential that the SCR should be reversed biase for a finite time after the anode current has reached zero.



The turn-off time t_q of an SCR is defined as the time between the instant anode current becomes zero and the instant SCR regains forward blocking capability. During turn-off time all the excess carriers from four layers of SCR must be removed. This removal of excess carriers consists of sweeping out of holes from outer P-layer and electrons from outer N-layer. The carriers around junction J_2 can be removed only by recombination. The turn-off time is divided into two intervals i.e. (i) reverse recovery time t_{rr} and (ii) gate recovery time t_{gr}.

At instant t_1, anode cement becomes Zero. After t_1 anode current builds up in the reverse direction. The reason for the reversal of anode current is due to the presence of carriers stored in the four layers. The reverse recovery current removes extra carriers from functions J_1 and J_3 between the instants t_1, and t_3. At instant t_3, when reverse recovery current has fallen to nearly zero, junctions J_1 and J_3 recover and SCR is able to block the reverse voltage.

But at this instant the SCR is not able to block the forward voltage as the junction J_2 has trapped charges. The trapped charges around J_2 can so not flow to the external circuit. Therefore, theses trapped charges must decay only by recombination. This recombination is possible if a reverse voltage is maintained across SCR. The rate of recombination of charges is independent of the external circuit parameters. The time for the recombination of charges between t_3 and t_4 is called gate recovery time. At instant t_4, junction J_2 is recovered and the SCR is capable of blocking forward voltage.

TURN-ON METHODS OF SCR (TRIGGERING METHOD):

FORWARD VOLTAGE TRIGGERING:

When anode to cathode forward voltage is increased with gate circuit open, the reversed bias junction J_2 will have an avalanche break down oat a voltage called forward break-over voltage V_{BO}. Then the SCR gets turned-on.

THERMAL TRIGGERING:

Like other semiconductor, the width as the depletion layer of an SCR decreases on increasing the junction temperature. Thus in an SCR when the applied forward voltage is near to its breakdown voltage, the device can be triggered by increasing its junction temperature. This method of triggering the device by heating is known as thermal triggering or temperature triggering.

LIGHT TRIGGERING:

For light triggering, a recess (or niche) is made in the inner P layer of the SCR. When this recess is irradiated, free charge carriers (pairs of holes & electrons) are generated just like when gate signal is applied between gate & cathode. The pulse of light of suitable wavelength is guided by optical fibers for irradiation. If the intensity of this light thrown on the recess exceeds a certain value, forward biased SCR is turned-on. Such an SCR is known as light activated SCR (LASCR).

$\frac{dV}{dt}$ TRIGGERING:

With forward voltage across the anode and cathode of an SCR, the two outer junctions J_1 and J_3 are forward biased, but inner junction J_2 is reversed bias. This reverse biased function J_2 has the characteristic of a capacitor due to charges existing across the junction. If forward voltage is suddenly applied, a charging current through junction capacitance C_J, may turn on the SCR. Charging current

$$I_C = \frac{dQ}{dt} = \frac{dC_J V_a}{dt} = C_J \frac{dV_a}{dt}$$

Therefore, if the rise of the forward voltage is high, the charging current I_C would be more.

GATE TRIGGERING:

This method of triggering of SCR is commonly used. In this method, when positive gate current is applied, the inner P layer is flooded with electrons from the Cathode. This is because cathode N layer is heavily doped as compared to gate P layer. As the SCR is forward biased, some of these electrons reach junction J_2. As a result, width of depletion layer near junction J_2 is reduced. This causes the junction J_2 to breakdown at an applied voltage lower than forward break-over voltage V_{BO}.

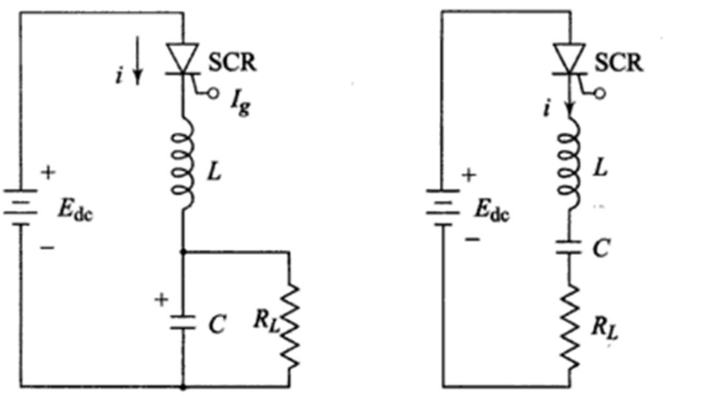
TURN-OFF METHOD (COMMUTATION METHOD):

LINE COMMUTATION:

If the load is connected to an AC source through an SCR, load current will flow during the positive half cycle. During negative half cycle, the SCR will turn-off due to the reverse polarity across it. This is known as Line commutation.

FORCED COMMUTATION:

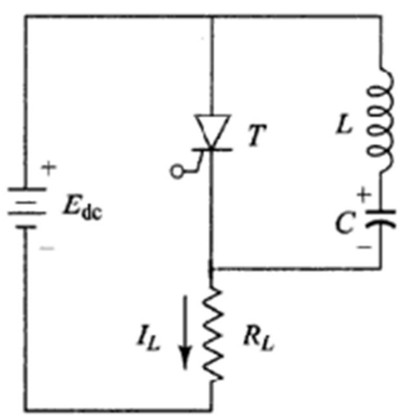
LOAD COMMUTATION:



Load in parallel with capacitor   Load in series with capacitor

For load commutation, the commutating components Land C are connected as shown above in the figure. For low value of R_L, L and C are connected in series with R_L. For high value of R_L, C is connected across R_L. When the circuit is supplied by a DC Source and the SCR is triggered, the SCR carries only the charging current of a capacitor 'C'. The charging current soon decays to a value which is less than the holding current of the device, whenever the capacitor gets charged to the supply voltage E_{dc}..

RESONANT PULSE COMMUTATION:



In this method, the LC resonating circuit is across the SCR and not in series with the load. Initially, as soon as the supply voltage E_{dc} is applied, the capacitor 'C' starts getting charged with its upper plate positive and the lower plate negative and it charges up to the voltage $E_{dc.}$

When SCR T is triggered, the load Current flows through the path E_{dc+}-T-R_L-E_{dc-} and capacitor 'C' starts discharging through the path C_+-L-T-C_-. When the capacitor 'C' becomes completely discharged, it starts getting charged with reverse polarity. Due to the reverse voltage, commutating current I_C starts flowing which opposes the load current I_L. When the commutating current I_C is greater than load current I_L, SCT T becomes turned-off.

VOLTAGE AND CURRENT RATINGS OF SCR:

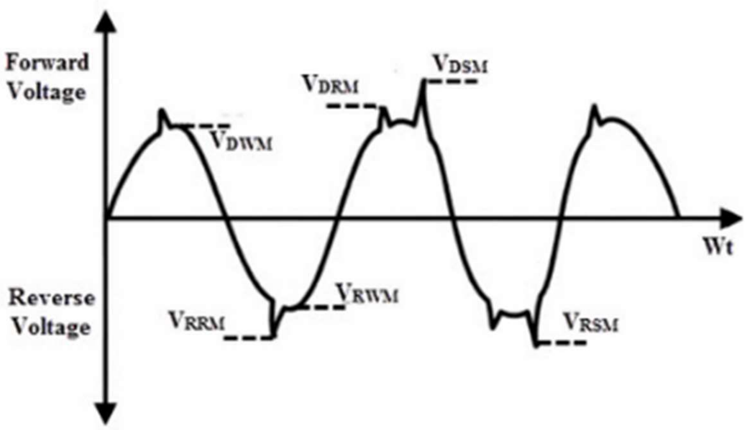
VOLTAGE RATING:

V_{DWM} (PEAK WORKING FORWARD BLOCKING VOLTAGE):

It is the maximum forward blocking voltage that an SCR can withstand during its working.

V_{DRM} (PEAK REPETITIVE FORWARD BLOCKING VOLTAGE):

It refers to the peak transient voltage that an SCR can withstand repeatedly or periodically in its forward blocking mode.



V_{DSM} (PEAK SURGE FORWARDING BLOCKING VOLTAGE):

It refers to peak value of the forward surge voltage that does not repeat.

V_{RWM} (PEAK WORKING REVERSE VOLTAGE):

It is the maximum reveres voltage that an SCR can withstand during reverse bias.

V_{RRM} (PEAK REPETITIVE REVERSE VOLTAGE):

It refers to peak reverse transient voltage that an SCR can withstand repeatedly or periodically during reverse blocking mode.

V_{RSM} (PEAK SURGE REVERSE VOLTAGE):

It refers to the peak Value of the reverse surge voltage that does not repeat.

V_T (ON STATE VOLTAGE DROP):

It is the voltage drop between anode and cathode with specified forward on state current and junction temperature. Its value is of the order of 1 to 1.5V.

FORWARD $\frac{dV}{dt}$ RATING:

This is the maximum rate of rise of anode current that will not trigger the SCR without any gate pulse.

V_{GT} (GATE TRIGGERING VOLTAGE):

This is the minimum voltage required to produce the gate triggering current.

FINGER VOLTAGE:

It is the minimum value of forward bias Voltage between anode and cathode for turning on the device by gate triggering.

CURRENT RATING:

I_{TAV} (AVERAGE ON-STATE CURRENT RATING):

This is the maximum repetitive average value of anode current that can flow through the SCR such that the maximum temperature and RMS current limits are not exceeded.

I_{TRMS} (RMS ON-STATE CURRENT):

This is the maximum repetitive RMS current specified at a maximum junction temperature that can flow through the SCR

I_{TSM} (SURGE CURRENT RATING):

It specifies the maximum non-repetitive or surge current that the SCR can withstand for a limited number of times during its life span.

$\frac{dI}{dt}$ RATING:

It is the maximum allowable rate of rise of anode to cathode current without any damage or harm to an SCR.

$(I_T)^2$ RATING:

It is the time integral of the square of the maximum instantaneous current. This rating is used to determine the thermal energy absorption of the device. This rating is required in the choice of a fuse or other protective equipment employed for the SCR.

LATCHING CURRENT:

It is the minimum value of anode Current which it must attain during turn-on process to maintain conduction when gate signal is removed.

HOLDING CURRENT:

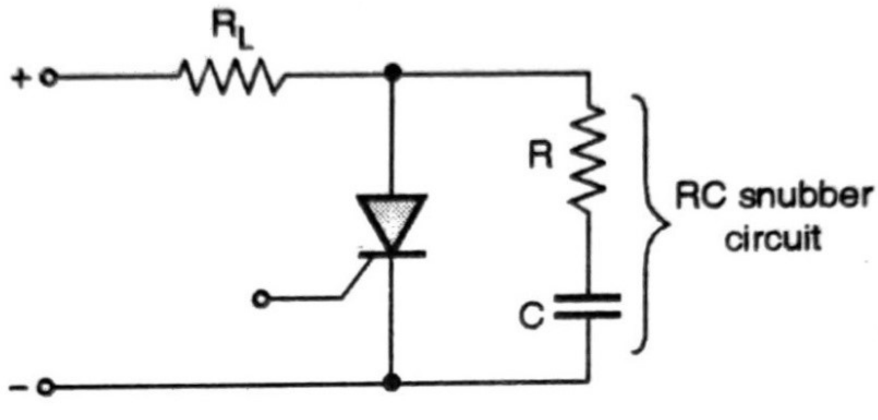
It is the minimum value of anode current below which it must fall turning off the SCR. Note that latching current is higher than holding current.

PROTECTION OF SCR:

OVER VOLTAGE PROTECTION:

SNUBBER CIRCUIT ($\frac{dV}{dt}$ SUPPRESSION):

A snubber circuit basically consists of a series - connected resistor and capacitor placed in shunt with an SCR. When switch 'S' is closed, a sudden voltage appears across the circuit. Capacitor C_S behaves like a short circuit, therefore voltage across SCR zero. With the passage of time, voltage across C_S builds up at a slow rate such that dV/dt across C_S and therefore across SCR is less. The resistor R_S is connected to limit the discharging Current.

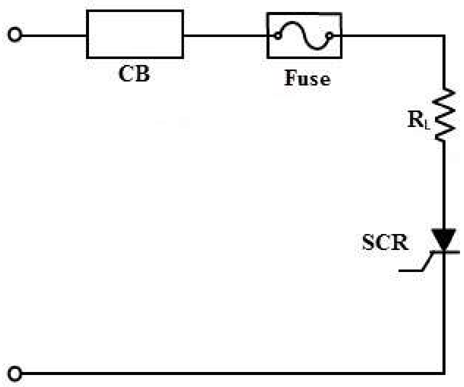


NON-LINEAR SURGE SUPPRESSOR:

To protect the SCR from non-linear surges, a voltage clamping device is connected across SCR. A voltage clamping device is a non-linear resistor. Under normal working condition of voltage, the device shows a high resistance and draws only a small leakage Current. When a voltage surge appears, the device operates in the low resistance region produces a virtual short current across the SCR. Hence the SCR is protected. The voltage Clamping device may be a metal oxide varistor or a Selenium surge suppressor.

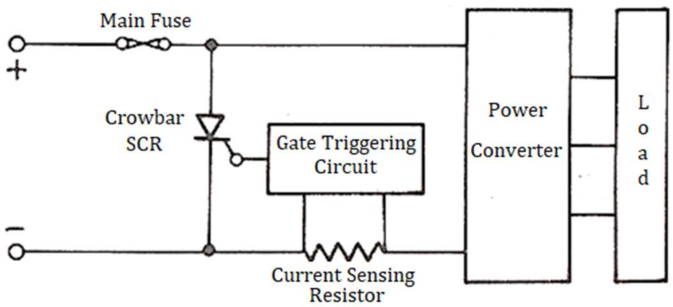
OVER CURRENT PROTECTION:

BY CIRCUIT BREAKER AND FUSE:



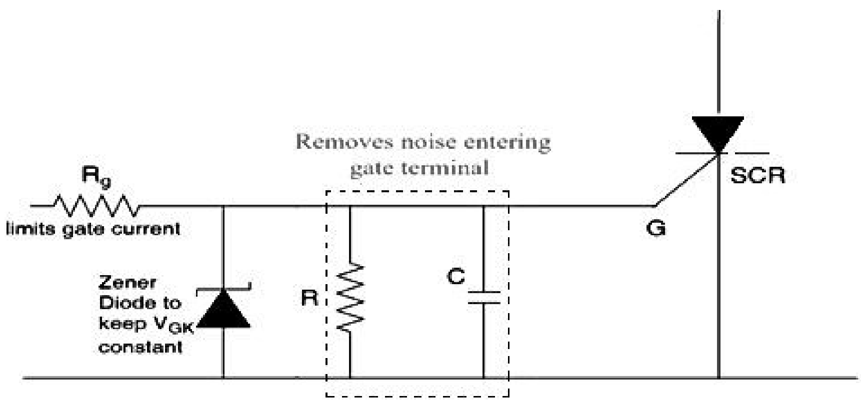
For protection against overcurrent a circuit breaker and a fast acting current limiting fuse are connected is series with the voltage source. The fuse must be capable of carrying the full load current. But when an overcurrent occurs, the fuse blows out and the SCR is protected. If the Current still present due to arc, the circuit breaker breaks the circuit, thus isolate the SCR from supply.

BY CROWBAR CIRCUIT:



In this type of overcurrent protection a crowbar SCR is connected across the DC supply. A current sensing resistor trigger detects the value of converter Current. If it exceeds preset value, gate circuit provides signal to crowbar SCR. The input terminals are then short circuited by crowbar SCR and it shunts away the converter overcurrent.

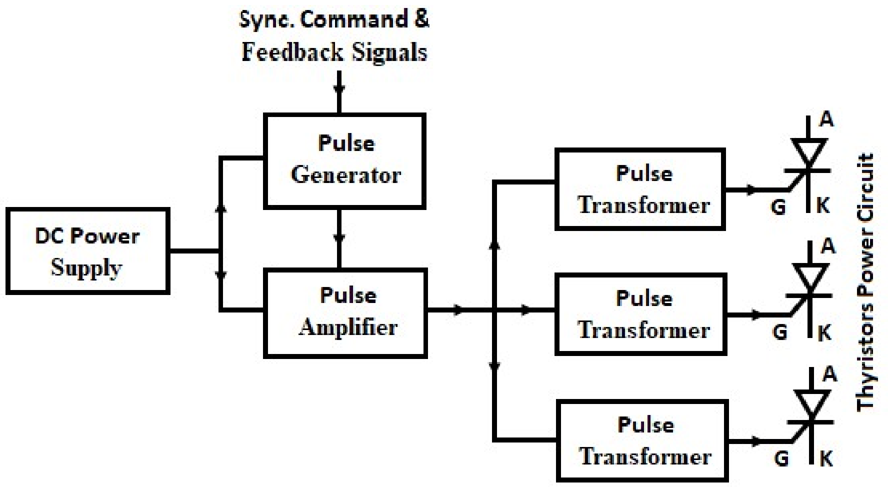
GATE PROTECTION:



Gate circuit should also be protected against over voltage and over current. Protection against overvoltage is achieved by connecting a Zener diode Z_D across the gate circuit. A resistor R_2 connected in series with the gate circuit provides protection against over current. A capacitor C_1 and resistor R_1 are also connected across gate to cathode to bypass the noise signal.

FIRING CIRCUITS:

GENERAL LAYOUT DIAGRAM OF FIRING CIRCUIT:



Basic Triggering Circuit of SCR

The widespread use of SCRs for controlling power is their ability to switch from non-conducting to conducting state in response to a small control signal. The proper triggering of SCRs requires that the source of the trigger-signal should supply adequate gate current and voltage, without exceeding the SCRs gate ratings in accordance with the characteristics of the SCRs and the nature of its load and supply. Only a correctly designed firing circuit to supply the gate currents to SCRs will enable the full potential of both SCRs and equipment. The performance capabilities of a particular SCR depend on the magnitude and wave-shape of the gate current; it will decide whether the device will fire over its full operating range, and whether the SCR will be successful in accepting the circuit currents and voltage to which it is exposed. Some systems operate successfully only when the gate current is flowing throughout the conduction period, while in others a single pulse is all that is required. The unbalance or harmonics in equipment will be decided by the firing system used. The basic requirements for the successful firing of a SCR are that the current supplied to the gate should:

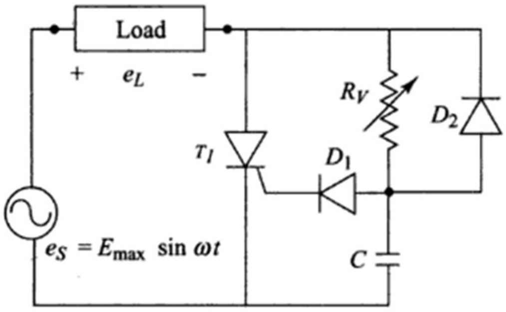
Be of adequate amplitude and sufficiently short rise time.

Be of adequate duration.

Occur at a time when the main circuit conditions are favorable to conduction.

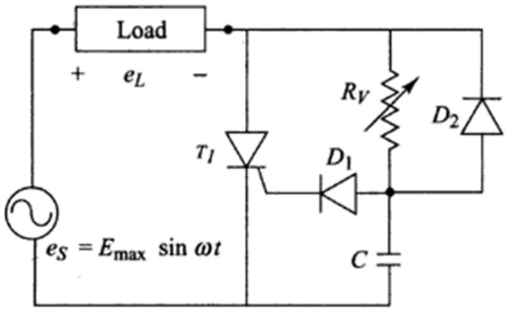
RESISTANCE FINING CIRCUIT:

In the resistance firing circuit shown below as e_s goes positive the SCR becomes forward biased, however it will not conduct (e_L =0) until its gate current exceeds I_{gmin} . When the gate current reaches a value equal to I_{gmin}, the SCR turns-on and a value equal to I_{gmin}, the SCR turns-on and e_L will approximately equal to e_S. In type method firing angle 'α' can be varried between 0° to 90°. The load voltage can be controlled by varying R_V which varies the resistance in the gate circuit.



If R_V is increased, the gate current will reach its trigger value I_{gmin} at a greater value of e_S making the SCR to trigger a latter point in the e_S positive half cycle. Thus the firing angle 'α' will increase. The opposite will occur if R_V is decreased. The minimum firing angle is obtained with R_V equal to zero.

RESISTANCE-CAPACITANCE FIRING CIRCUIT:



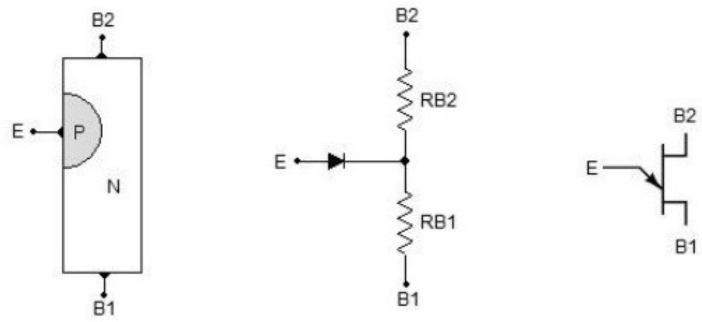
In resistance- capacitance firing, at first in the negative half cycle, capacitance 'C' ' charges through diode D_2 with lower plate positive to the peak supply voltage e_{max}. This capacitance voltage remains at – e_{max} until supply voltage attains zero value. Now as SCR anode voltage passes through zero and becomes positive, capacitor 'C' begins to charge through R_V from initial voltage -e_{max} . When the capacitor charges to positive voltage equal to gate trigger voltage V_{gt} (= V_{gmain} + V_{D1}), SCR is triggered. During negative half cycle, the diode D_1 prevents the breakdown of gate-cathode junction. In this firing method by varying the resistor R_V, the firing angle can be controlled from 0° to 180°.

UJT (UNI JUNCTION TRANSISTOR):

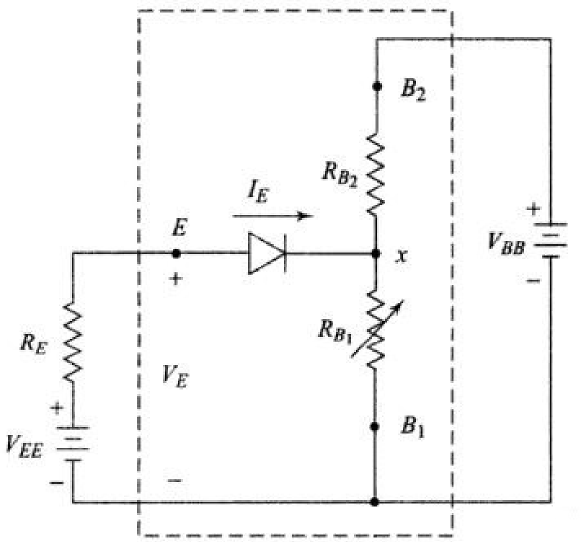
CONSTRUCTION:

UJT is it a three terminal, single junction semiconductor device. It consists of a lightly doped, N-type silicon bar provided with ohmic contacts at each end. The two end contacts are called base-1 (B_1) and base-2 (B_2). A small heavily doped P-type material, is alloyed into one side of the bar closes to B_2. A small heavily doped P-type material, is alloyed into one side of the bar closes to

B_2. This P material is called emitter (E) and forms a P-N junction with the bar. An inter-base resistance R_{BB} exists between B_1 and B_2.



This resistance can be broken up into two resistances, the resistance from B_1 to E, called R_{B1} and Resistance from B_2 to E, called R_{B2}. Since emitter is closed to B_2, the value of R_{B1} is greater than R_{B2}.



The UJT is normally operated with both B2 and E biased positive relative to B_1. The reference terminal of UJT is always B_1. The V_{BB} Source is fixed and provides a constant voltage from B_2 to B_1. The V_{EE} source is variable voltage and is considered the input to the Circuit. Very often , V_{EE} is not a source but a voltage across a capacitor.

OFF States: By voltage divider rule, the voltage V_x from point X and B_1

$$V_x = \frac{V_{BB}R_{B1}}{R_{B1}+R_{B2}} = \frac{V_{BB}R_{B1}}{R_{BB}} = \eta V_{BB}$$

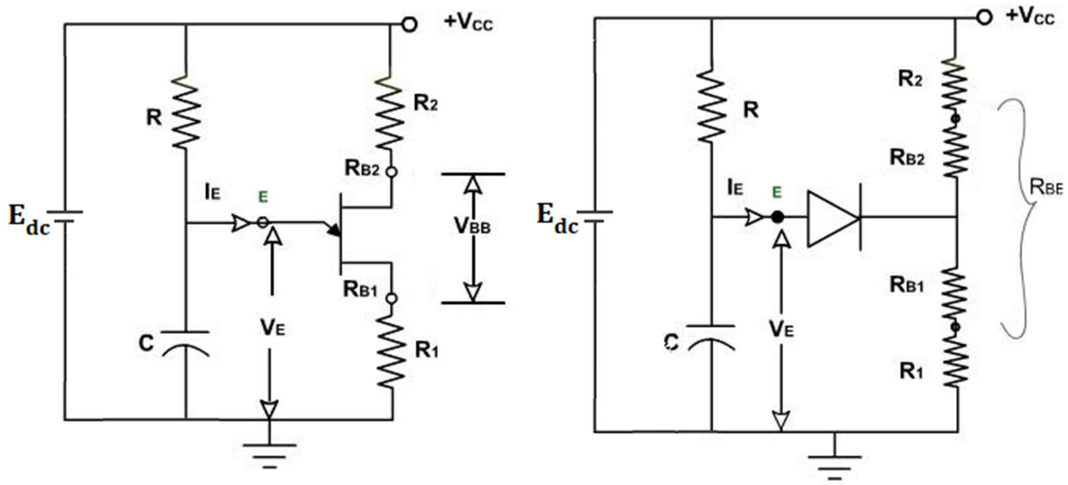
Where $\eta = \frac{R_{B1}}{R_{BB}}$ and known as intrinsic standoff ratio.

The voltage at point x is the voltage on the N side of the P-N Junction. The V_{EE} source is applied to emitter which is the P side. So the emitter diode will be reversed bias as long as V_{EE} is less than V_x. This is known as OFF state. In OFF state the UJT has a very high resistance between E & B_1.The OFF state actually extends to the point where the emitter voltage exceeds V_x by the diode threshold voltage V_D. At this point the emitter voltage is! Called peak point voltage V_P and given by

$$V_P = V_x + V_D = \eta V_{BB} + V_D$$

ON State: As emitter voltage V_E approaches V_P, the P-N junction becomes forward biased and begins to conduct. At this time emitter Current I_E becomes positive and called peak point current. The holes from the heavily doped emitter are injected into the N-type bar, especially into the B_1 region. The bar which is lightly doped, offers very little chance for these holes to recombine. So current carriers (holes) in lower half are increased and its resistance $R_{B1}$is drastically reduced. The decrease in R_{B1} causes V_x to drop. This drop in turn causes the diode to become more forward biased and emitter current I_E increases even further. The larger I_E injects more holes into B_1, further reducing R_{B1} and so on. The emitter current is limited by the external resistance R_E.

UJT RELAXATION OSCILLATOR:

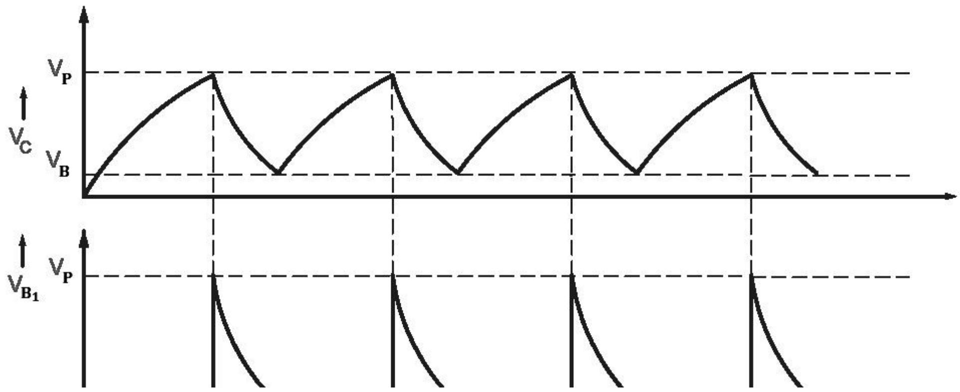


When the voltage across capacitor $V_C = 0 = V_E$, let the switch is suddenly closed at t = 0 applying E_{dc} to the circuit. The emitter diode is reverse-biased and the UJT is OFF. The amount of reverse bias voltage V_x volt and its value is given as

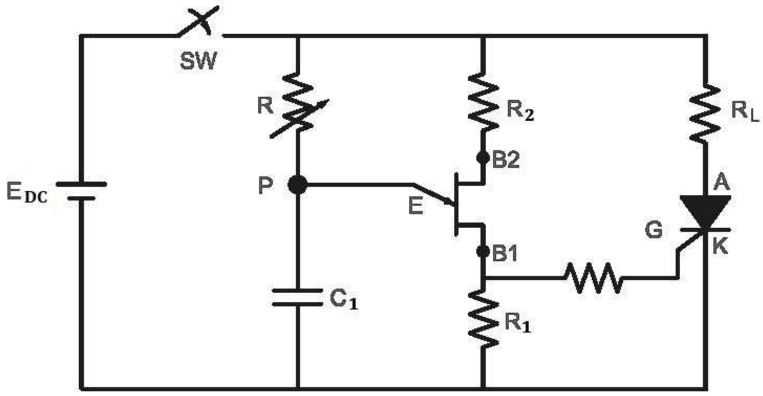
$$V_x = \frac{E_{dc}(R_1 + R_{B1})}{R_1 + R_{B1} + R_2 + R_{B2}}$$

In this condition the only emitter current flowing will be small reverse-leakage current and we can consider the emitter to be open. Then the capacitor will begin to charge towards the input voltage Edc through resistor R. The capacitor voltage increases with a time constant of RC. It will continue to increase until the voltage at the emitter reaches the peak-point value V_P. At this time, the emitter diode becomes forward biased and the UJT turns on with R_{B1} dropping to a very low value. Since the diode is now forward biased, the capacitor will discharge through the low resistance path containing the diode, R_{B1} and R_1. The capacitor discharge time constant is normally very short compared to its charging time constant. The discharging capacitor provides the emitter current needed to keep the UJT ON. It will remain ON until I_E drops below the valley current I_V, at which time the UJT will turn OFF. This occurs when the capacitor voltage has dropped to the valley voltage V_V. At this time, R_{B1} returns to its OFF value and the emitter diode becomes reversed bias.

Then the capacitor will begin charging again towards E_{dc} and the previous chain of events will repeat itself indefinitely as long as power is applied to the circuit. The result is a periodic saw tooth wane form across the capacitor.

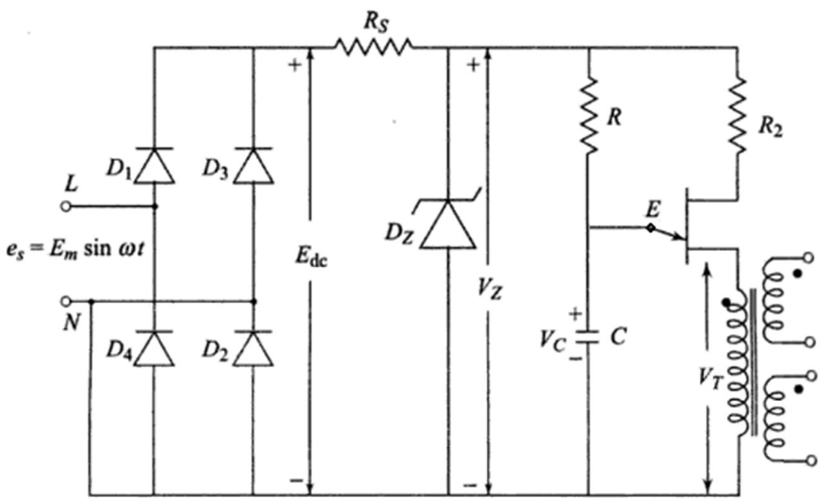


UJT PULSE TRIGGERING CIRCUIT:



When the switch 'S' is closed, the SCR is forward biased but not conducting. Then after the first output pulse is supplied to the gate terminal of SCR, the SCR will starts conducting. Now the subsequent output will have no effect at gate.

SYNCHRONOUS TRIGGERING (RAMP TRIGGERING):



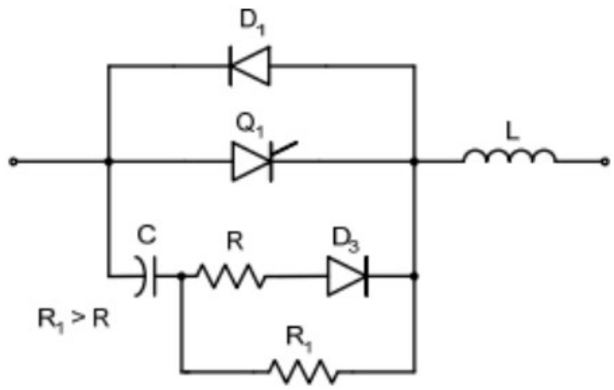
In ramp triggering the diode bridge $D_1 - D_4$, rectifies a.c. to d.c. Resistor R_S lowers E_{dc} to a suitable value for the zener diode and UJT. The zener diode D_Z is used to clip the rectified-voltage to a fixed voltage V_Z. This voltage V_Z is applied to the charging circuit RC. Capacitor C charges through R until it reaches the UJT trigger voltage V_P. The UJT then turns "ON" and C discharges through the UJT emitter and primary of the pulse transformer. The windings of the pulse transformer have pulse voltages at their secondary terminals. Pulses at the two secondary windings feed the same in phase pulse to two SCRs of a full wave circuit. SCR with positive anode voltage would turn ON. Rate of rise of capacitor voltage can be controlled by varying R. The firing angle can be controlled up to about 150°. This method of controlling the output power by varying charging resistor R is called as ramp control, open loop control or manual control.

As the zener diode voltage V_Z, goes to zero at the end of each half cycle, the synchronization of the triggering circuit with the supply voltage across SCRs is achieved

DESIGN OF RC SNUBBER CIRCUITS:

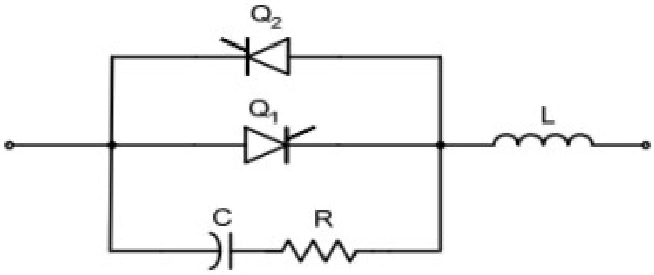
This circuit is a capacitor and series resistor connected across a switch. For designing the snubber circuits. The amount of energy is to dissipate in the snubber resistance is equal to the amount of energy is stored in the capacitors. An RC snubber placed across the switch can be used to reduce the peak voltage at turn-off and to lamp the ring. An RC snubber circuit can be polarized or non-polarized. If you assume the source has negligible impedance, the worst case peak current in the snubber circuit.

$I = \frac{V_O}{R_S}$ and $I = \frac{CdV}{dt}$



For an appropriate forward-polarized RC snubber circuit a thyristor or a transistor is connected with an anti-parallel diode. R will limit the forward dv/dt and R1 limits the discharge current of 48 the capacitor when transistor Q1 is turned on. These are used as overvoltage snubbers to clamp the voltage.

An un-polarized snubber circuit is used when a pair of switching devices is used in anti-parallel. For determining the resistor and capacitor values a simple design technique can be used. For this an optimum design is needed. Hence a complex procedure will be used. These can be used to protect and thyristors.



Capacitors selection: Snubber capacitors are subjected to high peak and RMS currents and high dv/dt. An example is turn-on and turn-off current spikes in a typical RCD snubber capacitor. The pulse will have high peak and RMS amplitudes. The snubber capacitor has to meet two requirements. First, the energy stored in the snubber capacitor must be greater than the energy in the circuit's inductance. Secondly, the time constant of snubber circuits should me small compared to shortest on time expected, usually 10% of the on time. By allowing the resistor to be effective in the ringing frequency this capacitor is used to minimize the dissipation at switching frequency. The best 49 design is selecting the impedance of the capacitor is same that of resistor at the ringing frequency.

Resistors selection: It is important that R in the RC snubber, have low self-inductance. Inductance in R will increase the peak voltage and it will tend to defeat the purpose of the snubber. Low inductance will also be desirable for R in snubber but it is not critical since the effect of a small amount of inductance is to slightly increase the reset time of C and it will reduce the peak current in switch at turn-on. The normal choice of R is usually the carbon composition or metal film. The resistor power dissipation must be independent of the resistance R because it dissipates the energy stored in the snubber capacitor in each transition of voltage in the capacitor. If we select the resistor as that the characteristic impedance, the ringing is well damped. When comparing the Quick design to optimum design, the required snubber resistor's power capability will be reduced. Usually the "Quick" design is completely adequate for final design. Going to the "Optimum" approach is only if power efficiency and size constraints dictate the need for optimum design.

QUESTION BANK

SHORT QUESTIONS WITH ANSWER:

Q: Define latching current.

A: It is the minimum value of anode Current which it must attain during turn-on process to maintain conduction when gate signal is removed.

Q: Define holding current.

A: It is the minimum value of anode current below which it must fall turning off the SCR. Note that latching current is higher than holding current.

Q: Define finger voltage.

A: It is the minimum value of forward bias Voltage between anode and cathode for turning on the device by gate triggering.

Q: What is Snubber Circuit?

A: A snubber circuit basically consists of a series - connected resistor and capacitor placed in shunt with an SCR. When switch 'S' is closed, a sudden voltage appears across the circuit. Capacitor C_S behaves like a short circuit, therefore voltage across SCR zero.

Q: What is Crowbar Circuit?

A: In this type of overcurrent protection a crowbar SCR is connected across the DC supply. A current sensing resistor trigger detects the value of converter Current. If it exceeds preset value, gate circuit provides signal to crowbar SCR. The input terminals are then short circuited by crowbar SCR and it shunts away the converter overcurrent.

Q: Define UJT.

A: UJT is it a three terminal, single junction semiconductor device. It consists of a lightly doped, N-type silicon bar provided with ohmic contacts at each end. The two end contacts are called base-1 (B_1) and base-2 (B_2). A small heavily doped P-type material, is alloyed into one side of the bar closes to B_2. A small heavily doped P-type material, is alloyed into one side of the bar closes to B_2. This P material is called emitter (E) and forms a P-N junction with the bar. An inter-base resistance R_{BB} exists between B_1 and B_2.

Q: what is the application of Power Diode?

A: Power Diode is used in Rectifiers Clipper Circuits, Clamping Circuits, Reverse Current Protection Circuits and In Logic Gates.

Q: Define DIAC.

A: It is a two terminal and five layer bidirectional semiconductor device. Five layers consist of three N layers and two P layers. The layers which are close to the terminals are made up of both

N type and P type. The two terminals are named as MT_1 and MT_2. It stands for diode in 'ac'. It can be turned ON in both forward and negative direction.

Q: What are the application of DIAC?

A: The main application of a DIAC is its use in a TRIAC triggering circuit. It can be used in the lamp dimmer circuit, heat control circuit and speed control of a universal motor

Q: Define delay time.

A: The delay time t_d is the time interval between the instant at which the gate current reaches $0.9I_g$ and the instant at which anode current reaches $0.1I_a$. The delay time may also be defined as time during which anode voltage from V_a to $0.9\ V_a$.

Q: Define rise time.

A: The rise time t_r is the time taken by anode current to rise from $0.1I_a$ to $0.9I_a$. It may also be defined as the time duration in which the anode voltage decreases from $0.9V_a$ to $0.lV_a$.

LONG QUESTIONS:

Q: Describe the different modes of operation of a SCR with the help of its static V-I characteristic

Q: Describe the holding current and latching current as applicable to an SCR

Q: With the help of a neat diagram, explain the two transistor analogy of an SCR. Also discuss the triggering conditions of SCR.

Q: Give the constructional details of an SCR. Sketch its schematic diagram and the circuit symbol.

Q: Explain why (i) the inner two layers of an SCR are lightly doped and are wide, (ii) the inner n layer of an SCR is doped with gold and (iii) I_H is less than I_L.

Q: Explain in detail the turn-off mechanism of an SCR.

Q: Explain the various types of triggering methods of SCR briefly. Which is the universal method and why?

Q: What are the different signals which can be used for turning on an SCR by gate control? Compare them?

Q: Draw the gate characteristic of an SCR and explain it.

Q: Draw the turn-off characteristic of an SCR and explain the mechanism of turn- off

Q: What are the different methods for turning off an SCR? Explain all methods in detail?

Q: Draw and explain the equivalent circuit and V-I characteristic of the UJT in detail.

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

Q: Draw the V-I characteristics of a DIAC and explain its working principles.

Q: Explain with the help of layer diagram the construction of a TRIAC.

Q: Draw the V–I characteristics of a TRIAC and explain its working principle.

Q: Explain the difference between a TRIAC and an SCR.

CHAPTER 2: UNDERSTAND THE WORKING OF CONVERTERS, AC REGULATORS AND CHOPPERS.

CONTROLLED RECTIFIERS TECHNIQUES:

PHASE ANGLE-CONTROL (FIRING ANGLE CONTROL):

In A.C. circuits, the SCR can be turned "on" by the gate at any phase angle, with respect to the applied voltage. This phase angle is measured with respect to a given reference, at which the gate pulses are applied to the SCR gates. The reference point is the point at which the application of the gate pulses results the maximum mean positive D.C. terminal voltage of which the converter is capable. In other words, a phase-angle of 0° corresponds to the conditions when each SCR in the circuit is fired at the instant its anode voltage-first becomes positive in each cycle, under this condition, therefore, the converter operates in exactly the same manner as if it was an uncontrolled rectifier circuit. The 'α' is the symbol for the phase angle. Hence, the most efficient method to control the turning ON of an SCR is achieved by varying the phase-angle of SCR. Such a method of control is called as phase-angle control.

EXTINCTION ANGLE CONTROL:

In power electronics extinction angle is one where SCR gets switched off at desired angle. The output voltage is controlled by varying the extinction angle 'β'. In extinction angle control, SCR is turned on at $\omega t = 0$, and then turned off by forced commutation at $\omega t = (\pi-\beta)$. The output voltage is controlled by varying the extinction angle β.

EXPLAIN SINGLE QUADRANT SEMI CONVERTER, TWO QUADRANT FULL CONVERTER AND DUAL CONVERTER:

The phase controlled converters may be classified as semi-converter, full converter and dual converter. Depending on the input A.C. supply used they are classified as single phase and three phase converters.

SEMI-CONVERTER:

A semi-converter is a one quadrant converter and it has one polarity of output voltage and current. It contains a mixture of diodes and SCRs allowing more limited control over the dc output voltage level than the full controlled rectifier. It is cheaper. It permits power flow from AC system to DC load. It is also known as half-wave controlled converter.

FULL-CONVERTER:

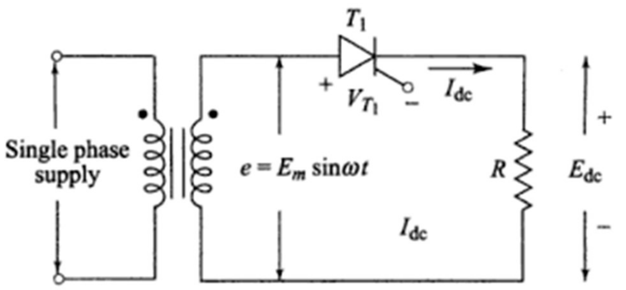
A full-converter is a two-quadrant converter and the polarity of its output voltage can be either positive or negative. However, the output current of full-converter has one polarity only. Here power can be transmitted from AC side to DC side (conversion) and from DC side to AC side (inversion). It uses only SCRs as rectifying elements.

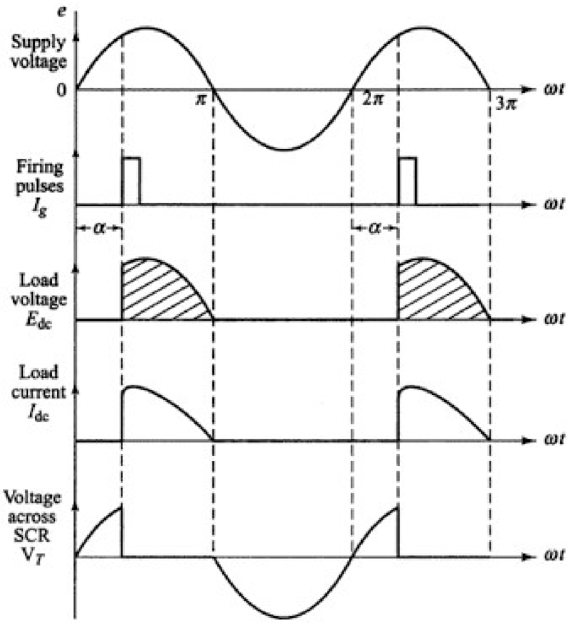
DUAL-CONVERTER:

If two full converters are connected back to back they form a dual converter. It can operate in four quadrants and both the output voltage and current can be either positive or negative. Normally these are used in high power applications.

SINGLE PHASE HALF WAVE CONVERTER:

WITH RESISTIVE LOAD:





During the positive half cycle of the supply voltage, the SCR anode is positive with respect to its cathode and until the SCR is triggered by a proper gate pulse, it blocks the flow load current in the forward direction. When the SCR is fined at an angle α, full supply voltage is applied to the load. Hence the load is directly connected to the ac supply. With a zero reactance source and a purely resistive load, the wave form of current, after the SCR is triggered will be identical to the applied voltage wave and of a magnitude depending on the amplitude of the voltage and the value of load resistance R. The load current will flow until it is commutated by reversal of supply voltage at ωt=π.

The angle during which the SCR conducts is called conduction angle β. By varying the firing angle α, the output voltage can be controlled. During the period of conduction, voltage drop across the SCR is as the order of one volt. During the negative half-cycle of the supply voltage, the SCR blocks the flow of load current.

Average load voltage:

$$E_{DC} = \frac{1}{2\pi}\int_{\alpha}^{\pi} E_m \text{Sin}\omega t\, d(\omega t)$$

Or $E_{DC} = \frac{E_m}{2\pi}\int_{\alpha}^{\pi} Sin\omega t d(\omega t)$

Or $E_{DC} = \frac{E_m}{2\pi}[-Cos\ \omega t]_{\pi}^{\alpha}$

Or $E_{DC} = \frac{E_m}{2\pi}[1+Cos\ \alpha]$

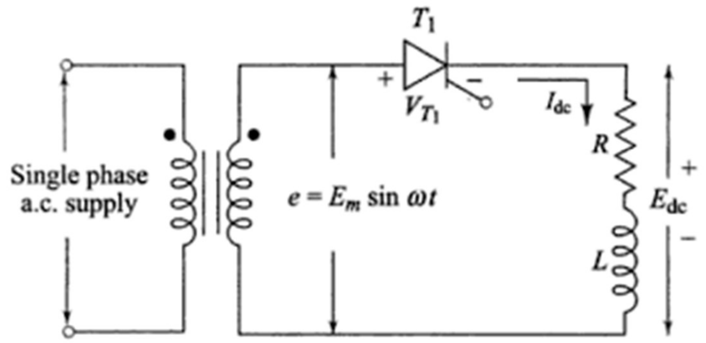
The maximum output voltage is obtained at α = 0

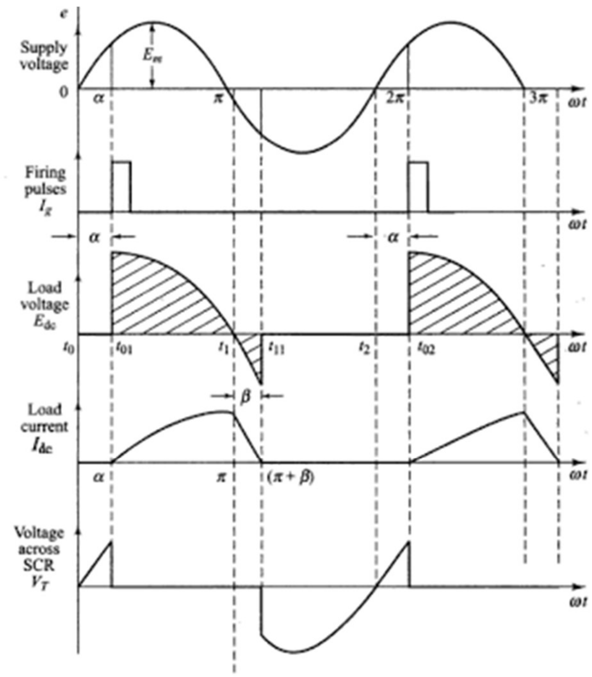
$$E_{DCmax} = \frac{E_m}{2\pi}$$

Average load current:

$$I_{DC} = \frac{E_m}{2\pi R}[1+Cos\ \alpha]$$

WITH RESISTIVE-INDUCTIVE LOAD:





At the instant when the SCR is triggered, the load current will increase in a finite time through the inductive load. The supply voltage from this instant appears across the load. Due to inductive load, the increase in current is gradual. The inductor stores some energy. So when the supply voltage reverses, the SCR is kept conducting. When the stored energy is dissipated in the resistor and a part of it is bed back to the source, the load current becomes zero and due to the reverse voltage & SCR turns-off. When during next positive cycle, the gate pulse is applied, the above cycle repeats. Hence the effect of the inductive load is increased in the conduction period of SCR.

Average load voltage is

$$E_{DC} = \frac{1}{2\pi}\int_{\alpha}^{\pi+\alpha} E_m Sin\omega t d(\omega t)$$

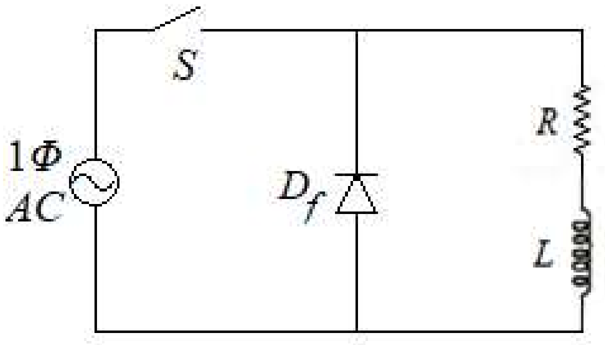
Or $E_{DC} = \frac{E_m}{2\pi}[-\text{Cos } \omega t]_{\pi}^{\pi+\alpha}$

Or $E_{DC} = \frac{E_m}{\pi}\text{Cos } \alpha$

UNDERSTAND NEED OF FREEWHEELING DIODE:

A freewheeling diode is basically a diode connected across the inductive load terminals to prevent the development of high voltage across the switch. When the inductive circuit is switched off, this diode gives a short circuit path for the flow of inductor decay current and hence dissipation of stored energy in the inductor. This diode is also called Flywheel or Fly-back diode.

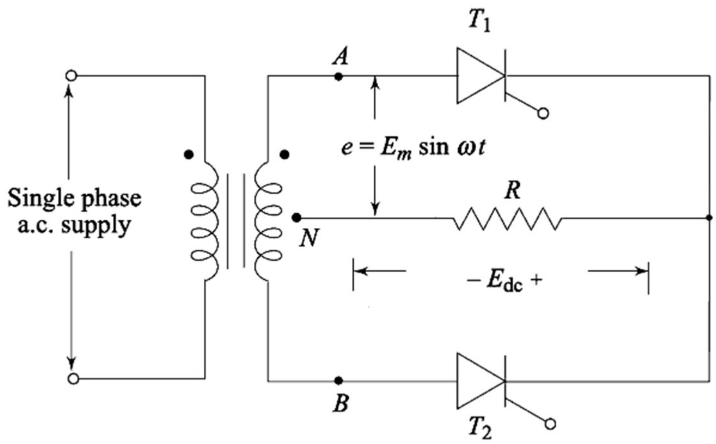
WORKING PRINCIPLE OF FREEWHEELING DIODE:



When switch S is closed, the steady state current I through the circuit is (E/R) and hence the stored energy in inductor is $(LI^2)/2$. When this switch S is opened, the current will suddenly decay to zero from steady value I = (E/R). Due to this sudden decay of current, a high reverse voltage (as per lenz's law) equal to L(di/dt) will appear across the inductor terminals and hence across the diode and switch. This will lead to sparking across the switch contacts. If this reverse voltage exceeds the Peak Inverse Voltage of diode, then it may get damage. To avoid such occurrences, a diode, called freewheeling or fly-back diode is connected across the inductive load RL as shown in figure below.

SINGLE PHASE FULL WAVE CONVERTER:

WITH RESISTIVE LOAD (MID-POINT CONVERTER):



In this configuration two SCRS are connected to a center-tapped secondary of a transformer. The input signal is coupled through the transformer to the center-tapped secondary. During the positive half cycle of the AC supply, when terminal A of the transformer is positive with respect to B and N, SCR T_1 is forward biased and SCR T_2 is reverse biased. Since no triggering pulses are given to the gates of the SCRs, they are in Off-state. When SCR T_1 is triggered at a firing angle α, current would flow from terminal A through SCR T_1, the resistive load R and back to the center tap of the transformer (point N). This Current continues to flow up to angle π, when the line voltage reverses its polarity and SCR T_1 is turned off. During the negative half cycle, the terminal B of the transformer is Positive to A and N. Now SCR T_2 is forward biased and when SCR T_2 is triggered at an angle π + α, current would flow from terminal B, through SCR T_2, the resistive load and back to center–tap of transformer (N). This current continues till angle 2 and then SCR T_2 is turned off. Here it is assumed that both SCRs are triggered with the same firing angle, hence they share the load current equally.

The average value of load voltage is

$$E_{DC} = \frac{1}{\pi}\int_{\alpha}^{\pi} E_m \mathrm{Sin}\omega t d(\omega t)$$

Or $$E_{DC} = \frac{E_m}{\pi}\int_{\alpha}^{\pi} \mathrm{Sin}\omega t d(\omega t)$$

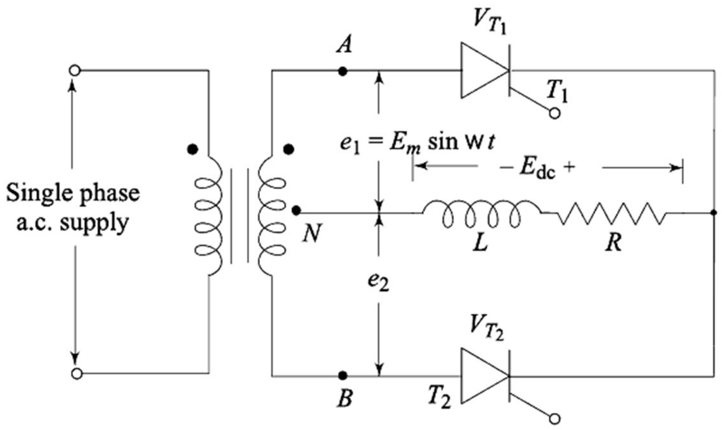
Or $$E_{DC} = \frac{E_m}{\pi}[-\mathrm{Cos}\ \omega t]_{\pi}^{\alpha}$$

Or $$E_{DC} = \frac{E_m}{\pi}[1+\mathrm{Cos}\ \alpha]$$

The average load current is

$$I_{DC} = \frac{E_m}{\pi R}[1+\mathrm{Cos}\ \alpha]$$

WITH RESISTIVE-INDUCTIVE(R-L) LOAD (MID-POINT CONVERTER):



During positive half cycle, when SCR T_1 is triggered at angle α, load current flows through terminal A, SCR T_1 , resistor R, inductor L and point N. At angle π, the supply voltage reverses but the load current continues to flow through SCR T_1, because the SCR T_1 is not gated till π + α and the inductor energy is dissipated through SCR T_1, and R. At angle π + α, SCR T_2 is fired and the load current is transferred to SCR T_2 and flows through B, SCRT, Resistor R, inductor L and point N. During the negative half cycle, in between the instant π + α to 2α, the voltage across SCR T_1 is negative with a maximum value of $-2E_m$. At angle 2α, the supply voltage again becomes positive but the SCR continues conducting until 2π+α due to the inductor energy. From the instant 2π + α to 3π, the voltage across T_2 becomes negative with maximum Value $-2E_m$. In resistive–inductive load case, the load current may be continuous or discontinuous, depending upon the value of inductance.

The average value of lead voltage is

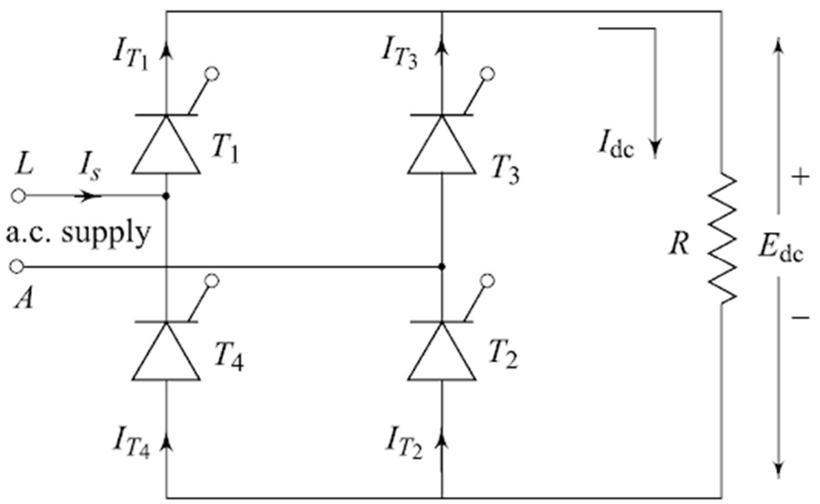
$$E_{DC}= \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} E_m \sin\omega t\, d(\omega t)$$

Or $$E_{DC} = \frac{E_m}{\pi}[-\cos \omega t]_{\pi}^{\pi+\alpha}$$

Or $$E_{DC} = \frac{2E_m}{\pi}\cos \alpha$$

WITH RESISTIVE LOAD (BRIDGE CONVERTER):

In bridge Converter two pairs of SCRs are used, diagonally opposite pairs are made to conduct and commutated simultaneously. During the first positive half cycle, SCRs T_1 and T_2 are fired simultaneously at a firing angle α. So the load current flows through the path L-T_1- R-T_2–N. At the instant α, when the negative half cycle starts SCRs T_1 and T_2 are commuted naturally and load current becomes zero. At instant π + α, the SCRs T_3 and T_4 are fired and load current flows through the path N-T_3-R-T_4-L. At instant 2π, when the positive half cycle starts, SCRs T_3 and T_4 are commutated and load current again becomes zero. This cycle of operation is repeated.



The average load voltage is

$$E_{DC} = \frac{1}{\pi}\int_{\alpha}^{\pi} E_m Sin\omega t d(\omega t)$$

Or $$E_{DC} = \frac{E_m}{\pi}\int_{\alpha}^{\pi} Sin\omega t d(\omega t)$$

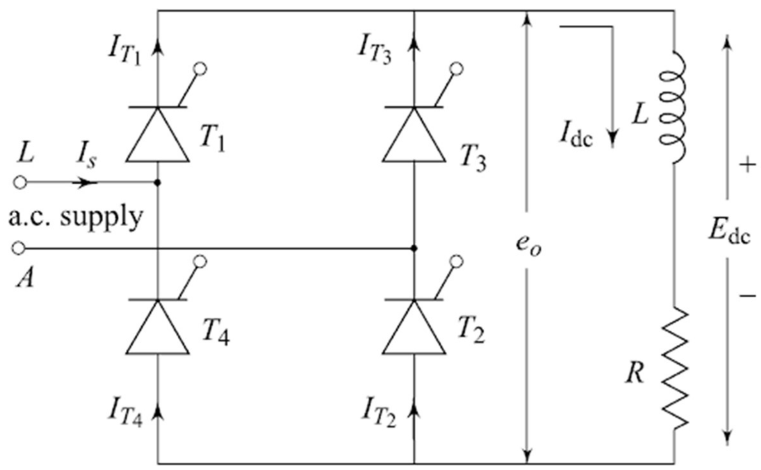
Or $$E_{DC} = \frac{E_m}{\pi}[-Cos\ \omega t]_{\pi}^{\alpha}$$

Or $$E_{DC} = \frac{E_m}{\pi}[1+Cos\ \alpha]$$

The average load current is

$$I_{DC} = \frac{E_m}{\pi R}[1+Cos\ \alpha]$$

WITH RESISTIVE-INDUCTIVE(R-L) LOAD (BRIDGE CONVERTER):



During first positive half cycle, SCRs T_1 and T_2 are fired at fining angle α. So the current flows through the path L-T_1-L-R-T_2-N. Supply voltage from this instant appears across output load terminal. At instant π, voltage reverses, however the current is maintained in the same direction which keeps the SCRs T_1 and T_2 conducting and hence the negative supply voltage appears across load terminals. At an angle π + α, SCRs T_3 and T_4 are fired. With this, the negative line voltage reverse-biases SCRs T_1 and T_2 to commutate. Now the current flows through the path N-T_3-L-R-T_4-L. This continues in every half cycle and we get the output voltage across load.

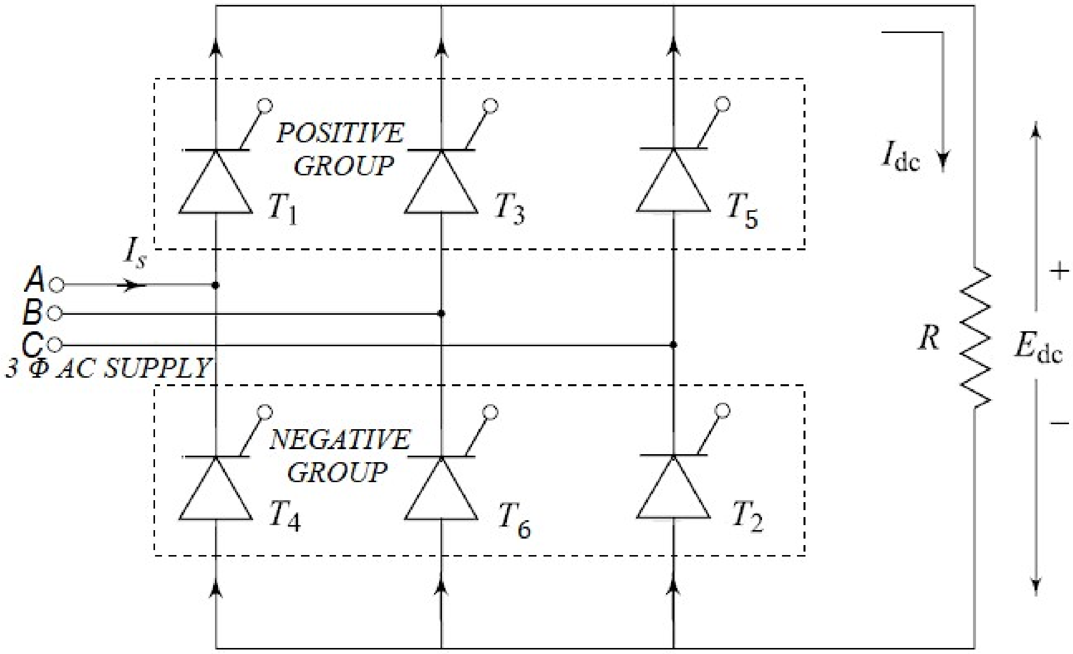
The average load voltage is

$$E_{DC} = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} E_m Sin\omega t d(\omega t)$$

Or $$E_{DC} = \frac{E_m}{\pi}[-Cos\ \omega t]_{\pi}^{\pi+\alpha}$$

Or $$E_{DC} = \frac{2E_m}{\pi}Cos\ \alpha$$

THREE PHASE FULLY CONTROLLED CONVERTER WITH RESISTIVE LOAD:



This converter consists of two groups of SCRs, positive group and negative group. Here SCRs T_1, T_3 and T_5 form a positive group, whereas SCRs T_2, T_4 and T_6 form negative group. The positive groups SCRs are tuned ON when the supply voltages are positive and negative group SCRs are turned ON when the supply voltages are negative. In order to start the circuit functioning, two SCRs must be fired at the same time in order to commence current flow, one of the upper arms and one of the lower arms. For describing the operation of the circuit, the following points to be remembered.

Each SCR should be triggered at same firing angle α

Each SCR can conduct for 120°.

SCRs must be triggered in the sequence T_1, T_2, T_3, T_4, T_5 & T_6.

The phase shift between the triggering of the two adjacent SCRs is 60°.

At any instant, two SCRs can conduct and there are such six pairs such as (T_6 & T_1), (T_1 & T_2), (T_2 & T_3), (T_3 & T_4), (T_4 & T_5) and (T_5 & T_6).

Each pair of SCR conducts for 60°.

The incoming SCR commutates the outgoing SCR, i.e. SCR T_1 commutates SCR T_5, SCR T_2 commutates SCR T_6 and so on.

When the two SCRs are conducting i.e. one from upper group and one from lower group, the corresponding line voltage is applied across the load for example, when T_6 and T_1 are conducting the line Voltage V_{AB} is applied.

Continuous conduction mode: (0°< α < 60°)

When the phasor AB is allowed to conduct at α between 0° to 60°, it continues to conduct by 60° when the phasor AC is fired. The conduction is shifted from SCR T_6 to T_2. T_6 is commutated by the reverse voltage of phase C and B across it. The phasor AC conducts after another Goo after which it is replaced by phasor BC when Phase B voltage assumes greater value than c and A. Hence load current is continuous for α between 0° to 60°.

Discontinuous conduction mode: (60°< α < 120°)

When the phasor AC is fired at angle & between 60°< α < 120°, it conducts upto an angle π after which phase B becomes positive with respect to phase C and after 60° phasor BA conducts also up to angle π. Hence load current remains zero from π to the next firing pulse and becomes discontinuous. Note that for α = 120°, the output voltage is zero.

For continuous mode:

The average load voltage is

$$E_{DC} = \frac{6}{2\pi} \int_{\frac{\pi}{6}+\alpha}^{\frac{\pi}{2}+\alpha} \sqrt{3}\ E_M \text{Sin}\ (\omega t + \frac{\pi}{6})d(\omega t)$$

Or $$E_{DC} = \frac{3\sqrt{3}}{\pi}\ E_M \int_{\frac{\pi}{3}+\alpha}^{\frac{2\pi}{3}+\alpha} \text{Sin}\ \omega t d(\omega t)$$

Or $$E_{DC} = \frac{3\sqrt{3}}{\pi}\ E_M\ [-\text{Cos}\ \omega t]_{\frac{\pi}{3}+\alpha}^{\frac{2\pi}{3}+\alpha}$$

Or $$E_{DC} = \frac{3\sqrt{3}}{\pi}\ E_M\ [\text{Cos}\ (\frac{\pi}{3}+\alpha) - \text{Cos}\ (\frac{2\pi}{3}+\alpha)]$$

Or $$E_{DC} = \frac{3\sqrt{3}}{\pi}\ E_M\ [\text{Cos}\ (\frac{\pi}{3}+\alpha) + \text{Cos}\ (\frac{\pi}{3}-\alpha)]$$

Or $$E_{DC} = \frac{3\sqrt{3}}{\pi}\ E_M 2\ \text{Cos}\frac{\pi}{3} \text{Cos}\alpha$$

Or $$E_{DC} = \frac{3\sqrt{3}}{\pi}\ E_M \text{Cos}\alpha$$

The average load current is

$$I_{DC} = \frac{3\sqrt{3}}{\pi R}\ E_M \text{Cos}\alpha$$

For discontinuous mode:

The average load voltage is

$$E_{DC} = \frac{6}{2\pi} \int_{\frac{\pi}{6}+\alpha}^{\frac{5\pi}{6}} \sqrt{3}\ E_M \text{Sin}\ (\omega t + \frac{\pi}{6})d(\omega t)$$

Or $$E_{DC} = \frac{3\sqrt{3}}{\pi}\ E_M \int_{\frac{\pi}{3}+\alpha}^{\pi} \text{Sin}\ \omega t d(\omega t)$$

Or $E_{DC} = \frac{3\sqrt{3}}{\pi} E_M [-\text{Cos } \omega t]_{\frac{\pi}{3}+\alpha}^{\pi}$

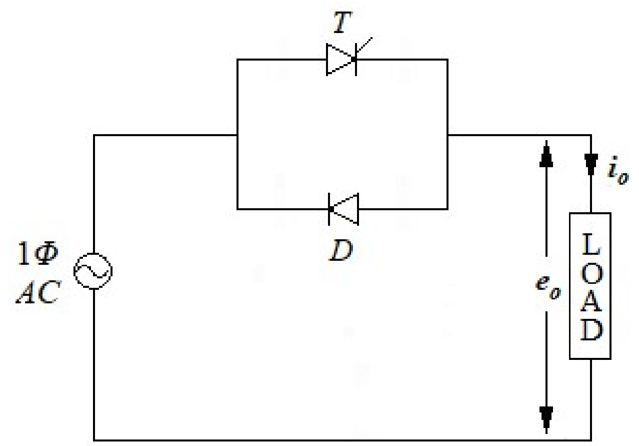
Or $E_{DC} = \frac{3\sqrt{3}}{\pi} E_M [1 + \text{Cos } (\frac{\pi}{3}+\alpha)]$

The average load current is

$$I_{DC} = \frac{3\sqrt{3}}{\pi R} E_M [1 + \text{Cos } (\frac{\pi}{3}+\alpha)]$$

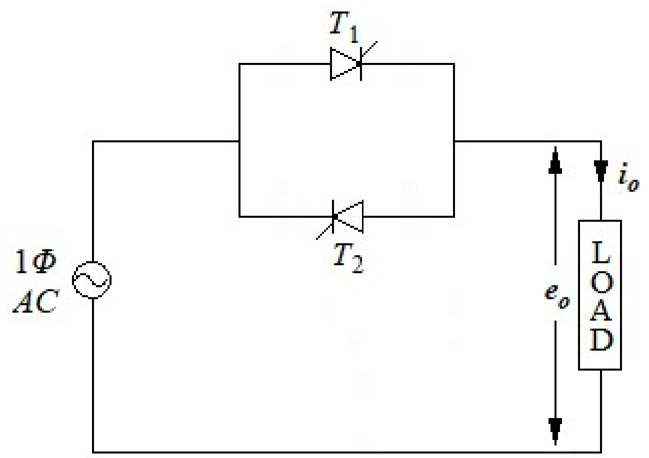
AC REGULATOR:

SINGLE PHASE HALF WAVE AC REGULATOR:



This half wave AC regulator consists of an SCR and diode connected in antiparallel. The power flow to the load is controlled by delaying the firing angle of SCR T. Due to the presence of diode D, the control range is limited and the output voltage can only be varied between to 70.7% to 100%. As the circuit is half controlled, the positive half cycle is not identical with negative half cycle. So DC component is introduced is in the supply and load circuits, which is undesirable. This type of regulator is unidirectional.

SINGLE PHASE FULL WAVE, AC REGULATOR:

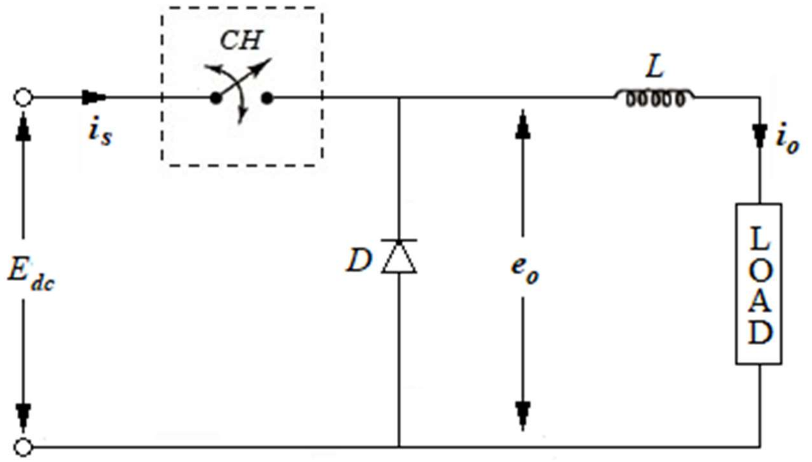


The full wave Ac regulator uses two SCRs connected in antiparallel. SCRs T_1 and T_2 are forward biased during positive and negative half cycle respectively. During positive half cycle SCR T_1 is triggered at a firing angle α. SCR T_1 starts conducting and supply voltage is applied to load from α to π. At π, SCR T_1 is commutated naturally. During negative half cycle SCR T_2 is triggered at π + α. So SER T_2 conducts from π + α to 2π and supply voltage is applied to load. At 2π, SCR T_2 is commutated naturally. The output voltage can be controlled by varying the firing angle in both half cycles, so the regulator is bidirectional.

CHOPPER:

A chopper is a static device (or switch) used to obtain variable DC voltage from a source of constant DC voltage. Therefore, chopper may be thought of as DC equivalent of an AC transformer, since they behave is an identical manner. It consists of semiconductor device (SCR, BJT, and IGBT etc.), DC source, and circuit elements.

WORKING PRINCIPLE OF STEP-DOWN CHOPPER:



During the period T_{ON}, when the chopper is ON, the supply terminals are connected to the load terminals and the inductor L stores energy. During the interval T_{OFF}, when the chopper is OFF, due to the stored energy, load current continues to flow and free wheels through the diode D. But as the freewheeling diode short circuits the load terminal, as a result load voltage is zero.

The average load voltage is

$$E_O = E_{DC} \frac{T_{ON}}{T_{ON}+T_{OFF}}$$

Or $$E_O = E_{DC} \frac{T_{ON}}{T}$$

Or $$E_O = E_{DC}\, \alpha$$

T_{ON} – Chopper turn ON time

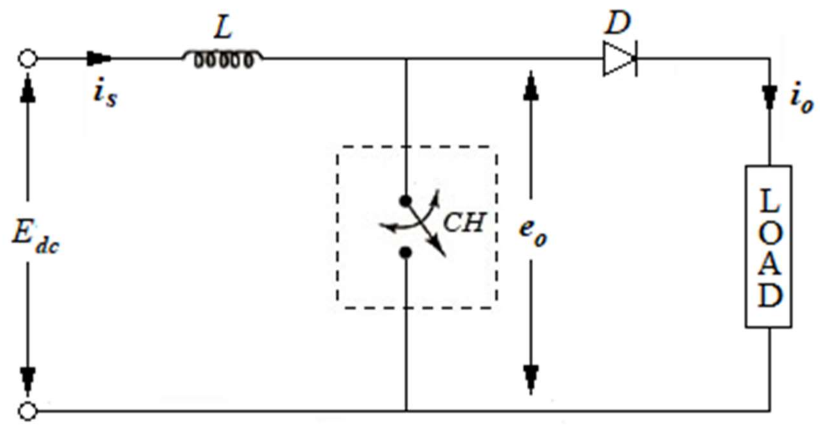
T_{OFF} – Chopper turn OFF time

$T = T_{ON} + T_{OFF}$ = Chopping time

$\alpha = \frac{T_{ON}}{T}$ = Duty cycle

When the duty cycle α is zero, the load voltage will be zero and when α is one, the load voltage is E_{DC}. Hence load voltage ranges between zero to E_{DC}.

WORKING PRINCIPLE OF STEP-UP CHOPPER:



When the chopper is ON, the inductor L is connected to the supply and stores energy during on period T_{ON}. When the chopper is made OFF, the inductor stored energy as well as Source E_{DC} supply the load. Hence the load voltage becomes

$$E_O = E_{DC} + L\frac{dI_{DC}}{dt}$$

During the time T_{ON} when chopper is ON, the energy input to the inductor from the source is given by $W_I = E_{DC} I_{DC} T_{ON}$

During the time T_{OFF} when chopper is OFF, energy released by the inductor to the load is given by

$$W_O = (E_O - E_{DC}) I_{DC} T_{OFF}$$

Considering the system to be lossless, the above two energies will be equal.

Hence WI = WO

Or $E_{DC} I_{DC} T_{ON} = (E_O - E_{DC}) I_{DC} T_{OFF}$

Or $E_{DC} T_{ON} + E_{DC} T_{OFF} = E_O T_{OFF}$

Or $E_O = E_{DC} \frac{T_{ON}+T_{OFF}}{T_{ON}}$

Or $E_O = E_{DC} \frac{T}{T_{OFF}}$

Or $$E_O = E_{DC} \frac{1}{1 - \frac{T_{ON}}{T}}$$

Or $$E_O = \frac{E_{DC}}{1 - \alpha}$$

Hence the output voltage E_O will vary in the range $E_{DC} < E_O < \infty$ for the variation of duty cycle α in the range $0 < \alpha < 1$.

CONTROL MODES OF CHOPPER:

There are two types of control modes of Chopper

(i) Time ratio control

(ii) Current limit control

TIME RATIO CONTROL:

In time ratio control the value of T_{ON} and T_{OFF} is varied. This is affected in two ways.

(a) Constant frequency system

(b) Variable frequency system

CONSTANT FREQUENCY SYSTEM:

In this type of control mode, the ON time T_{ON} is varied but the chopping frequency f (f=1/T) is kept constant. This control strategy is also called pulse width modulation control.

VARIABLE FREQUENCY SYSTEM:

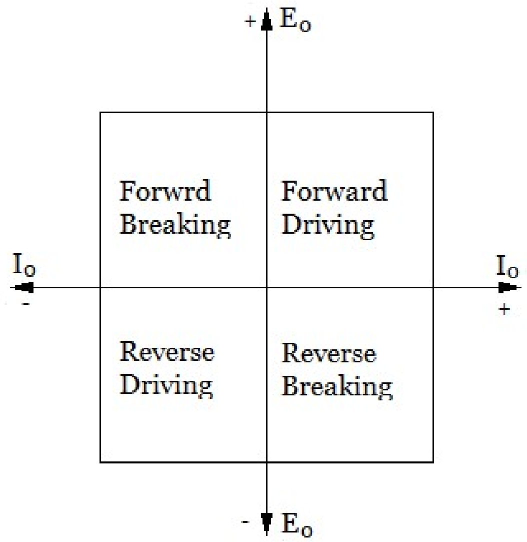
In this type of control mode, the chopping frequency *f* is varied and either ON time T_{ON} is kept constant or OFF time T_{OFF} is kept constant. This control strategy is also called frequency modulation control.

CURRENT LIMIT CONTROL:

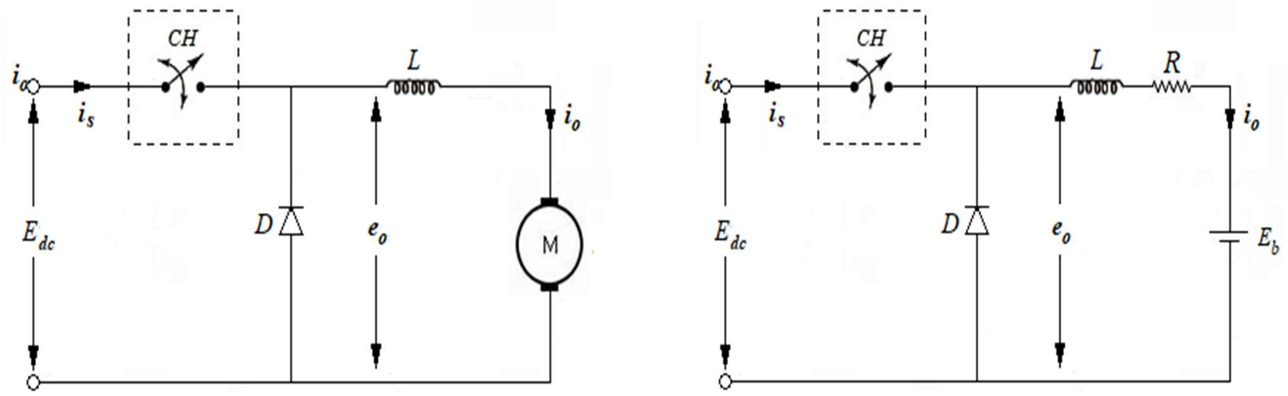
In current limit control mode, the chopper is switched ON and OFF so that the current in the load is maintained between two limits. When the current exceeds upper limit, the chopper is switched OFF. During off period, the load current freewheels and decreases exponentially. When it reaches the lower limit, the chopper is switched ON. Current limit control is possible either with constant frequency or variable frequency. The current limit is only used when the load has energy stored elements.

OPERATION OF CHOPPER IN ALL FOUR QUADRANTS:

Choppers may be classified according to the number of quadrant of the E_O-I_O diagram in which they are capable of operating. By various combination of connection it is possible to realize any combination of output voltage and current. If the load is a separately excited motor of constant field, then the positive voltage and Positive current in the first quadrant give rise to a forward drive. Changing the polarity of voltage and current results is a reverse drive (third quadrant). In second and fourth quadrants, the direction of energy flow is reversed and the motor operates as a generator braking rather than driving.

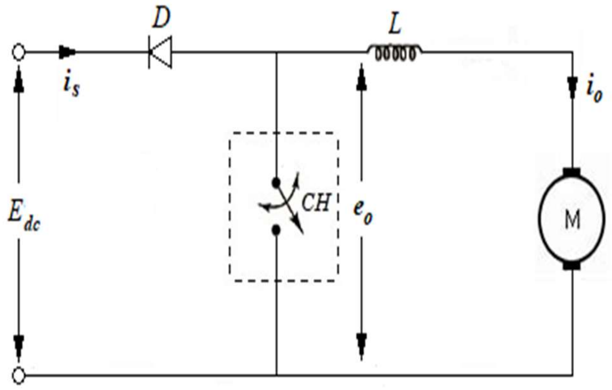


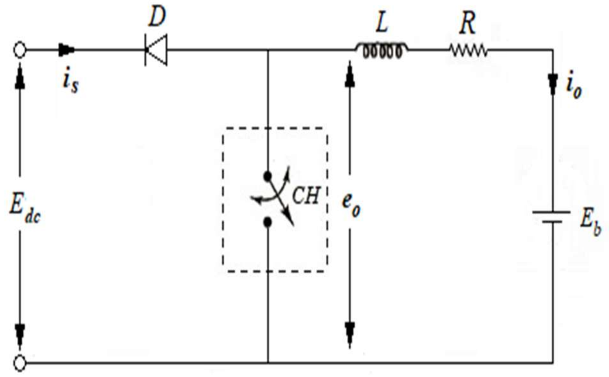
CLASS A CHOPPER:



When the chopper is ON, $E_O = E_{DC}$ and load current flows into the load. When chopper is OFF, $E_O = 0$ and a load current due to inductor stored energy continues to flow in the same direction through the freewheeling diode D. Therefore both average load voltage E_O and current I_O are positive and this power flows from source to load. Therefore this configuration is used for motoring operation of DC motor load. This Chopper is also called step down chopper as average output voltage is always less than input voltage.

CLASS B CHOPPER:

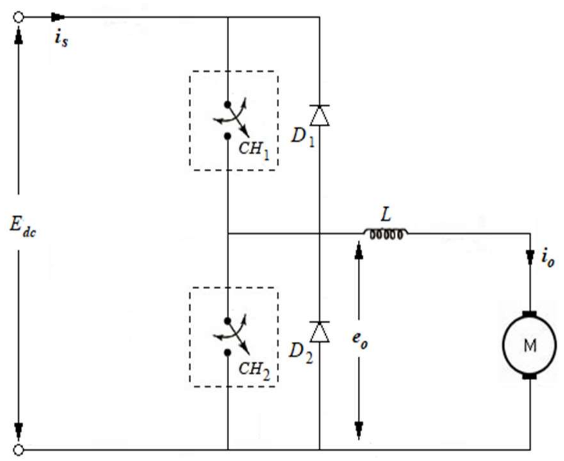


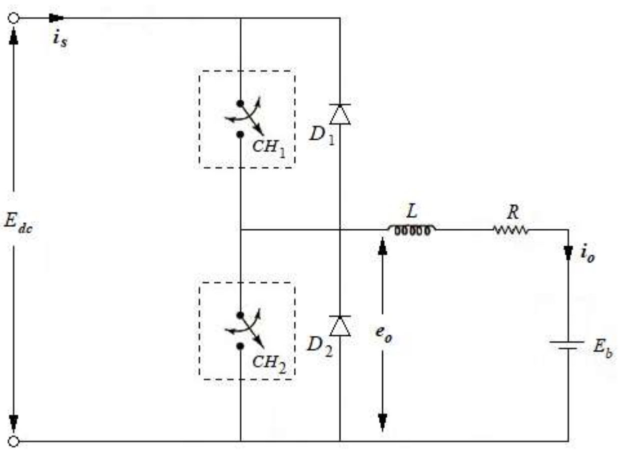


When the chopper is ON, the back emf E_B stores energy in inductance L, when the chopper is OFF, the inductor load energy and the back emf E_B delivered Current to the input source E_{DC}. As the direction of the load current has opposite direction, so the average load current is negative. The average load is positive as the direction of the load voltage is same. This results in the power flow from the load to Source. Hence this type of chopper operates in second quadrant. This chopper is used for regenerative braking of de motors.

CLASS C CHOPPER:

When chopper CH_1 is closed load current I_{DC} flows through L, R and return to source, hence it is positive. Here load receives power from the supply. Therefore the output voltage E_O = E_{DC} and positive. As both the current and voltage are positive, we can say that the chopper operates in the first quadrant and motor drives. When the chopper CH_1 is turned OFF, the stored energy dissipates through diode D_1 in the same direction.

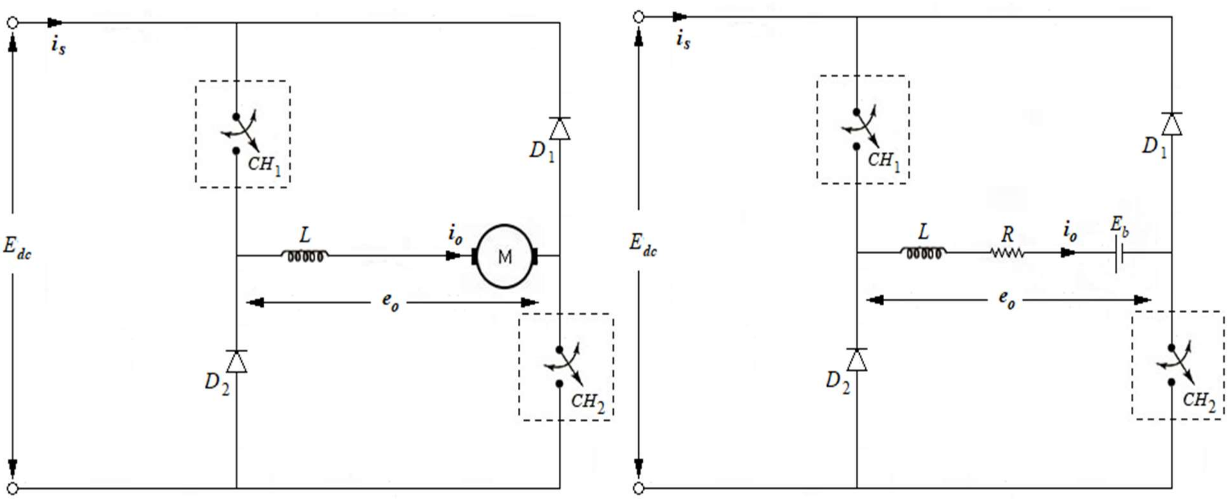




When the load current becomes zero, the chopper CH_2 is turned ON. Then the back emf E_B forces the current through R, L and CH_2. This continues until CH_2 is turned OFF. Then the back emf and inductor stored energy forces current through diode D_2 to the supply. The direction as the current becomes negative but the polarity of the output voltage is same. So here the chopper operates is second quadrant. As the current direction is negative, the motor experiences, breaking.

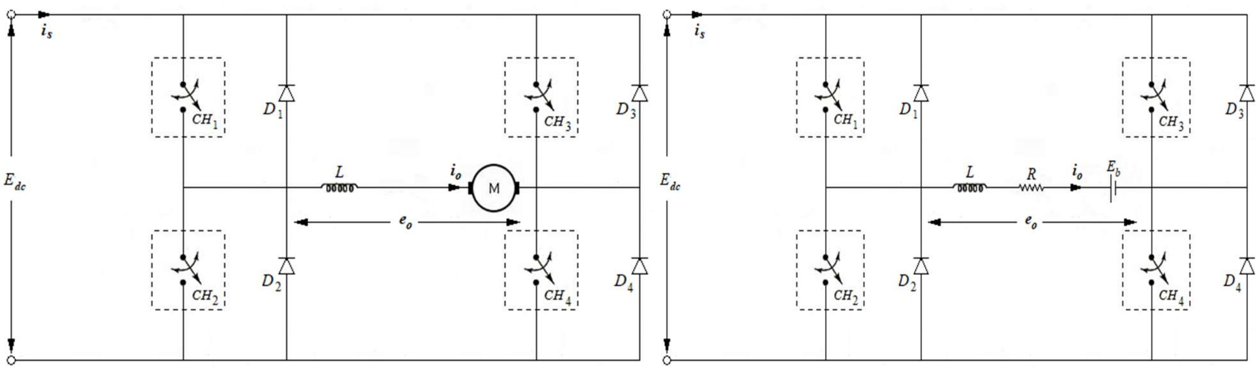
CLASS D CHOPPER:

When both the choppers are turned ON, the load current flows through the path E_{DC+}-CH_1–load-CH_2–E_{DC-}. Here both load current and load voltage are positive and hence the chopper operates in first quadrant. When one chopper is turned OFF, a diode short circuits the load and load voltage becomes zero. When both the choppers are turned OFF, the load current flows through Load-D_2-E_{DC+}-E_{DC-}-D_1-load.



Here the direction of the load remains same but the polarity of the output voltage becomes negative. So the chopper operates in fourth quadrant.

CLASS E CHOPPER:



When the choppers CH_1 and CH_4 are turned ON, the current flows through the path E_{DC+}-CH_1-load-Ch_4-E_{DC-}. Since both E_O and I_O are positive, we get the first quadrant operation. When both the choppers are turned OFF, load dissipates its energy through the path load-D_3-E_{DC+}-E_{DC-}-D_2-load. In this case E_O is negative while I_O is positive and fourth quadrant of operation is possible. When choppers CH_2 and CH_3 are turned ON, current flows through the path, E_{DC+}-CH_3-load-CH_2-E_{DC-}.

Since both E_O and I_O are negative, we get the third quadrant operation. When both the choppers are turned OFF, load dissipates its energy through the path load-D_1-E_{DC+}-E_{DC-}-D_4-load. In this case E_O is positive and I_O is negative and second quadrant operation is possible.

QUESTION BANK

SHORT QUESTIONS WITH ANSWER:

Q: What is meant by phase angle?

A: The angle at which gate pulse is given to the SCR when it is forward biased. It is denoted by ‘α’.

Q: What is meant by extinction angle?

A: The angle at which the SCR is turned OFF before the forward voltage becomes zero. It is denoted by ‘β’.

Q: What is semi-converter?

A: A semi-converter is a one quadrant converter and it has one polarity of output voltage and current. It contains a mixture of diodes and SCRs allowing more limited control over the dc output voltage level than the full controlled rectifier.

Q: What is full-converter?

A: A full-converter is a two-quadrant converter and the polarity of its output voltage can be either positive or negative. However, the output current of full-converter has one polarity only. Here power can be transmitted from AC side to DC side (conversion) and from DC side to AC side (inversion).

Q: What is dual-converter?

A: If two full converters are connected back to back they form a dual converter. It can operate in four quadrants and both the output voltage and current can be either positive or negative.

Q: What is the function of freewheeling diodes in controlled rectifier?

A: A freewheeling diode is basically a diode connected across the inductive load terminals to prevent the development of high voltage across the switch. When the inductive circuit is switched off, this diode gives a short circuit path for the flow of inductor decay current and hence dissipation of stored energy in the inductor.

Q: Define chopper.

A: A chopper is a static device (or switch) used to obtain variable DC voltage from a source of constant DC voltage. Therefore, chopper may be thought of as DC equivalent of an AC transformer, since they behave is an identical manner. It consists of semiconductor device (SCR, BJT, and IGBT etc.), DC source, and circuit elements.

Q: What is meant by duty-cycle?

A: Duty cycle is defined as the ratio of the ON time of the chopper to the total time period of the chopper. It is denoted by α. Duty cycle $\alpha = \frac{T_{ON}}{T}$

Q: What are the control modes of chopper?

A: There are two types of control modes of Chopper

(i) Time ratio control

(ii) Current limit control

Q: Define current limit control.

A: In current limit control mode, the chopper is switched ON and OFF so that the current in the load is maintained between two limits. When the current exceeds upper limit, the chopper is switched OFF. During off period, the load current freewheels and decreases exponentially. When it reaches the lower limit, the chopper is switched ON.

LONG QUESTIONS:

Q: Explain single phase half wave converter with resistive load.

Q: Explain single phase half wave converter with resistive-inductive load.

Q: Explain single phase full wave bridge converter with resistive load.

Q: Explain single phase full wave bridge converter with resistive-inductive load.

Q: Explain three phase full wave bridge converter with resistive load.

Q: Explain single phase half wave ac regulator.

Q: Explain single phase full wave ac regulator.

Q: Explain working principle of step-down chopper.

Q: Explain working principle of step-up chopper.

Q: Explain class A chopper.

Q: Explain class B chopper.

Q: Explain class C chopper.

Q: Explain class D chopper.

Q: Explain class E chopper.

3. UNDERSTAND THE INVERTERS AND CYCLO-CONVERTERS

INVERTERS

A device that converts dc power into ac power at desired output voltage and frequency is called an inverter. Some industrial applications of inverters are for adjustable-speed ac drives, induction heating, stand by air-craft power supplies, UPS (uninterruptible power supplies) for computers, hvdc transmission lines etc

3.1 CLASSIFY INVERTERS.

1. Inverters can be broadly classified into two types;

Voltage source inverters and current source inverters. A voltage-fed inverter (VFI), or voltage-source inverter (VSI), is one in which the dc source h small or negligible impedance. In other words, a voltage source inverter has stiff de voltage source at its input terminals.

A current-fed inverter (CFI) or current-source inverter (CSI) is fed with adjustable current from a dc source of high impedance, i.e. from a stiff dc current source. In: a CSI fed with stiff current source, output current waves are not affected by the load.

2. From the viewpoint of connections of semiconductor devices, inverters are classified as under:
   1. Bridge inverters 2. Series inverters 3. Parallel inverters
3. According to the Type of Load
   Single-phase Inverter
   Three-phase Inverter
4. According to the Number of Levels at the Output
   Regular Two-Level Inverter
   Multi-level Inverter

3.2 EXPLAIN THE WORKING OF SERIES INVERTER.

Series Inverter (Load Commutated Inverter or Self Commutated Inverter)

The commutating components L and C are connected in series with the load therefore this inverter is called as SERIES INVERTER.

The value of commutating components is selected such that the circuit becomes under damped.

The anode current itself becomes zero in this inverter resulting the SCR turns off automatically therefore this inverter is also called as SELF COMMUTATED OR LOAD COMMUTATED INVERTER.

Power Circuit Diagram

The power circuit diagram of the series inverter is shown in the figure A. The SCR T1 and SCR T2 are turned on at regular interval in order to achieve desirable output voltage and output frequency.

The SCR T2 is kept off at starting condition and polarity of voltage across capacitor is shown in the figure A.

The operation of the series inverter is explained as follows.

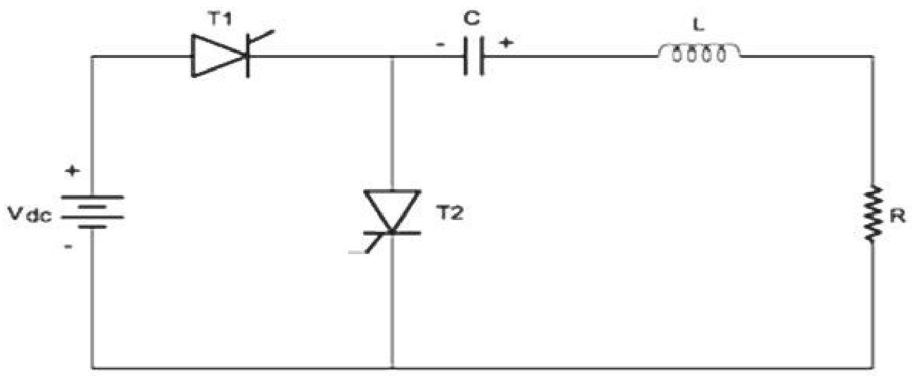


FIGURE A : BASIC SERIES INVERTER

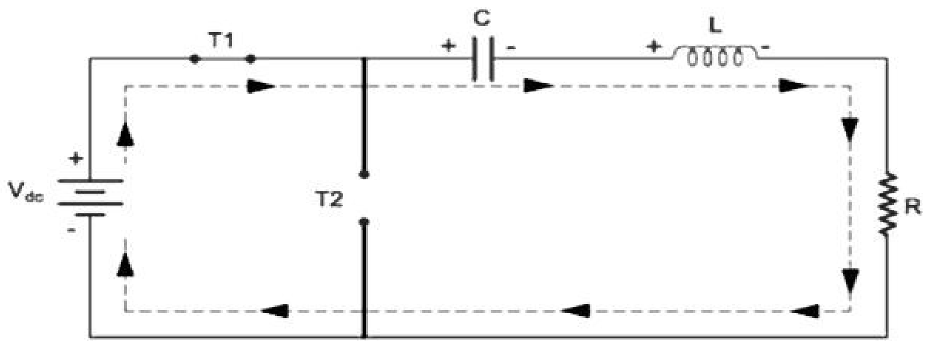


FIGURE B : EQUIVALENT CIRCUIT WHEN SCR T1 'ON'

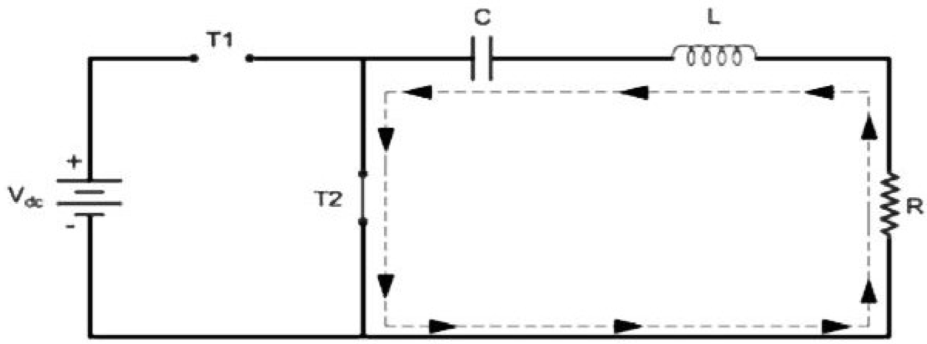


FIGURE C : EQUIVALENT CIRCUIT WHEN SCR T2 'ON'

Operation

Mode 1

The voltage V_{dc} directly applies to RLC series circuit as soon as the SCR T1 is turned on.

The polarity of capacitor charging is shown in the figure B.

The nature of the load current is alternating as there is under damped circuit of the commutating components.

The voltage across capacitor becomes + V_{dc} when the load current becomes maximum.

The voltage across capacitor becomes $+2V_{dc}$ when the load current becomes zero at point a (figure D).

The SCR T1 automatically turns off at point a because the load current becomes zero.

Mode 2

The load current becomes zero from point a to b as the SCR T1 turns off in this time period.
The SCR T1 and SCR T2 are turned off in this time duration and voltage across capacitor becomes equal to +2 V_{dc}.

Mode 3

The SCR T2 is turned on at point b due to it receives positive capacitor voltage.
The discharging of capacitor is done through SCR T2 and R – L circuit as shown in the figure C.
The load current becomes zero after it becomes maximum in the negative direction.
The capacitor discharges from +2 V_{dc} to – V_{dc} during this time and SCR T2 turns off automatically at point C due to load current becomes zero.
The SCR T2 turns off during point C to D and SCR T1 again turns on. This way cycle repeat after it complete one turns.
The positive AC output voltage half cycle generates due to DC voltage source whereas negative half cycle generates due to capacitor.
There is always some time delay kept between one SCR turned on time and other SCR turned on time.
The DC output gets short circuited due to continuous conduction of both SCRs if there is no time delay between SCRs.
The time duration ab and cd must be greater than the SCR specific turn off time and it is called as dead zone.

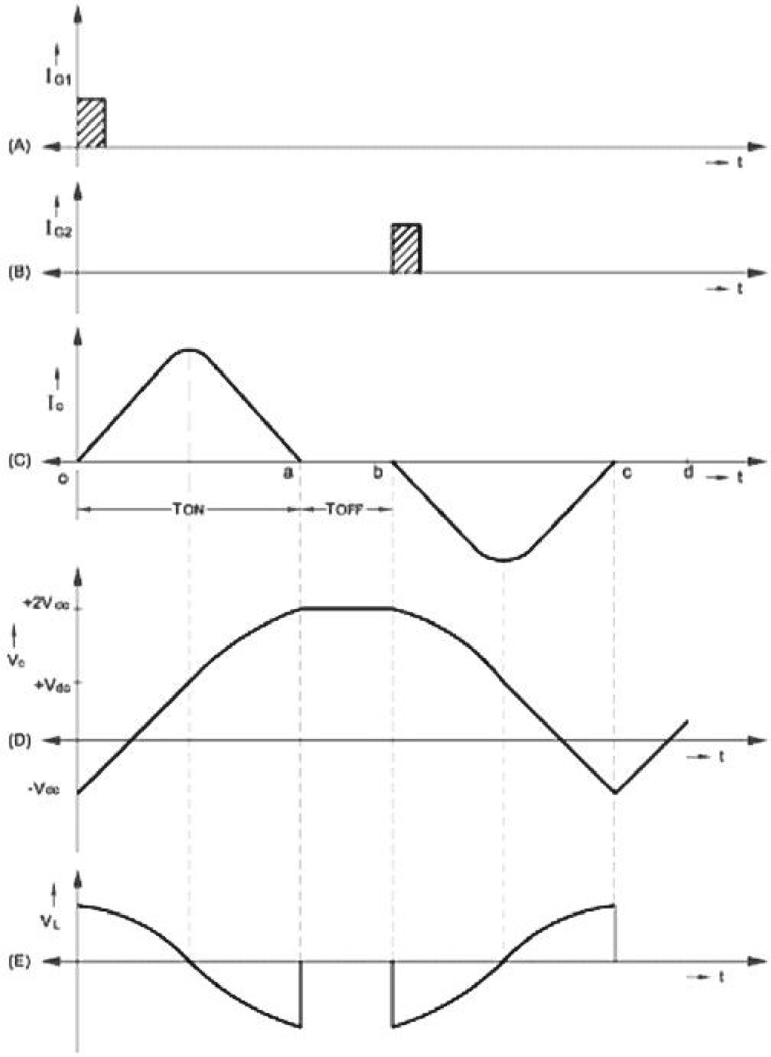


FIGURE D : VOLTAGE AND CURRENT WAVEFORMS OF SERIES INVERTER
(A) Gate pulse for SCR T1 (B) Gate pulse for SCR T2 (C) output current,
(D) Capacitor voltage (E) Load voltage

Limitations of Series Inverter

The limitation of series inverter is as given below.

The load current flows only during positive half cycle from supply source.

The DC supply source gets short circuited if SCR T1 and SCR T2 simultaneously turned on.

The rating of commutating components should high because the load current flows through it.

The load voltage waveform gets distorted if the dead zone time or SCR turns on time high.

The maximum output frequency of the inverter should be less than the ringing frequency.

The DC supply source is short circuited if the output frequency of the inverter is higher than the ringing frequency.

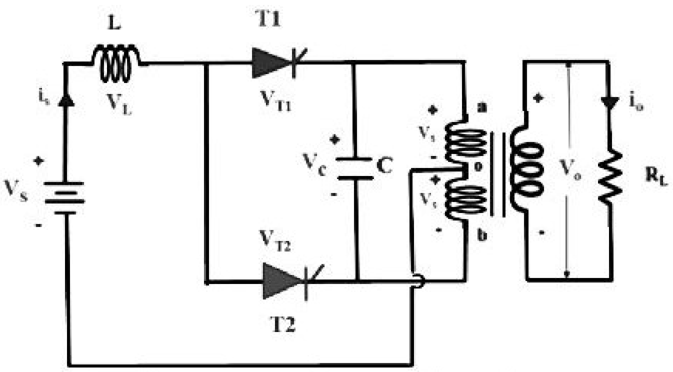
The maximum current during each high cycle and its time duration depends upon parameter of load this will result in poor regulation of the inverter output.

Applications

- This type of inverter generates sinusoidal waveform whose output frequency is in the range of 200 Hz to 100 kHz therefore it is applicable for
- Induction heating
- Sonar transmitter
- Fluorescent lighting and
- Ultrasonic generator

3.3 EXPLAIN THE WORKING OF PARALLEL INVERTER

Parallel inverter circuit consist of two thyristor T1 and T2, a transformer, inductor L and a commutating component C. Capacitor (C) is connected in parallel with the load via transformer therefore it is called a parallel inverter. And inductor (L) is connected in series with supply to make the source current constant. Here we also use a center -tapped transformer. Centre tapping is done in the primary winding of transformer so, primary winding is divided into two equal halves ao and ob.

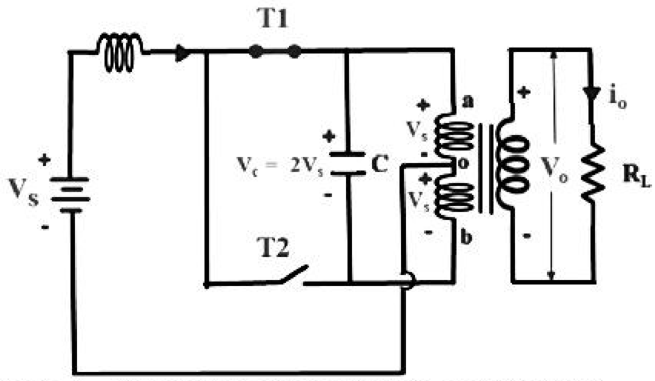


Circuit Diagram of Parallel Inverter

Operation of Parallel Inverter:

The operation is divided into four modes:

Mode I (0< t < t1): In this mode we give firing pulse to thyristor T1 and T1 get turned on and T2 is turned off. Current flow from Supply Vs .... T1.... ao (upper half of primary winding) .... back to Vs. As a result, Vs voltage is induced across upper as well as lower half of the primary winding of transformer. And Vs voltage is induced in secondary winding.

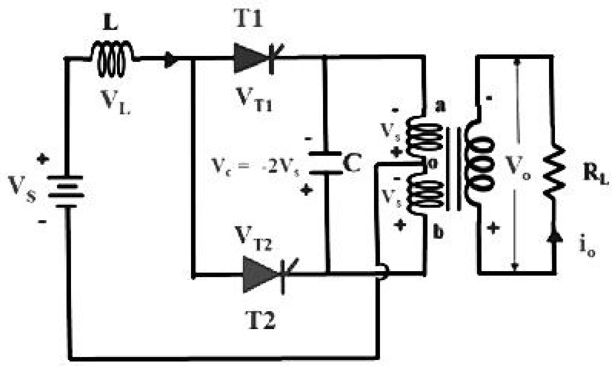


Mode I – Operation where T1 ON and T2 OFF

So, output voltage across load is Vs.

So, the total voltage across primary winding is 2Vs. Here capacitor is connected in parallel with primary winding therefore capacitor charge with 2Vs voltage with upper plate is positive and lower plate is negative.

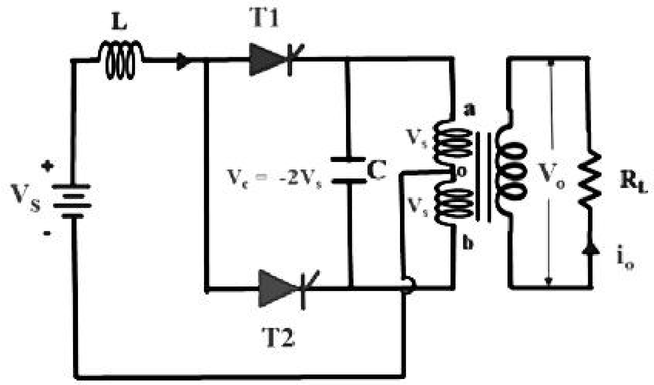
Mode II (t1< t < t3): In this duration we give firing pulse to thyristor T2 and T2 get turned on. At this time capacitor start discharging through T1 therefore T1 turned OFF. This time current flow from supply Vs …. T2…. bo (lower half of primary winding) …. back to Vs.



Mode II – Operation

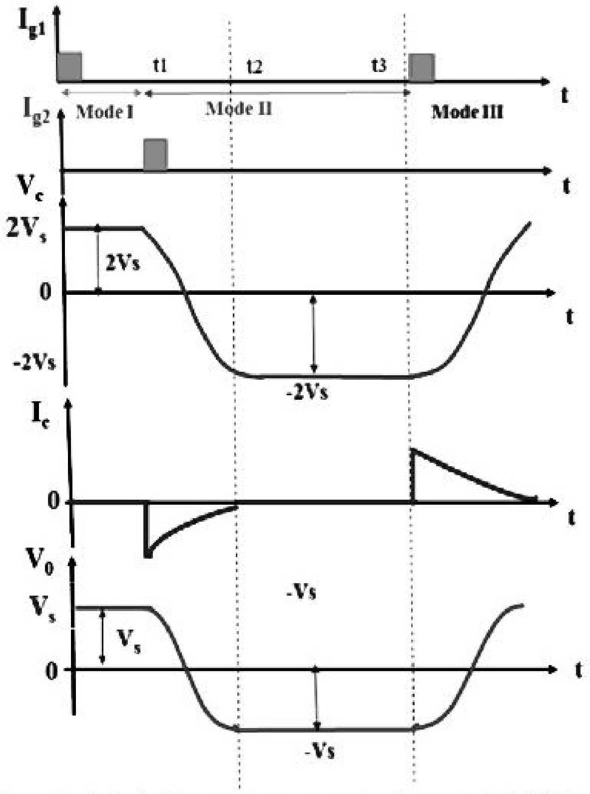
Now this time capacitor charged with upper plate is negative, from +2Vs at t=t1 to -2Vs at t=t2. Load voltage also changes from Vs at t=t1 to -Vs at t=t2. After t=t2 voltage across capacitor is maintain constant -2Vs between t= t2 to t3.So, load voltage is also constant -Vs.

Mode III (t3< t < t4): In this mode again, we give firing pulse to thyristor T1 and T1 get turned on. At this time capacitor start discharging through T2 therefore T2 turned OFF. This time current flow from supply Vs …. T1…. ao (upper half of primary winding) …. back to Vs. So, the total voltage across primary winding is 2Vs.



Mode III – Operation

Now this time capacitor charged with upper plate is positive, from -2Vs at t=t3 to +2Vs at t=t4. Load voltage also changes from Vs at t=t3 to -Vs at t=t4.So, output voltage across load is Vs.



Waveform of parallel Inverter 1) Ig1 is the gate current given to T1 2) Ig2 is the gate current given to T2. 3) Vc capacitor voltage 4) Ic current across capacitor 5) Vo output voltage waveform

3.4 EXPLAIN THE WORKING OF SINGLE-PHASE BRIDGE INVERTER.

Single phase half bridge inverter

Circuit Description:-

- Two Thyristor S1 and S2 are used along with two feedback diode D1 and D2 respectively.
- Resistive load is connect between point A and B, as shown in fig:-
- Supply voltage is divided into 2 parts, here two DC voltage source are used V/2 and V/2.
- Fig of the single phase half bridge inverter is given below:

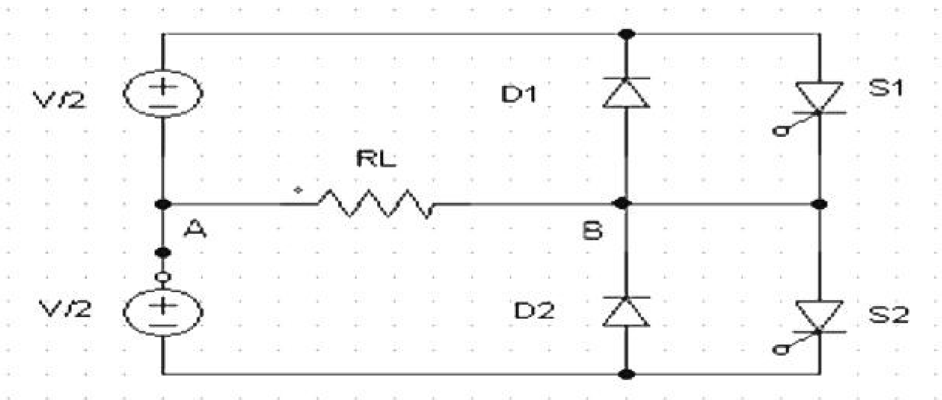


Fig : Single phase half bridge inverter

Working:

- Mode 1 (0 to T/2):-
- During this mode switch S1 is ON and switch S2 is OFF From period 0 to T/2.
- Current flowing path during this mode is V/2-S1-B-R(Load resistor)-A-V/2.
- Hence the voltage across the load is positive V/2

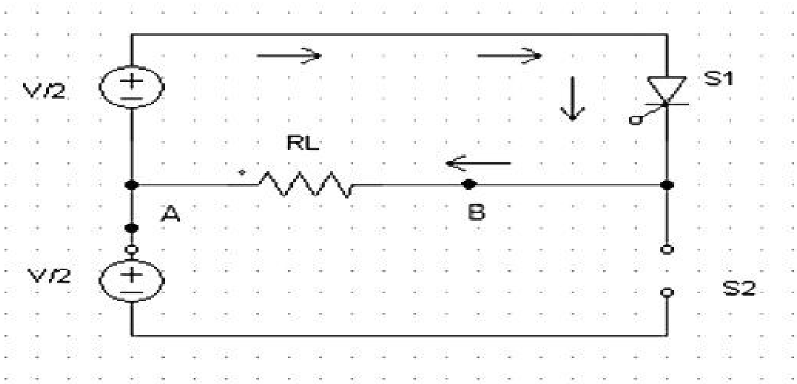


Fig: conducting mode 1

Mode 2 (T/2 to T):-

- During this mode switch S1 is OFF and switch S2 is ON From period T/2 to T.
- Current flowing path during this mode is V/2-A-R(Load resistor)-B-S2-V/2.
- Hence the voltage across the load is negative V/2.

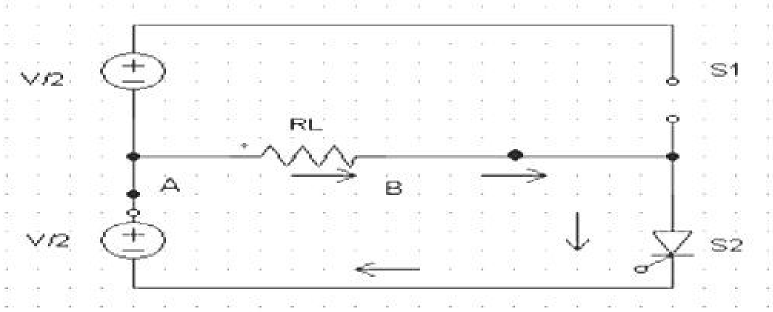


Fig: conducting mode 2

1. Load is resistive hence it does not store any charge therefore feedback diode D1 and D2 are not effective here.
2. The main drawback of half bridge inverter is that two DC voltage source are require. By using full bridge inverter we can overcome that drawback.

Waveform of output voltage thyristor current with resistive load are shown in fig

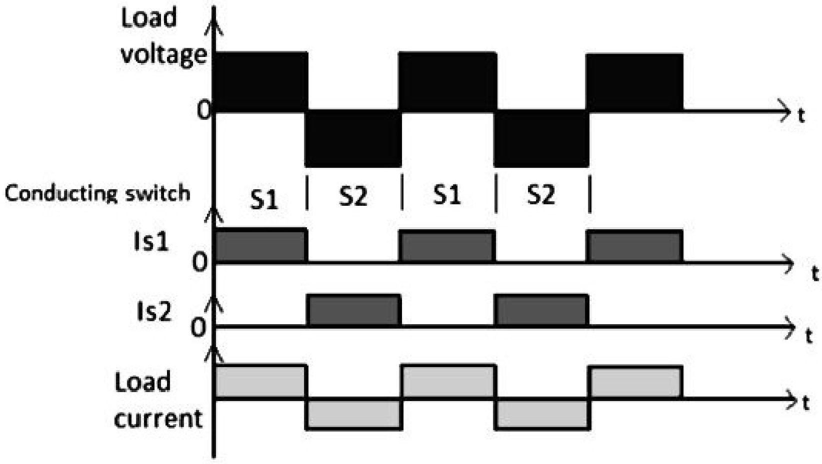


fig: waveform single phase half bridge inverter

Single phase Full bridge inverter

Circuit Description:-

- Four thyristor are used in full bridge inverter. Thyristor S1 and S2 are used along with two feedback diode D1 and D2 and thyristor S3 and S4 are used along with another two feedback diode D3 and D4 respectively.
- Resistive load is connect between point A and B,as shown in fig:-
- DC voltage source is applied to circuit.
- Fig of the single phase full bridge inverter is given below:

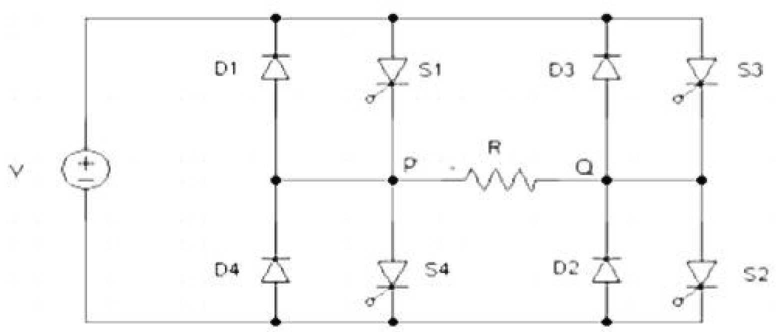
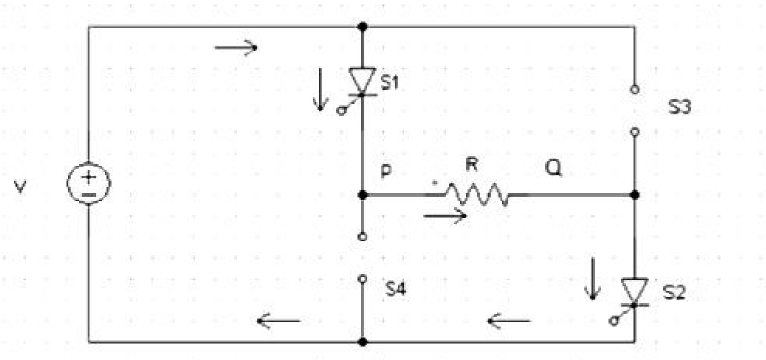


Fig: single phase full bridge inverter

Mode 1 (0 to T/2):-

- During this mode switch S1 and switch S2 are ON and switch S3 and switch S4 are OFF From period 0 to T/2.
- Current flowing path during this mode is Vdc – S1- P -R(load reistor) – Q – S2 – Vdc.
- Voltage across the load resistor is positive Vdc



fig; conducting mode 1

Mode 2 (T/2 to T):-

- During this mode switch S3 and switch S4 are ON and switch S1 and switch S2 are OFF From period T/2 to T.
- Current flowing path during this mode is Vdc – S3 – Q – R(load reistor) – P – S4 – Vdc.
- Voltage across the load resistor is negative Vdc.

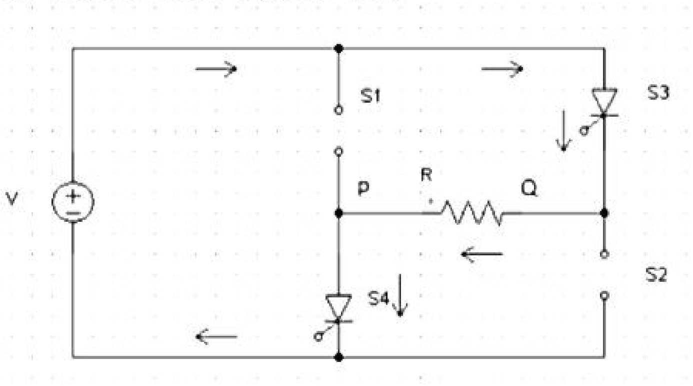


fig : conducting mode 2

1. Load is resistive hence it does not store any charge. therefore, feedback diode D1, D2, D3 and D4 are not effective here.

Waveform of output voltage thyristor current with resistive load are shown in fig:

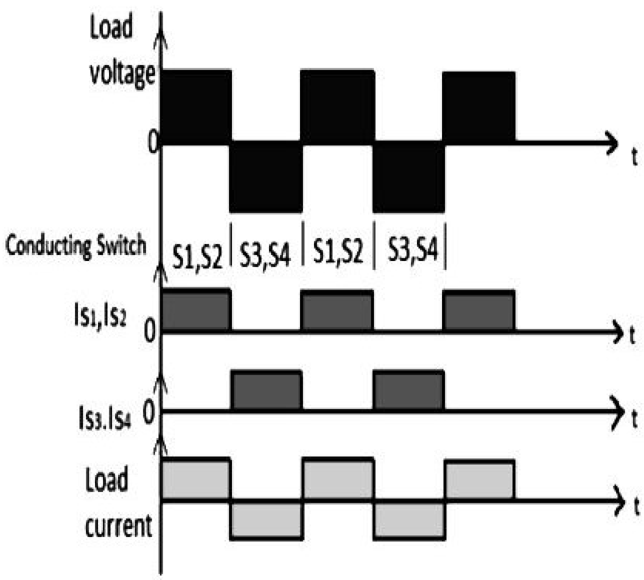


Fig: waveform single phase full bridge inverter

3.5 EXPLAIN THE BASIC PRINCIPLE OF CYCLO-CONVERTER

Cyclo-converters are AC to AC converters and are used to vary the frequency of a supply to a desired load frequency. A cycloconverter achieves this through synthesizing the output waveform from segments of the AC supply (without an intermediate DC link). These are naturally commutated, direct frequency converters that use naturally commutated thyristors. These are mainly used in high power applications up to tens of megawatts for frequency reduction.

Some of the applications of Cyclo-converter include high power AC drives, propulsion systems, high frequency induction heating, synchronous motors in sea and undersea vehicles, electromagnetic launchers, etc.

3.6 EXPLAIN THE WORKING OF SINGLE-PHASE STEP UP & STEP DOWN CYCLO-CONVERTER.

STEP-DOWN CYCLOCONVERTER

Step-down cycloconverter is a device which steps down the fixed frequency power supply input into some lower frequency. It is a frequency changer. If f_s & f_o are the supply and output frequency, then $f_o < f_s$ for this cycloconverter.

The most important feature of step-down cycloconverter is that it does not require force commutation. Line or Natural Commutation is used which is provided by the input AC supply.

Circuit Diagram:

There are two circuit configurations of a step-down cycloconverter: Mid-point and Bridge type. This article focuses on the mid-point type. The operation for continuous and discontinuous type of RL load is explained for mid-point type cycloconverter.

Figure below shows the circuit diagram of mid-point type cycloconverter. The positive direction of voltage and current are marked in the diagram.

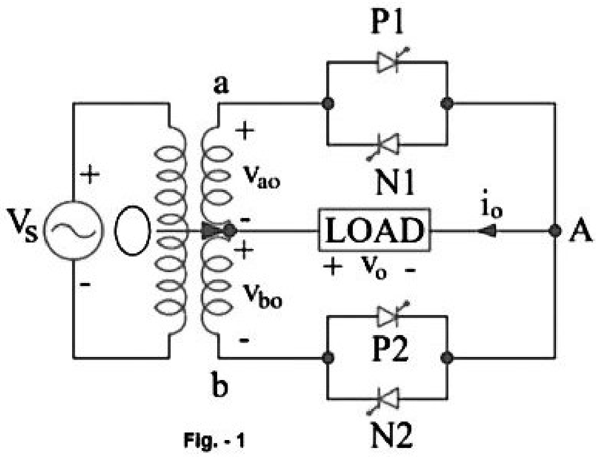


Fig. - 1

Working of Step-down Cycloconverter:

The working principle of step-down cycloconverter is explained for discontinuous and continuous load current. The load is assumed to be comprised of resistance (R) & inductance (L).

Discontinuous Load Current:

For positive cycle of input AC supply, the terminal A is positive with respect to point O. This makes SCRs P1 forward biased. The forward biased SCR P1 is triggered at $\omega t = 0$. With this, load current i_o starts building up in the positive direction from A to O. Load current i_o becomes zero at $\omega t = \beta > \pi$ but less than $(\pi+\alpha)$. Refer figure-2. The thyristor P1 is thus, naturally commutated at $\omega t = \beta$ which is already reversed biased after π.

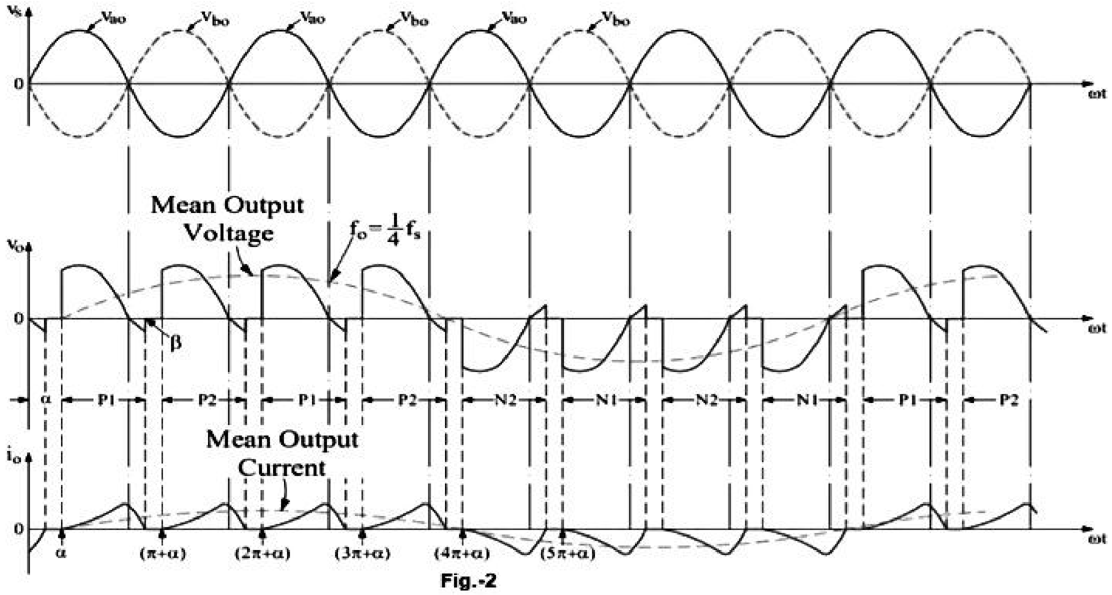


Fig.-2

After half a cycle, b is positive with respect to O. Now forward biased thyristor P2 is fired at $\omega t = (\pi+\alpha)$. Load current is again positive from A to O and builds up from zero as shown in figure-2. At $\omega t = (\pi+ \beta)$, i_o decays to zero and P2 is naturally commutated. At $\omega t = (2\pi+\alpha)$, P is again turned ON. Load current in figure-2 is seen to be discontinuous.

After four positive half cycles of load voltage and load current, thyristor N2 is gated at $(4\pi+\alpha)$ when O is positive with respect to b. As N2 is forward biased, it starts conducting but the direction of load current is reverse this time i.e. it flows from O to A. After N2 is triggered, O is positive with respect to "a" but before N1 is fired, i_o decays to zero and N2 is naturally commutated. Now when N1 is gated at $(5\pi+\alpha)$, i_o again builds up but it decays to zero before thyristor N2 in sequence is again gated.

In this manner, four negative half cycles of load voltage and load current, equal to number of positive half cycles of load voltage & current, are generated. Now P1 is again triggered to fabricate four positive half cycles of load voltage and so on. It may be noted that, natural commutation is achieved for discontinuous current load.

Form figure-2, the waveform of mean load voltage & current may be noted. It is clear that the output frequency of load voltage & current is (¼) times of input supply frequency.

STEP-UP CYCLOCONVERTER

Working Principle of Step-up Cycloconverter:

The working principle of a step-up cycloconverter is based on switching of thyristors in a proper sequence. The thyristor acts as a power switch. These switches are arranged is a specific pattern

so that the output power is available for both the positive and negative half of the input power supply. Forced commutation technique is used to turn OFF the conducting thyristor.
Two circuit configurations are possible for step-up cycloconverter: Mid-point Type and Bridge Type. In this article, we will consider mid-point type of circuit arrangement for better understanding of working principle.
Circuit Diagram:
Figure below shows the circuit diagram of Mid-point step-up cycloconverter:

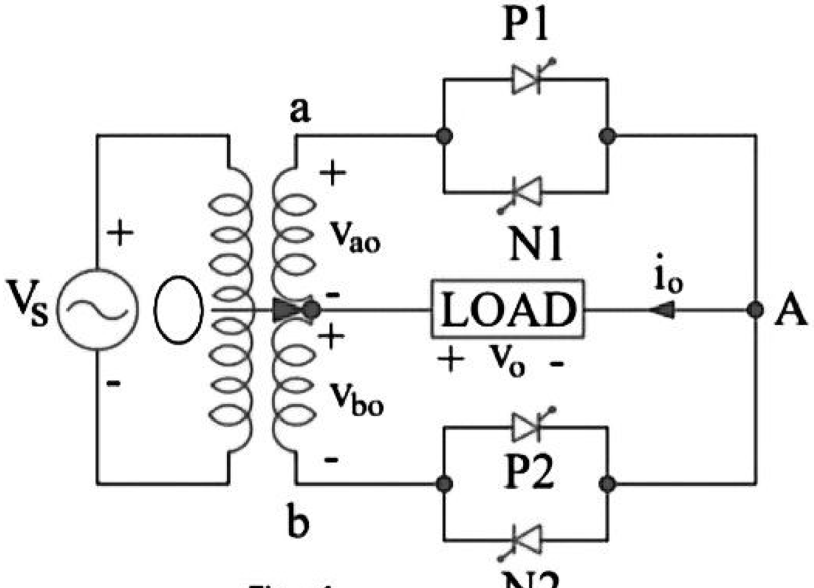


Fig. - 1

The circuit consists of a single phase transformer with mid tap on the secondary winding and four thyristors. Two of these thyristors P1 & P2 are for positive group. Here positive group means when either P1 or P2 conducts, the load voltage is positive. Other two thyristors N1 & N2 are for negative group. Load is connected between secondary winding mid-point O and terminal A. The load is assumed resistive for simplicity. Assumed positive direction for voltage and current are marked in the circuit diagram.

Operation of Step-up Cycloconverter:
During the positive half cycle of input supply voltage, positive group thyristors P1 & N2 are forward biased for $\omega t = 0$ to $\omega t = \pi$. As such SCR P1 is fired to turn it ON at $\omega t = 0$ such that load voltage is positive with terminal A positive and O negative. The load voltage, thus, follows the positive envelop of the input supply voltage. At some time instant $\omega t = \omega t_1$, the conducting thyristor P1 is force commutated and the forward biased thyristor N2 is fired to turn it ON. During the period N2 conducts, the load voltage is negative because O is positive & A is negative this time. The load or output voltage traces the negative envelop of the supply voltage. This is shown in figure below.

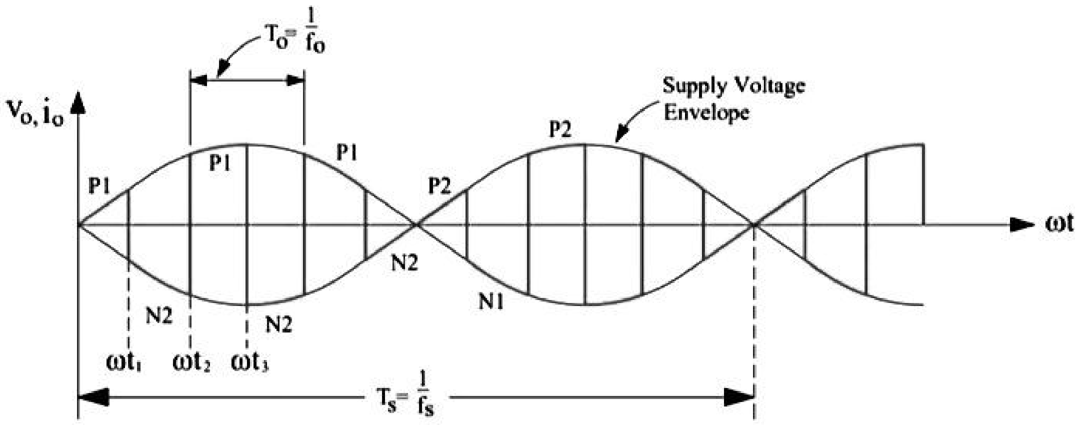


Fig. - 2

At $\omega t = \omega t_2$, N2 is force commutated and P1 is turned ON. The load voltage is now positive and follows the positive envelop of the supply voltage. At $\omega t = \pi$, terminal "b" is positive with respect to terminal "a"; both SCRs P2 & N1 are therefore forward biased from $\omega t = \pi$ to $\omega t = 2\pi$. AT $\omega t = \pi$, N2 is force commutated and forward biased SCR P2 is turned ON. The load voltage is positive and follows the positive envelop of supply voltage.
If the supply frequency is f_s and output frequency is f_o, P2 will be force commutated at $\omega t = (1/2f_s) + (1/2f_o)$. Carefully note this from the waveform shown in the figure-2.
When P2 is force commutated, forward biased SCR N1 is turned ON. This time, the load voltage is negative and follows the negative envelop of the supply input.
In this manner, SCRs P1, N2 for the first half cycle; P2, N1 in the second half cycle and so on are switched alternately between positive and negative envelops at a high frequency. This results in output frequency f_o more than the input supply frequency f_s. In our example of figure-2, note that there is a total of 6 cycles of output in one cycle of input supply. This means that frequency of output voltage is 6 times of input frequency i.e. $f_o = 6f_s$.

3.7 APPLICATIONS OF CYCLO-CONVERTER.

Application of Cycloconverter:
The general use of cycloconverter is to provide either a variable frequency power from a fixed input frequency power as in AC motor speed control or a fixed frequency power from a variable frequency power as in aircraft or wind generators.
Some of the major applications of cycloconverter are as follows:

- Speed control of high power AC drives
- Induction heating
- Static VAR compensation
- It is used for converting variable speed alternator voltage to constant frequency output voltage for use as power supply in aircrafts or shipboards.

QUESTION BANK

SHORT QUESTIONS WITH ANSWER:

Q: What is inverter?

A: An inverter is an circuit which converts DC power into an AC power at desired output voltage fand frequency.

Q: Write two advantage of inverter.

A: Two advantage of inverter are

It is used for variable speed of AC motor drives.

It is used for induction heating.

Q: What is series inverter?

A: The inverter circuit in which the commutating elements L and C are connected in series with the load to form an under damped circuit is called a series inverter.

Q: What is parallel converter?

A: The inverter circuit in which the commutating elements L and C are connected in parallel with the load.

Q: What are the Disadvantages of Series Inverter?

A: Disadvantages of Series Inverter are

A parallel inverter circuit is very simple, small in size, and less expensive as it employs complementary voltage commutation.

By using filter circuits at the output side, a good quality waveform can be obtained.

Compare to a series inverter, the commutating components in parallel inverter do not have to carry the entire load current.

Compared to the series inverter, parallel inverters have better output voltage.

Q: What are the advantages of parallel Inverter?

A: Advantages of parallel Inverter are

A parallel inverter circuit is very simple, small in size, and less expensive as it employs complementary voltage commutation.

By using filter circuits at the output side, a good quality waveform can be obtained.

Compare to a series inverter, the commutating components in parallel inverter do not have to carry the entire load current.

Compared to the series inverter, parallel inverters have better output voltage.

Q: Define cyclo converter.

A: Cycloconverters are frequency changers that convert AC power of specific frequency and voltage to different frequency and voltage of AC power without any intermediate DC link.

Q: What is the function of cyclo converter?

A: Function of cyclo converter are

Speed control of high power AC drives.

Static VAR compensation

converting variable speed alternator voltage to constant frequency output voltage for use as power supply in aircrafts or shipboards.

LONG QUESTIONS:

Q: Explain operation of siries inverter.

Q: Explain operation of parallel inverter.

Q: Explain operation of single phase half bridge inverter

Q: Explain operation of single phase full bridge inverter.

Q: Explain operation of step-up cyclo-converter.

Q: Explain operation of step-down cyclo-converter.

4. UNDERSTAND APPLICATIONS OF POWER ELECTRONIC CIRCUITS

4.1 LIST APPLICATIONS OF POWER ELECTRONIC CIRCUITS.

- Our Daily Life: If we look around ourselves, we can find a whole lot of power electronics applications such as a fan regulator, light dimmer, air-conditioning, induction cooking, emergency lights, personal computers, vacuum cleaners, UPS (uninterrupted power system), battery charges, etc.
- Automotives and Traction: Subways, hybrid electric vehicles, trolley, fork-lifts, and many more. A modern car itself has so many components where power electronic is used such as ignition switch, windshield wiper control, adaptive front lighting, interior lighting, electric power steering and so on. Besides power electronics are extensively used in modern traction systems and ships.
- Industries: Almost all the motors employed in the industries are controlled by power electronic drives, for eg. Rolling mills, textile mills, cement mills, compressors, pumps, fans, blowers, elevators, rotary kilns etc. Other applications include welding, arc furnace, cranes, heating applications, emergency power systems, construction machinery, excavators etc.
- Defense and Aerospace: Power supplies in aircraft, satellites, space shuttles, advance control in missiles, unmanned vehicles and other defense equipments.
- Renewable Energy: Generation systems such as solar, wind etc. needs power conditioning systems, storage systems and conversion systems in order to become usable. For example solar cells generate DC power and for general application we need AC power and hence power electronic converter is used.
- Utility System: HVDC transmission, VAR compensation (SVC), static circuit breakers, generator excitation systems, FACTS, smart grids, etc.

4.2 LIST THE FACTORS AFFECTING THE SPEED OF DC MOTORS.

According to the speed equation of a d.c. motor we can write,

$$N \propto \frac{E_b}{\phi}$$

or $$N = K\frac{(V - I_a R)}{\phi} \text{ r.p.m.} \qquad \text{(i)}$$

where $R = R_a$ for shunt motor

$= R_a + R_{se}$. for series motor

The factors affecting DC control are therefore:

- The applied voltage
- The flux

- The voltage across an armature

Considering these factors, speed control can then be achieved through the following techniques:

- Flux control method: This is done by varying the current via the field winding, thus altering the flux.
- Rheostat control: changing the armature route resistance which also changes the applied voltage across the armature.
- Voltage method: changing the applied voltage

4.3 SPEED CONTROL FOR DC SHUNT MOTOR USING CONVERTER.

Speed Control of DC Shunt Motor

The power circuit diagram for speed control of the DC Shunt Motor is shown in the figure E.

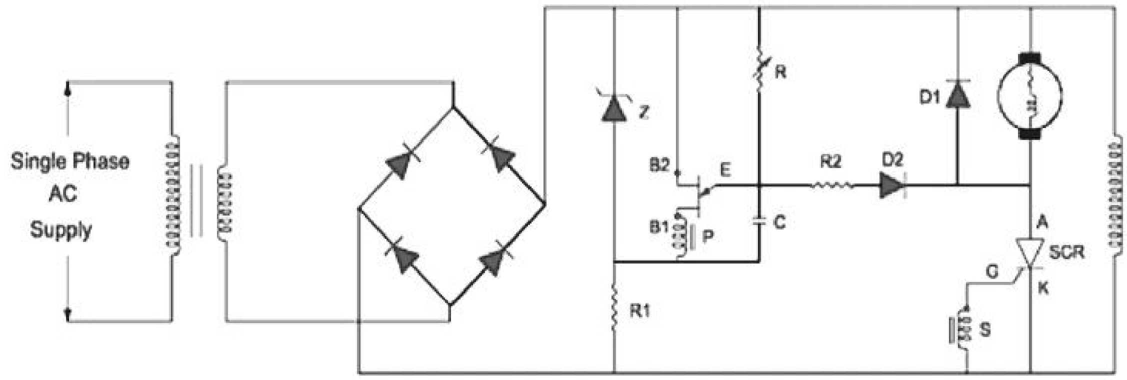


FIG E : Speed control of DC Shunt Motor

1. The function of the bridge rectifier is to converter alternating voltage in to direct voltage.
2. The zener diode clips the voltage and provides constant voltage.
3. The field winding of the DC shunt motor is connected across supply voltage.
4. The SCR is connected in series with the armature winding of the DC shunt motor.
5. The charging of capacitor is done through variable resistor R.
6. When the voltage across capacitor becomes equal to peak point voltage, the UJT turns on.
7. The discharging of capacitor is done through path C – EB1 – Primary of pulse transformer – C.
8. As soon as the pulse transformer primary energies, the SCR gets pulse through pulse transformer secondary.
9. Now the current passes through the armature winding of the DC motor.
10. The charging rate of the capacitor depends upon variable resistor R.
11. If the value of variable R is set minimum, the charging of capacitor done faster resulting UJT turns on in short time.

12. This will resulting the firing angle of the SCR decreases and DC motor speed increases.
13. If the value of resistor R set at maximum, the firing angle of SCR increases and DC motor speed decreases.
14. As the field winding gets constant voltage, the motor speed is directly proportional to back emf.
15. If the armature winding drop is neglected, the speed of the DC motor is directly proportional to armature voltage.
16. The speed of the DC motor is adjusted by the firing angle of the SCR.
17. When the UJT turns on, the diode D2 forward biases and diode D1 reverse biased therefore the charging of capacitor is done only through variable resistor R.
18. The diode D1 reverse biases when current passes through the armature winding.
19. As soon as the current passes through the armature winding becomes zero, the stored energy of armature winding dissipates through diode D1.

Speed Regulation

1. As the motor speed increases, the back emf also increases and diode D2 becomes forward biased in this condition.
2. As the charging path of capacitor and resistor R2 becomes parallel, the charging current of capacitor decreases and firing angle of SCR increases.
3. This will result the speed of motor decreases. If the motor speed decreases by any chance, the back emf decreases.
4. This will result in small current passes through shunt resistor R2 and firing angle of SCR decreases due to charging rate of capacitor increases.
5. The DC shunt motor speed increases due to decrease of firing angle.

4.4 SPEED CONTROL FOR DC SHUNT MOTOR USING CHOPPER.

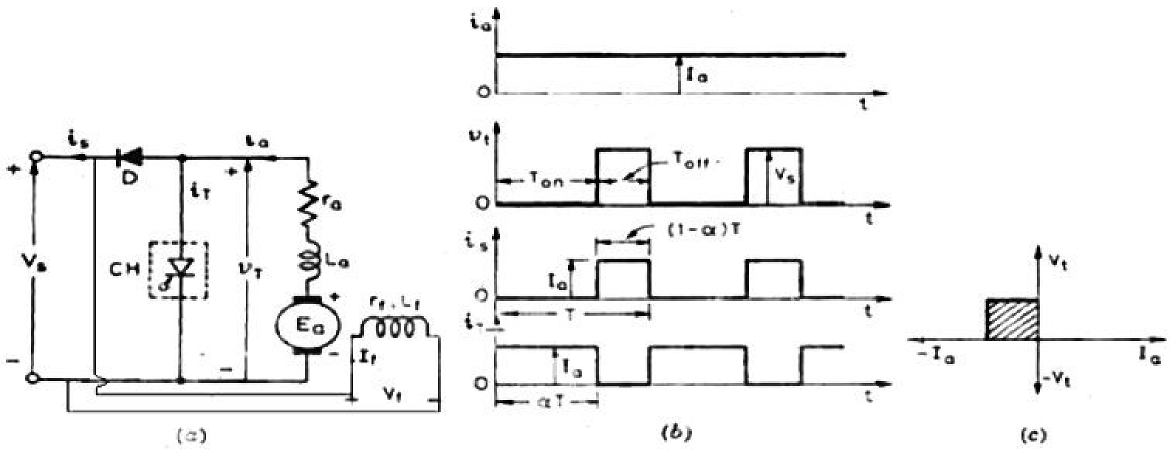
Chopper drive used for single quadrant regenerative braking control

In regenerative-braking control, the motor acts as a generator and the kinetic energy of the motor and connected load is returned to the supply.

During motoring mode, armature current Ia $=\frac{v_t - E_a}{r_a}$, i.e. armature current is positive and the motor consumes power. In case load drives the motor at a speed such that average value of motor counter emf Ea ($=k_m.\omega_m$) exceeds Vt, Ia is reversed and power is delivered to the dc bus. The motor is then working as a generator in the regenerative braking mode.

The principle of regenerative braking mode is explained with the help of Fig.(a), where a separately-excited dc motor and a chopper are shown. For active loads, such as a train going down the hill or a descending hoist, let it be assumed that motor counter emf Ea is more than the source voltage Vs When chopper CH is on, current through armature inductance La rises as the armature terminals get short 'circuited through CH. Also, v_t =0 during Ton. When chopper is turned off, Ea being more than source voltage Vs diode D conducts and the energy stored in armature inductance is transferred to the source. During T_{off} $v_t = V_s$ On the assumption of continuous and ripple free armature current, the relevant voltage and current waveforms are shown in Fig. (b). Regenerative braking control offers second quadrant operation as armature terminal voltage has the same polarity but the direction of armature current is reversed, Figs. (a) and (c). From the waveforms of Fig.(b), the following relations can be derived: The average voltage across chopper (or armature terminals) is

$$V_t = \frac{T_{off}}{T} . V_s = (1-\alpha)\ V_s$$



Regenerative braking of separately excited dc motor (a) circuit diagram (b)waveform (c)quadrant operation

Power generated by the motor

$$= V_t \cdot I_a = (1-\alpha)\ V_s \cdot I_a$$

Motor emf generated, $E_a = K_m\ \omega_m = V_t + I_a\ r_a$

$$= (1-\alpha)\ V_s + I_a\ r_a$$

Motor speed during regenerative braking,

$$\omega_m = \frac{(1-\alpha)\ V_s + I_a r_a}{K_m}$$

Motor speed during regenerative braking,

$$\omega_m = \frac{(1-\alpha)\ V_s + I_a r_a}{K_m}$$

When chopper is on, $E_a - I_a r_a - L_a \dfrac{di_a}{dt} = 0$

or $$(E_a - I_a r_a) = L_a \cdot \frac{di_a}{dt}$$

With chopper on, L_a must store energy and current must rise, *i.e.* $\frac{di_a}{dt}$ must be positive or

$$(E_a - I_a r_a) \geq 0$$

When chopper is off, $E_a - I_a r_a - L_a \cdot \frac{di_a}{dt} = V_s$

or
$$V_s - (E_a - I_a r_a) = - L_a \cdot \frac{di_a}{dt}$$

With chopper off, $(E_a - I_a r_a)$ must be more than V_s for regeneration purposes and therefore $[V_s - (E_a - I_a r_a)]$ must be negative. This is possible only if current decreases during off period, *i.e.* $\frac{di_a}{dt}$ in the above expression must be negative.

$\therefore$
$$[V_s - (E_a - I_a r_a)] \leq 0$$
$$-(E_a - I_a r_a) \leq (-V_s)$$

or
$$(E_a - I_a r_a) \geq V_s$$

Eqs. can be combined to give the conditions for controlling the power during regenerative braking as

$$0 \leq (E_a - I_a r_a) \geq V_s$$

Eq. gives the conditions for the two voltages and their polarity for the regenerative braking control of dc separately-excited motor.

Minimum braking speed is obtained when $E_a - I_a r_a = 0$

or
$$K_m \, \omega_{mn} = I_a r_a$$

$\therefore$ Minimum braking speed $\quad \omega_{mn} = \frac{I_a r_a}{K_m}$

Maximum possible braking speed is obtained when

$$E_a - I_a r_a = V_s$$

$\therefore$ Maximum braking speed, $\quad \omega_{mx} = \frac{V_s + I_a r_a}{K_m}$

Thus regenerative braking control is effective only when motor speed is less than ω_{mx} and more than ω_{mn}. This can be expressed as

$$\omega_{mn} < \omega_m < \omega_{mx}$$
$$\frac{I_a r_a}{K_m} < \omega_m < \frac{V_s + I_a r_a}{K_m}$$

Therefore, the speed range for regenerative braking is $\frac{V_s + I_a r_a}{K_m} : \frac{I_a r_a}{K_m}$ or $(V_s + I_a r_a) : I_a r_a$.

Regenerative braking of chopper-fed separately-excited or self excited dc shunt motor is more stable, it is therefore discussed here. DC series motors, however, offer unstable operating characteristics during regenerative braking. As such, regenerative braking of chopper-controlled series motors is difficult.

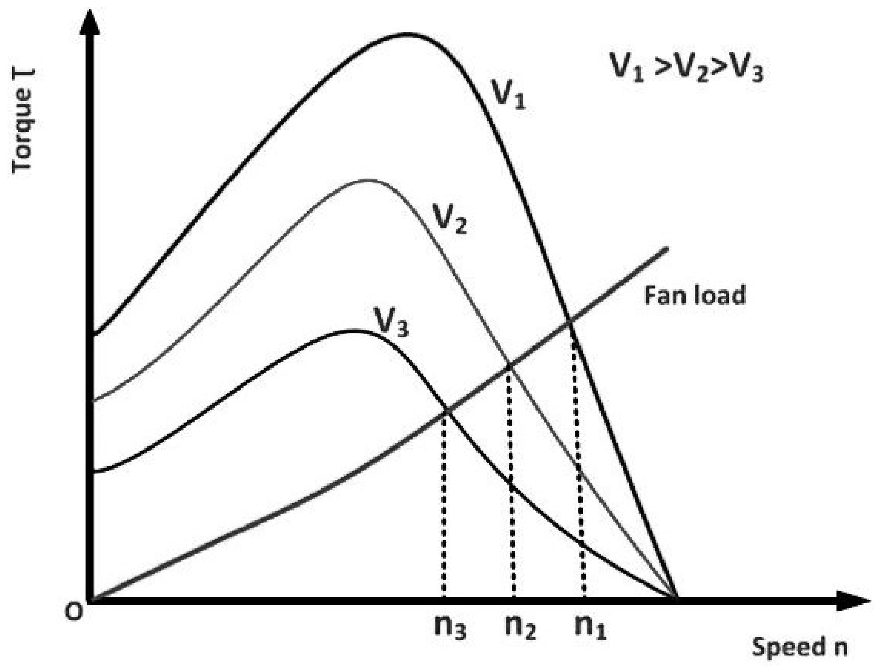
4.5 LIST THE FACTORS AFFECTING SPEED OF THE AC MOTORS

The factors that affect speed of the ac motors are

- Voltage
- Frequency
- Slip
- Current
- Rotor resistance

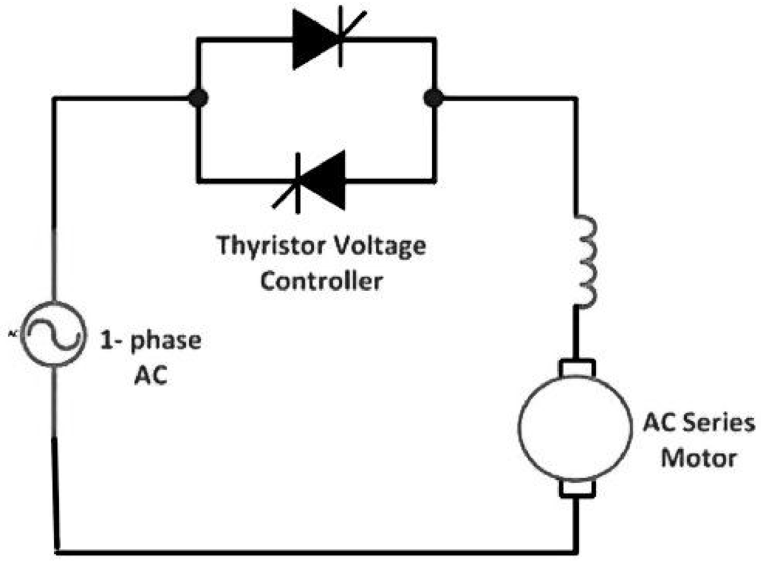
4.6 SPEED CONTROL OF INDUCTION MOTOR BY USING AC VOLTAGE REGULATOR.

The speed of a three-phase induction motor can be varied by varying the supply voltage. As we already know that the torque developed is proportional to the square of the supply voltage and the slip at the maximum torque is independent of the supply voltage. The variation in the supply voltage does not alter the synchronous speed of the motor. The Torque-Speed Characteristics of the three-phase induction motors for varying supply voltage and also for fan load are shown below:

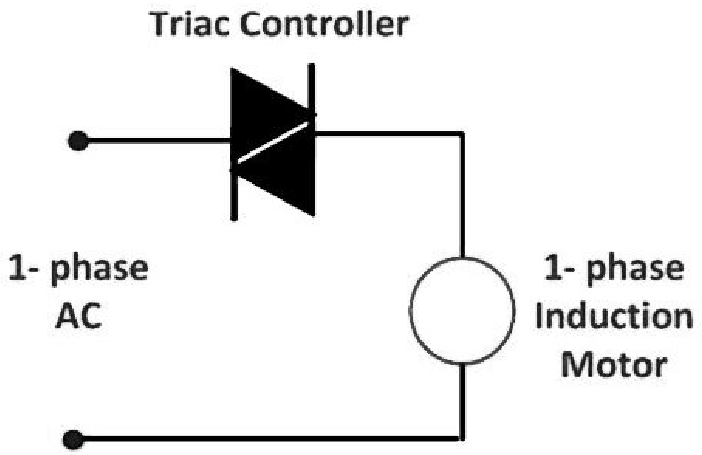


By varying the supplying voltage, the speed can be controlled. The voltage is varied until the torque required by the load is developed, at the desired speed. The torque developed is proportional to the square of the supply voltage and the current is proportional to the voltage.
Hence, to reduce the speed for the same value of the same current, the value of the voltage is reduced and as a result, the torque developed by the motor is reduced. This stator voltage control method is suitable for applications where the load torque decreases with the speed.

Thyristor voltage controller method is preferred for varying the voltage. For a single phase supply, two thyristors are connected back to back as shown in the figure below:

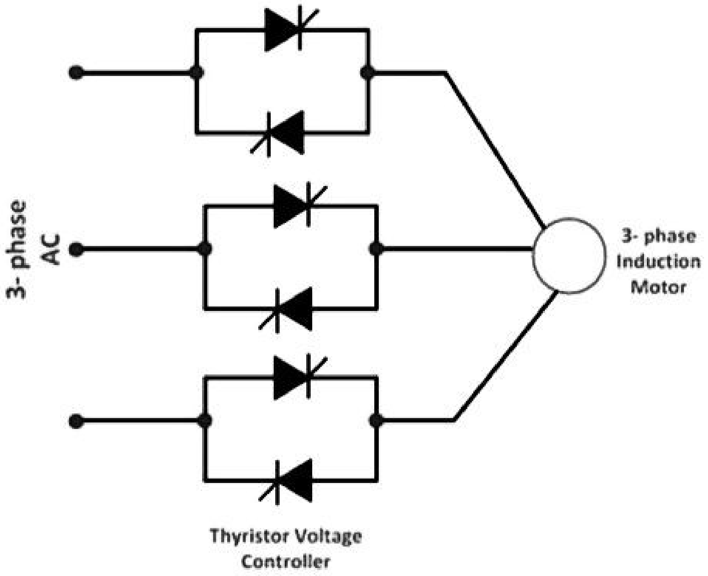


The domestic fan motors, which are single-phase, are controlled by a single-phase Triac Voltage Controller as shown in the figure below:



Speed control is obtained by varying the firing angle of the Triac. These controllers are known as Solid State fan regulators. As the solid-state regulators are more compact and efficient as compared to the conventional variable regulator. Thus, they are preferred over the normal regulator.

In the case of a three-phase induction motor, three pairs of thyristors are required which are connected back to back. Each pair consists of two thyristors. The diagram below shows the Stator Voltage Control of the three-phase induction motors by Thyristor Voltage Controller.



Each pair of the thyristor controls the voltage of the phase to which it is connected. Speed control is obtained by varying the conduction period of the Thyristor. For lower power ratings, the back-to-back thyristor pairs connected in each phase are replaced by the Traic.

4.7 Speed control of induction motor by using converters and inverters (V/F control).

For a 3-ph IM stator voltage per phase is given by

$v_i = \sqrt{2}\pi f_1 . N_{ph1} . \varphi . k_{w1}$

It is seen from above equation that if the ratio of supply voltage V_1 to supply frequency f_1 is kept constant, the air-gap flux remains constant. From Fig., the starting torque is given by

$$T_{e.st} = \frac{3}{\omega_s} \cdot \frac{V_1^2}{(r_1 + r_2)^2 + (x_1 + x_2)^2} \cdot r_2$$

As $(r_1 + r_2) << (x_1 + x_2)$ and $\omega_s = \frac{2\omega_1}{P}$, we get

$$T_{e.st} = \frac{3P}{2\omega_1} \cdot \frac{V_1^2 \cdot r_2}{\omega_1^2 (l_1 + l_2)^2}$$

$$= \frac{3P}{2\omega_1} \cdot \left(\frac{V_1}{\omega_1}\right)^2 \cdot \frac{r_2}{(l_1 + l_2)^2}$$

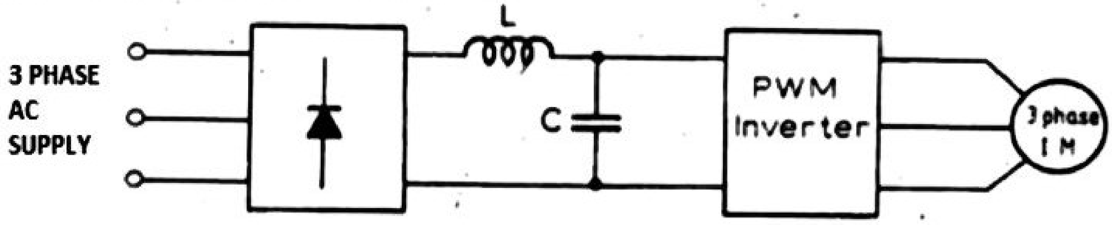
maximum torque is given by

$$T_{e.m} = \frac{3}{\omega_s} \cdot \frac{V_1^2}{2(x_1 + x_2)}$$
$$= \frac{3P}{2\omega_1} \cdot \frac{V_1^2}{2 \cdot \omega_1 (l_1 + l_2)}$$
$$= \frac{3P}{4} \cdot \left(\frac{V_1}{\omega_1}\right)^2 \frac{1}{l_1 + l_2}$$

The Eq. shows that if $\frac{v_1}{\omega_1}$, or air-gap flux φ, is kept constant, the maximum torque remains unaltered. Eq. indicates that starting torque inversely proportional to supply frequency $\omega_1$even if air-gap flux is kept constant. At low values of frequencies, the effect of resistances cannot be neglected as compared to the reactances. This has the effect of reducing the magnitude of maximum torque at lower frequencies as shown in Fig. In practice, at low frequencies, the supply voltage is increased to maintain the level of maximum torque. This method of speed control is also called volts / hertz control.
If stator reactance is neglected the slip at which maximum torque occurs is given by

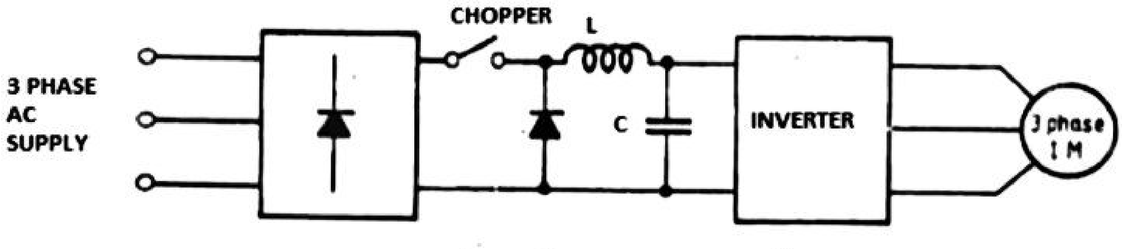
$$s_m = \frac{r_2}{x_1 + x_2}$$
$$= \frac{r_2}{\omega_1 (l_1 + l_2)}$$

As the supply frequency (ω_1 is reduced, the slip at maximum torque increases. In Fig.load torque T_L for a certain load is also shown. It is seen from this figure that as both voltage and frequency are varied (usually below their rated values), speed of the drive can be controlled. The control of both voltage and frequency can be carried out (so as to keep $\frac{V}{f}$ constant through the use of three-phase inverters or cycloconverters. Inverters are used in low and medium power drives whereas cycloconverters are suitable for high-power drives like cement mills, locomotives etc.
Variable voltage and variable -frequency can be obtained from voltage-source inverters. Four such circuit configurations are shown in Fig.



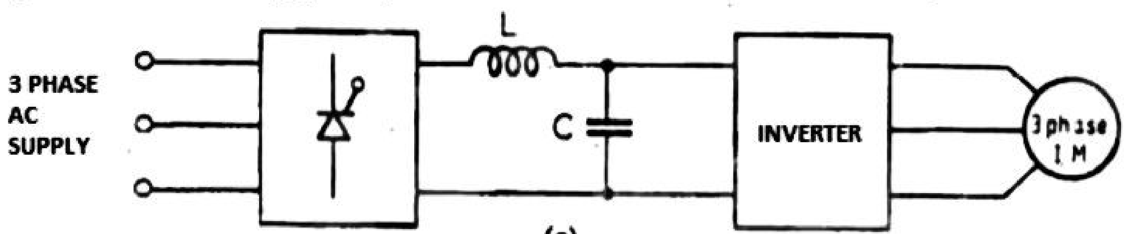
(a)

In Fig. Three-phase ac is converted to constant dc by diode rectifier. Voltage and frequency are both varied by PWM inverter. The circuitry between the rectifier and the inverter consists of an inductor L and capacitor C, called filter circuit. The function of filter circuit is to smooth dc input voltage to the inverter. This Circuitry in between rectifier and inverter is called dc link. In Fig. - regeneration is not possible because of diode rectifier. Also, inverter would inject harmonics into the 3-phase ac supply.



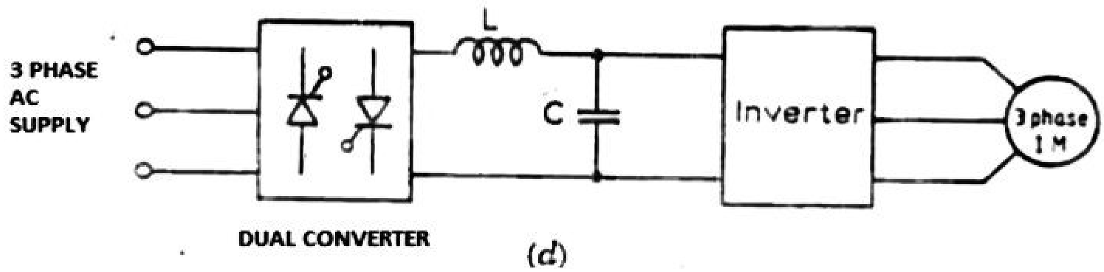
(b)

In Fig. three-phase ac is converted to dc by diode rectifier. Chopper varies the dc input voltage to the inverter and frequency is controlled by the inverter. Use of chopper reduces the harmonic injection into the ac supply. Regeneration is not feasible in the scheme of Fig.



(c)

Fig. uses a 3-phase controlled rectifier, dc link consisting of Land C and a force-commutated VSI. Voltage is regulated by controlled rectifier and frequency is varied within the inverter. Here regeneration is possible if three-phase full converter is used. Regeneration is also feasible in the scheme shown in Fig. below It uses a 3-phase dual -- converter, L-C filter and inverter. Level of dc input voltage to the inverter is regulated in dual converter whereas frequency is varied within the VSI inverter.



(d)

It may be observed from above that volt/hertz control offers speed control from standstill up to rated speed of IM. This method is similar to the armature-voltage control method used for the speed control of a dc motor.

4.8 WORKING OF UPS WITH BLOCK DIAGRAM.

Uninterruptible Power Supply | UPS

In a UPS, the energy is generally stored in flywheels, batteries, or super capacitors. When compared to other immediate power supply system, UPS have the advantage of immediate protection against the input power interruptions. It has very short on-battery run time; however this time is enough to safely shut down the connected apparatus (computers, telecommunication equipment etc) or to switch on a standby power source.
UPS can be used as a protective device for some hardware which can cause serious damage or loss with a sudden power disruption. Uninterruptible power source, Battery backup and Flywheel back up are the other names often used for UPS. The available size of UPS units ranges from 200 VA which is used for a solo computer to several large units up to 46 MVA.

Major Roles of UPS

When there is any failure in main power source, the UPS will supply the power for a short time. This is the prime role of UPS. In addition to that, it can also able to correct some general power problems related to utility services in varying degrees. The problems that can be corrected are voltage spike (sustained over voltage), Noise, Quick reduction in input voltage, Harmonic distortion and the instability of frequency in mains.
Types of UPS

Generally, the UPS system is categorized into On-line UPS, Off- line UPS and Line interactive UPS. Other designs include Standby on-line hybrid, Standby-Ferro, Delta conversion On-Line.

Off-line UPS

This UPS is also called as Standby UPS system which can give only the most basic features. Here, the primary source is the filtered AC mains (shown in solid path in figure 1). When the power breakage occurs, the transfer switch will select the backup source (shown in dashed path in figure 1). Thus we can clearly see that the stand by system will start working only when there is any failure in mains. In this system, the AC voltage is first rectified and stored in the storage battery connected to the rectifier.

When power breakage occurs, this DC voltage is converted to AC voltage by means of a power inverter, and is transferred to the load connected to it. This is the least expensive UPS system and it provides surge protection in addition to back up. The transfer time can be about 25 milliseconds which can be related to the time taken by the UPS system to detect the utility voltage that is lost.
The block diagram is shown below.

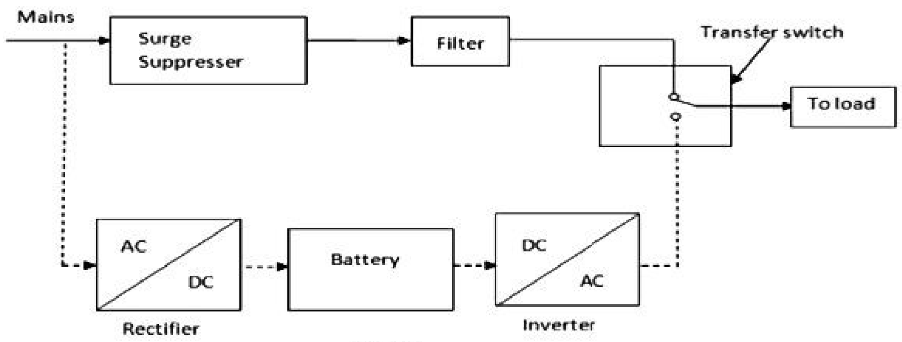


Figure 1

On-line UPS

In this **type of UPS**, double conversion method is used. Here, first the AC input is converted into DC by rectifying process for storing it in the rechargeable battery. This DC is converted into AC by the process of inversion and given to the load or equipment which it is connected (figure 2). This type of UPS is used where electrical isolation is mandatory. This system is a bit more costly due to the design of constantly running converters and cooling systems. Here, the rectifier which is powered with the normal AC current is directly driving the inverter. Hence it is also known as Double conversion UPS. The block diagram is shown below.

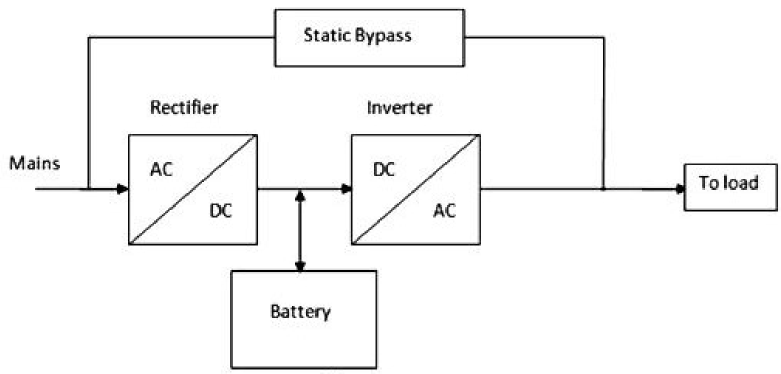


Figure 2

When there is any power failure, the rectifier have no role in the circuit and the steady power stored in the batteries which is connected to the inverter is given to the load by means of transfer switch. Once the power is restored, the rectifier begins to charge the batteries. To prevent the batteries from overheating due to the high power rectifier, the charging current is limited. During a main power breakdown, this UPS system operates with zero transfer time. The reason is that the backup source acts as a primary source and not the main AC input. But the presence of inrush current and large load step current can result in a transfer time of about 4-6 milliseconds in this system.

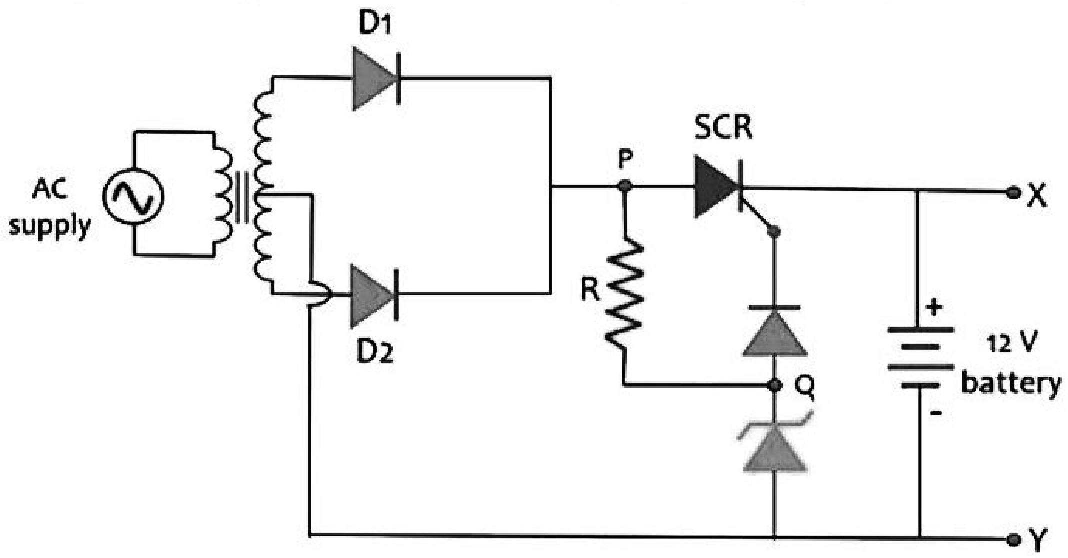
Applications of a UPS:

- Data Centers
- Industries
- Telecommunications

- Hospitals
- Banks and insurance
- Some special projects (events)

4.9 BATTERY CHARGER CIRCUIT USING SCR WITH THE HELP OF A DIAGRAM

An SCR-based battery charger makes use of the switching principle of the thyristor in order to get the specific output. The circuit includes a transformer, rectifier, and control circuit as its major elements.
As we have already discussed in the beginning that a small amount of ac or dc input voltage is needed for the purpose of charging the battery. So, the elements of the circuit help to provide the desired voltage to charge the battery.
Working of Battery Charger circuit using SCR
The figure below represents the circuit of a battery charger incorporating an SCR:



Battery Charger Circuit using SCR

Here, an ac voltage signal of value 230 V, 50 Hz is applied as input and the load is a 12 V battery that is required to be charged.
Following are the circuit elements:

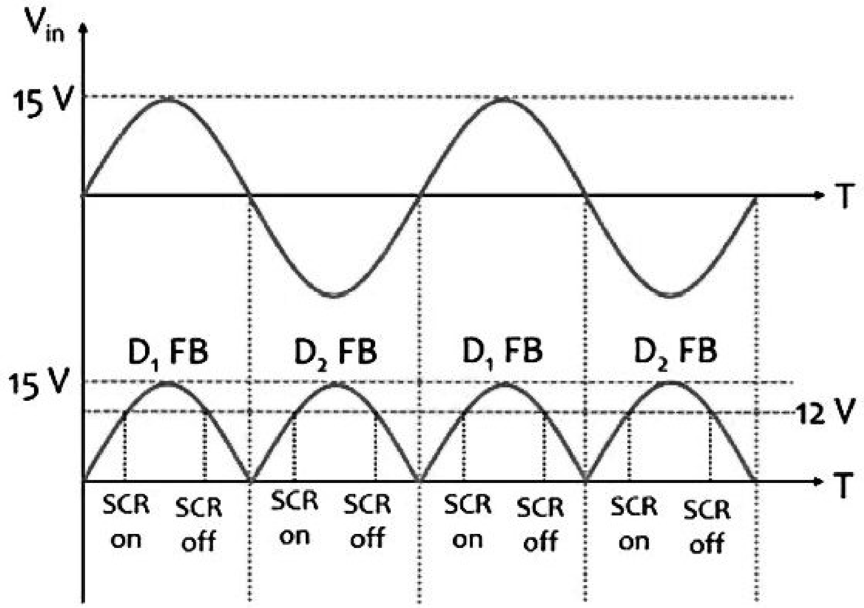
- AC supply
- Step down transformer
- Rectifier circuit
- SCR
- Zener diode as a voltage regulator
- Battery to be charged

Let us now understand how the above-given circuit operates.

So, initially, 230 V ac supply is provided to the step-down transformer which converts the high voltage given at the input of the primary winding into a low voltage which is obtained at the output of the secondary winding. So, here the voltage obtained at the other side of the transformer is 15V with respect to neutral.

From the circuit, it is clearly shown that the transformer forms connection with the rectifier circuit, hence the output of the transformer will be provided to the rectifier circuit. As we have an ac input signal, so let us understand how the rectifier circuit operates when the two halves of the ac signal are applied.

Initially, when the positive half of the ac input signal is applied then the diode D_1 in the above-given configuration will be forward biased and will conduct however, D_2 will be in reverse biased condition thus will not conduct. Conversely, when the negative half of ac input is applied then D_1 will not conduct but D_2 will be in conducting state, this is clearly shown in the waveform representation given below:



So, the rectifier circuit will provide rectified output i.e., the dc voltage at terminal P.

Here we have used a Zener diode with breakdown voltage of 10 V as a voltage regulator to regulate the voltage level of the circuit. Therefore, terminal Q will be at 10 V due to the presence of the Zener diode.

As the terminal voltage at P which is nothing but the rectified voltage is comparatively more than at terminal Q thus, this makes the SCR forward biased, allowing it to conduct and due to this current will start flowing through the load i.e., the **12 V battery**. And we have already discussed in the beginning that when current flows through the battery then the cells present within it stores the energy. In this way, the battery gets charged.

However, in case, the rectified voltage is less than that of terminal voltage at Q then automatically SCR will come in a reverse-biased state, getting it turned off and no flow of current through the battery will take place further.

Thus, we can say that here the SCR is acting as a switch that controls the voltage fed to the battery. Now, the question arises, once the battery gets fully charged how the circuit will operate. So, basically what happens within the circuit is as the rectified voltage here is 15 V, so once the battery gets fully charged (suppose it reaches 14.5 V) then the remaining value of the voltage at terminal P will be insufficient to cause further conduction through the SCR because now the rectified voltage will be less than the voltage at terminal Q. This will not allow current to reach the battery further and resultantly the charging circuit will get deactivated.

Basically, this comparison between rectified voltage and the charging potential is made using a comparator circuit. Once the charging potential falls below a certain value then the charging circuit will automatically get activated and again the charging of the battery will take place.

It is to be noted here that the value of the breakdown voltage of the Zener diode and the transformer in the circuit depends on the charging potential of the battery. Thus, the potential at which the battery will be charged will decide the value of these two circuit parameters.

Drawbacks of Battery charger circuit using SCR

This charging is a quite time taking process.

The rectifier circuit for ac to dc conversion, do not remove ac ripples as the filter circuit is absent here.

The process of charging and discharging is slow due to the presence of a half-wave rectifier.

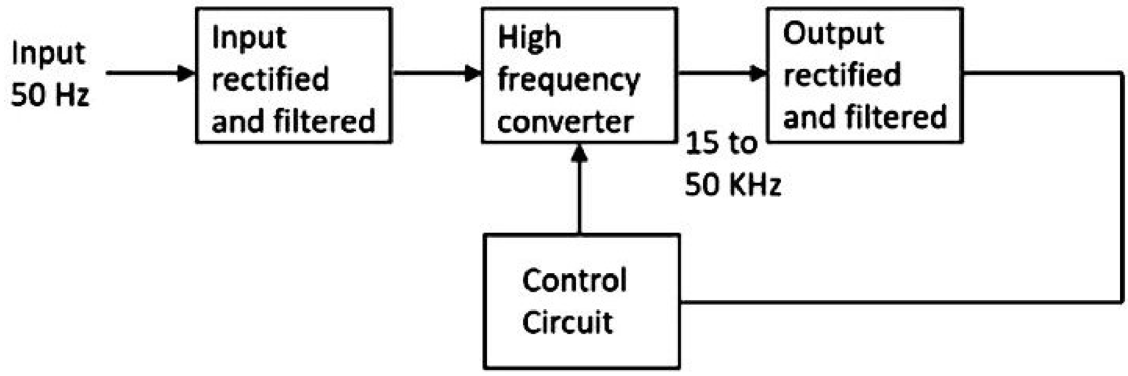
This is only suitable for charging the batteries with a low to medium ampere-hour rating.

4.10 BASIC SWITCHED MODE POWER SUPPLY (SMPS) - EXPLAIN ITS WORKING & APPLICATIONS

A switched-mode power supply (switched power supply,) is an electronic power supply that incorporates a switching regulator to convert electrical power efficiently.

Working

The working of SMPS can be understood by the following figure.



Let us try to understand what happens at each stage of SMPS circuit.

Input Stage

The AC input supply signal 50 Hz is given directly to the rectifier and filter circuit combination without using any transformer. This output will have many variations and the capacitance value of the capacitor should be higher to handle the input fluctuations. This unregulated dc is given to the central switching section of SMPS.

Switching Section

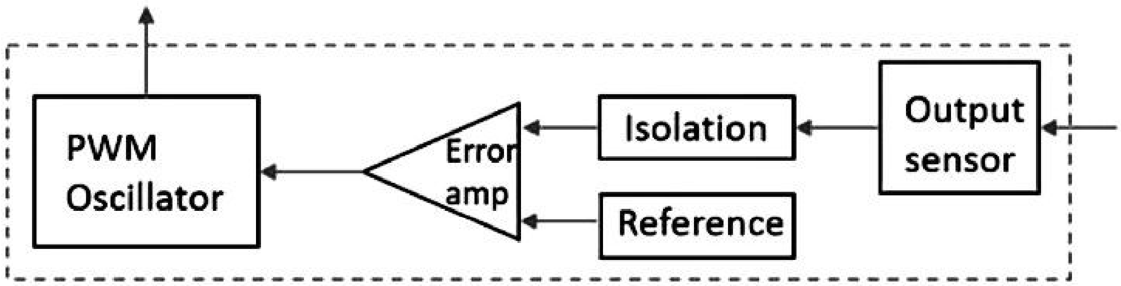
A fast switching device such as a Power transistor or a MOSFET is employed in this section, which switches ON and OFF according to the variations and this output is given to the primary of the transformer present in this section. The transformer used here are much smaller and lighter ones unlike the ones used for 60 Hz supply. These are much efficient and hence the power conversion ratio is higher.

Output Stage

The output signal from the switching section is again rectified and filtered, to get the required DC voltage. This is a regulated output voltage which is then given to the control circuit, which is a feedback circuit. The final output is obtained after considering the feedback signal.

Control Unit

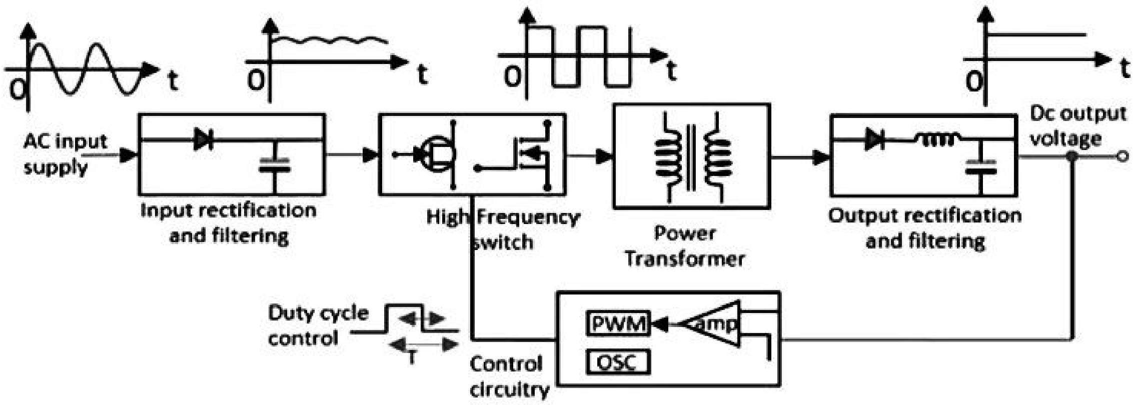
This unit is the feedback circuit which has many sections. Let us have a clear understanding about this from The following figure.



The above figure explains the inner parts of a control unit. The output sensor senses the signal and joins it to the control unit. The signal is isolated from the other section so that any sudden spikes should not affect the circuitry. A reference voltage is given as one input along with the signal to the error amplifier which is a comparator that compares the signal with the required signal level.

By controlling the chopping frequency the final voltage level is maintained. This is controlled by comparing the inputs given to the error amplifier, whose output helps to decide whether to increase or decrease the chopping frequency. The PWM oscillator produces a standard PWM wave fixed frequency.

We can get a better idea on the complete functioning of SMPS by having a look at the following figure.



Functional block diagram of SMPS

The SMPS is mostly used where switching of voltages is not at all a problem and where efficiency of the system really matters. There are few points which are to be noted regarding SMPS. They are

SMPS circuit is operated by switching and hence the voltages vary continuously.

The switching device is operated in saturation or cut off mode.

The output voltage is controlled by the switching time of the feedback circuitry.

Switching time is adjusted by adjusting the duty cycle.

The efficiency of SMPS is high because, instead of dissipating excess power as heat, it continuously switches its input to control the output.

Disadvantages

- There are few disadvantages in SMPS, such as
- The noise is present due to high frequency switching.
- The circuit is complex.
- It produces electromagnetic interference.

Advantages

- The advantages of SMPS include,
- The efficiency is as high as 80 to 90%
- Less heat generation; less power wastage.
- Reduced harmonic feedback into the supply mains.
- The device is compact and small in size.
- The manufacturing cost is reduced.
- Provision for providing the required number of voltages.

Applications

There are many applications of SMPS. They are used in the motherboard of computers, mobile phone chargers, HVDC measurements, battery chargers, central power distribution, motor vehicles, consumer electronics, laptops, security systems, space stations, etc.

Types of SMPS

SMPS is the Switched Mode Power Supply circuit which is designed for obtaining the regulated DC output voltage from an unregulated DC or AC voltage. There are four main types of SMPS such as

DC to DC Converter

AC to DC Converter

Fly back Converter

Forward Converter

QUESTION BANK

Short Questions With Answer:

Q: What are the factors affecting speed of DC motor?

A: Factors affecting speed of DC motor are

The flux

The applied voltage

The voltage across armature

Q: What are the methods used for speed control of DC motor?

A: Methods used for speed control of DC motor are

Flux control method

Rheostat control method

Voltage control method

Q: What are the factors affecting speed of AC motor?

A: Factors affecting speed of AC motor are

Voltage

Frequency

Slip

Current

Rotor resistance

Q: What is UPS?

A: A UPS is a device which provides an uninterruptable power supply so as to maintain the continuity of supply in case of power outage. UPS stands for Uninterruptable Power Supply.

Q: What are the types of UPS?

A: UPS are of two types. Online UPS and Ofline UPS.

Q: What are the functions of UPS?

A: Functions of UPS are to absorb relatively small power surges, smooth out noisy power sources and continuously provides power to equipment during line sags.

Q: What is SMPS?

A: SMPS is the Switched Mode Power Supply circuit which is designed for obtaining the regulated DC output voltage from an unregulated DC or AC voltage.

Q: What are the types of SMPS?

A: SMPS is of four types

DC to DC Converter

AC to DC Converter

Fly back Converter

Forward Converter

Long Questions:

Q: Explain the speed control of DC shunt motor using converter.

Q: Explain the speed control of induction motor using AC voltage regulator.

Q: Explain the speed control of induction motor by V / F control method.

Q: Explain working of UPS with block diagram.

Q: Explain working of Battery charger with block diagram.

5. PLC AND ITS APPLICATIONS

5.1 INTRODUCTION OF PROGRAMMABLE LOGIC CONTROLLER (PLC)

The Need for PLCs

PLC is used in the fully automated industries or plants or process, the actual processes handled and controlled by the controllers which are nothing but the programming logic controllers that means PLC plays a very important role in automation section.

PLCs constantly monitor the state of the systems through input devices and generate the control actions according to the logic given in the user program.

It is a heart of control systems, PLC monitors the state of the system through field input devices, feedback signals and based on the feedback signal PLC determine the type of action to be carried out at field output devices.

PLC provides easy and economic solution for many automation tasks like

- Operates control and monitoring.
- Co-ordination and communication.
- PID computing and control.
- Logic / sequence control.

Programmable Logic Controller

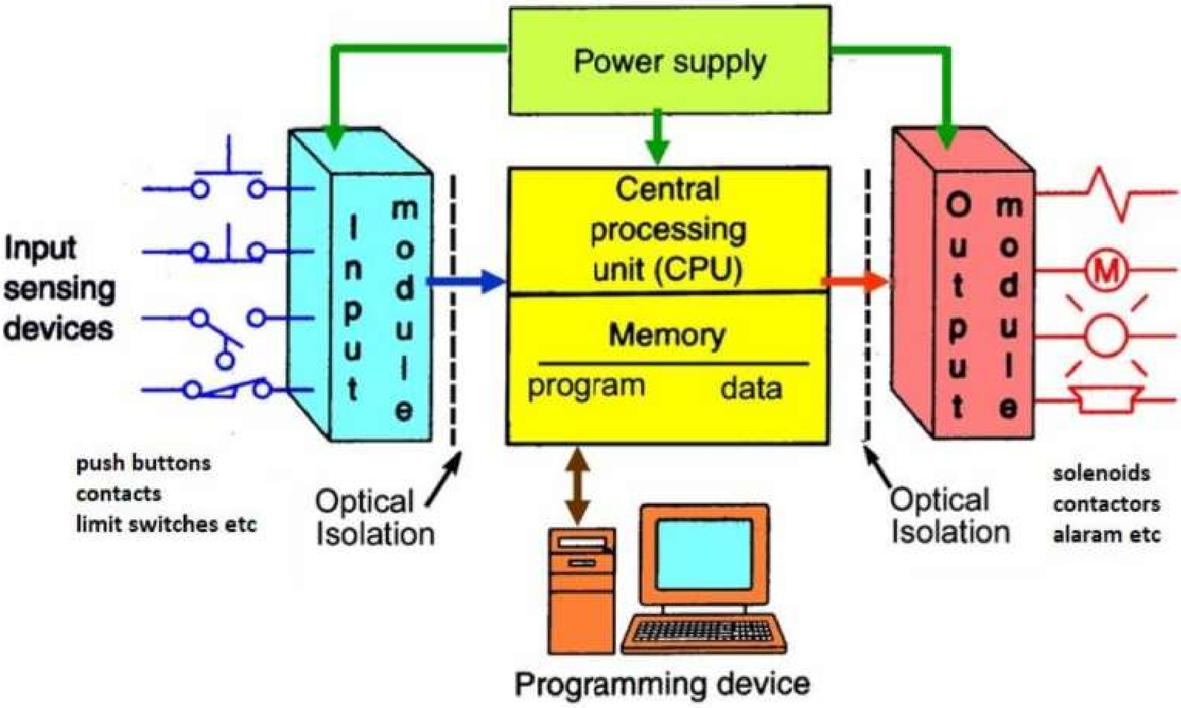
A programmable logic controller (PLC) is a specialized computer used to control machines and process.

It uses a programmable memory to store instructions and specific functions that include On/Off control, timing, counting, sequencing, arithmetic, and data handling

5.2 ADVANTAGES OF PLC

- Flexible
- Faster response time
- Less and simpler wiring
- Solid-state - no moving parts
- Modular design - easy to repair and expand
- Handles much more complicated systems
- Sophisticated instruction sets available
- Allows for diagnostics "easy to troubleshoot"
- Less expensive

5.3 DIFFERENT PARTS OF PLC BY DRAWING THE BLOCK DIAGRAM AND PURPOSE OF EACH PART OF PLC.



The block diagram of programming logic controller (PLC) is shown in above figure. The PLC has following basic sections are,

Processor section (CPU)

The processor section is brain of PLC which consists of RAM, ROM, logic solver and user memory. The central processing unit is heart of PLC. CPU controls monitors and supervises all operation within PLC. The CPU makes decision and executes control instructions based on the program instruction in memory.

Input and output module

The input module is a mediator between input devices and central processing unit (CPU) which is used to convert analog signal into digital signal.

The output module is a mediator between output devices and central processing unit (CPU) which is convert digital signal into analog signal.

Power supply

Power supply is provided to the processor unit, input and output module unit. Power supply may be integral or separately mounted unit. Most of the PLC operates on 0 volts DC and 24 volts.

Memory section

The memory section is the area of the CPU in which data and information is stored and retrieved. Data Memory is used to store numerical data required in math calculation, bar code data etc. User memory contains user's application program.

Programming device

Programming devices are dedicated devices used for loading the user program into the program memory or edit it and to monitor the execution of the program of the PLC. It is also used to troubleshoot the PLC ladder logic program. Hand held terminal (HHT) or dedicated terminal or personal computer are programming devices commonly used in most of the PLCs.

5.4 APPLICATIONS OF PLC

- In machining, packaging, material handling, automated assembly etc.
- In medical instruments and technologies
- In industrial manufacturing
- In Nano technology and robotics
- In automatic transfer switch
- In Traffic light Signal system
- It is used in civil applications such as washing machine, elevators working and traffic signals control.
- It is used to reducing the human control allocation of human sequence given to the technical equipments that is called **Automation**.
- It is used in batch process in chemical, cement, food and paper industries are sequential in nature, requiring time or event based decisions.

5.5 LADDER DIAGRAM

Ladder Diagram is a graphical programming language that you use to develop software for programmable logic controllers (PLCs). The most elementary objects in Ladder Diagram programming are contacts and coils, intended to mimic the contacts and coils of electromechanical relays.

Contacts and coils are discrete programming elements, dealing with Boolean (1 and 0; on and off; true and false) variable states.

Each contact in a Ladder Diagram PLC program represents the reading of a single bit in memory, while each coil represents the writing of a single bit in memory.

Discrete input signals to the PLC from real-world switches are read by a Ladder Diagram program by contacts referenced to those input channels.

5.6 DESCRIPTION OF CONTACTS AND COILS IN THE FOLLOWING STATES I) NORMALLY OPEN II) NORMALLY CLOSED III) ENERGIZED OUTPUT IV) LATCHED OUTPUT V) BRANCHING

Normally Open and Normally Closed electrical contacts make up electrical switches, relays, circuit breakers, and most any other electrical component that switches something on/off or can be switched on/off.

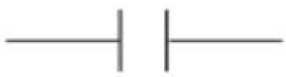
IMPORTANT CONCEPT:

Closed = Current flow

Open = No current flow

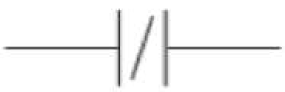
What is normally? This is simply the state that the contact is in when something else is not affecting it. If it is a relay then it is not energized. If it is a switch, then it is off. If it is a high limit such as a temperature alarm then the current temperature is below the limit.

NORMALLY OPEN - Is a contact that does not flow current in its normal state. Energizing it and switching it on will close the contact, causing it to allow current flow.



Normally Open
(NO)

Normally closed - Is a contact that flows current in its normal state. Energizing it and switching it on will open the contact, causing it to not allow current flow.



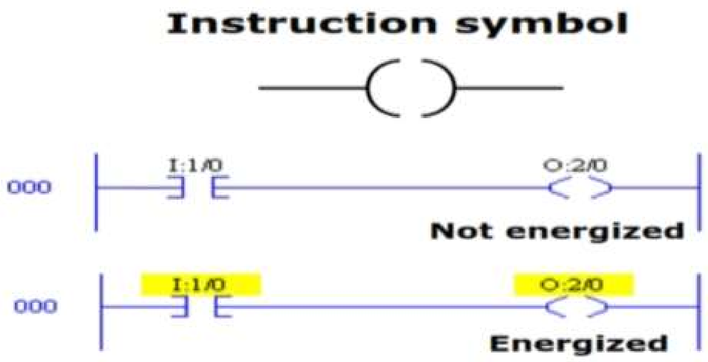
Normally Closed
(NC)

III) ENERGIZED OUTPUT

The OTE, also known as Output Energize, instruction will energize a single bit of data if the input leading to it is true. It's a fundamental instruction used in Programmable Logic Controllers (PLCs). This instruction will be found on the right side within a ladder logic structure and turn a bit to a HIGH state if the preceding instructions evaluate to true. If the same instructions evaluate to false, the OTE instruction will set the specified bit to a LOW state.

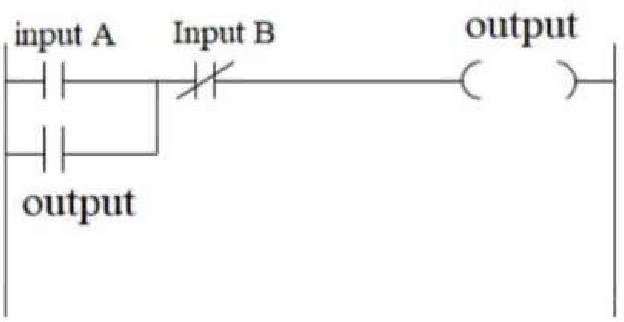
This Output energize (OTE) instruction is usually used in conjunction with XIC or XIO or any other input instruction in PLC.

If the logic preceding the OTE instruction is true (1), the OTE instruction will be energized.



IV) LATCHED OUTPUT

The latching is used where the output must be activated even after the entry ceases.



A simple example of such a situation is a motor, which is started by pressing a button switch. Although the switch contacts do not remain closed, it is required that the motor continue to run until a stop button switch is pressed. The latching used to stay the motor run until the push button is pressed again.

Circuits that are characteristic given the previous conditions are often needed in logic control. In this series the output is latched by using the output contact itself, so even though the input has changed, the output condition is fixed:

When there is an exit, another set of contacts associated with the exit is closed. These contacts form an OR logic gate system with the input contacts. Therefore, even if the A input is opened, the circuit will keep the output energized. The only way to release the output is to activate the normally closed contact B.

BRANCHING IN LADDER LOGIC

When two or more instructions are connected in parallel, it is called a branch. Ladder logic circuits almost always contain rungs with branches, and many have levels of branches. A branch level is assigned for each branch that is connected either in series or parallel.

1. SERIES BRANCH:

In the series branch, inputs or outputs are connected in the series.

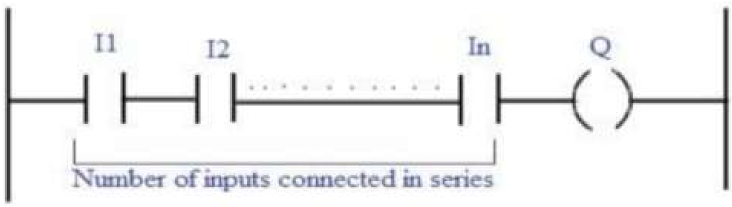


Figure: Representation of the Series Branch

2. PARALLEL BRANCH

In the parallel branch, inputs or outputs are connected parallelly.

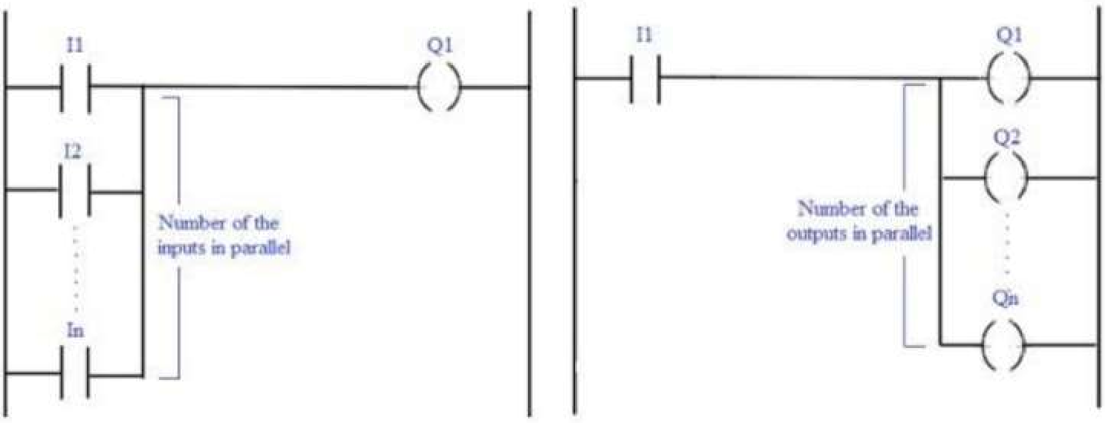


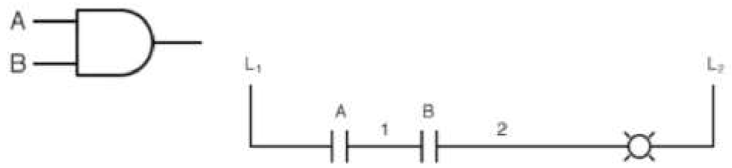
Figure: Representation of the Parallel Branch

5.7 LADDER DIAGRAMS FOR I) AND GATE II) OR GATE AND III) NOT GATE.

We can mimic the AND logic function by wiring the two contacts in series Now, the lamp energizes only if contact A and contact B are simultaneously actuated.

A path exists for current from wire L1 to the lamp (wire 2) if and only if both switch contacts are closed.

A	B	Output
0	0	0
0	1	0
1	0	0
1	1	1

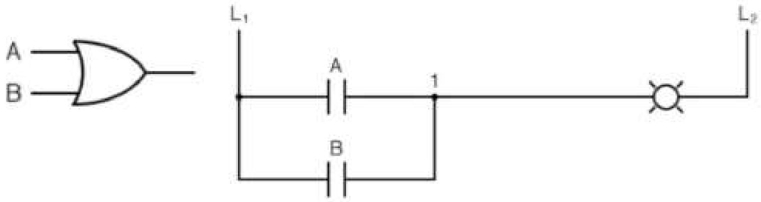


II) OR GATE

The lamp will come on if either contact A or contact B is actuated, because all it takes for the lamp to be energized is to have at least one path for current from wire L1 to wire 1.

What we have is a simple OR logic function, implemented with nothing more than contacts and a lamp.

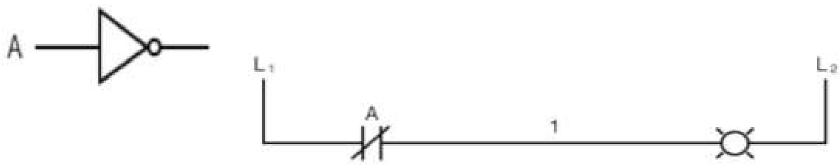
A	B	Output
0	0	0
0	1	1
1	0	1
1	1	1



III) NOT GATE.

The logical inversion, or NOT, function can be performed on a contact input simply by using a normally-closed contact.

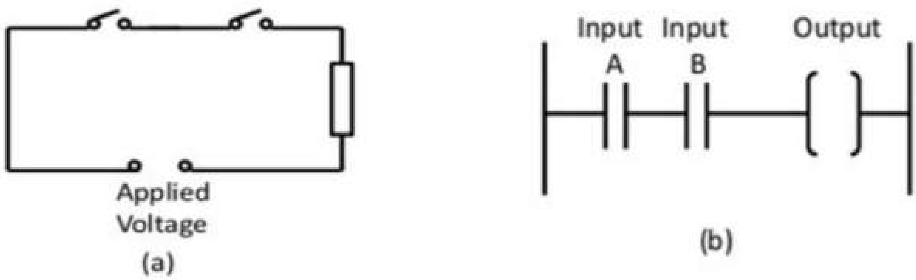
A	Output
0	1
1	0



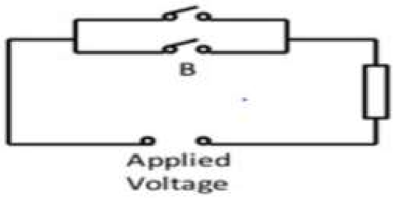
Now, the lamp energizes if the contact is not actuated, and de-energizes when the contact is actuated.

5.8 LADDER DIAGRAMS FOR COMBINATION CIRCUITS USING NAND, NOR, AND, OR AND NOT

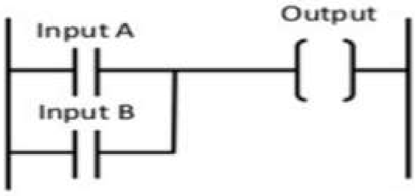
AND Gate:



OR Gate:

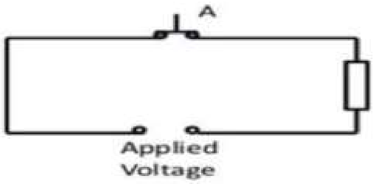


(a)

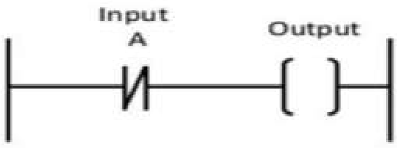


(b)

NOT Gate:

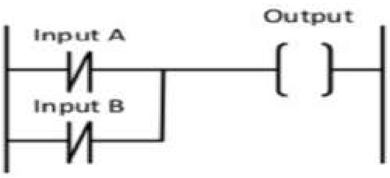


(a)

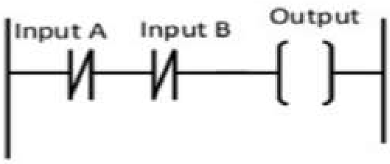


(b)

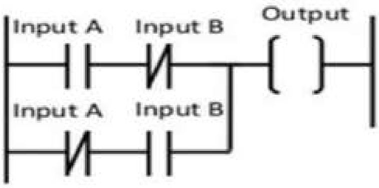
NAND Gate:



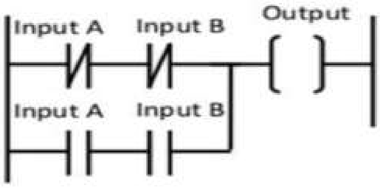
NOR Gate



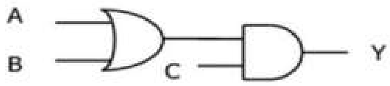
XOR Gate:

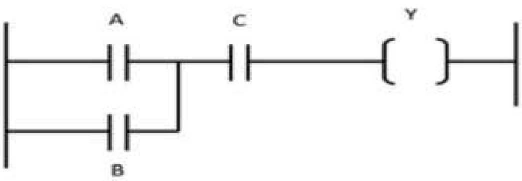


X-NOR Gate

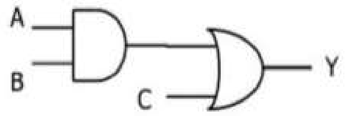


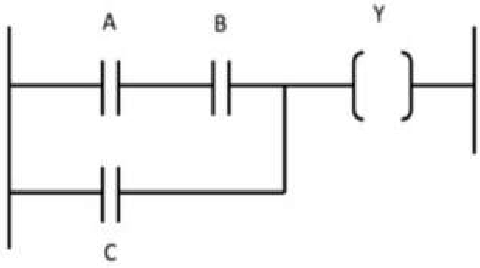
Draw Ladder diagram for given logic diagram



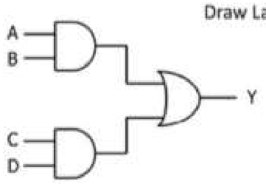


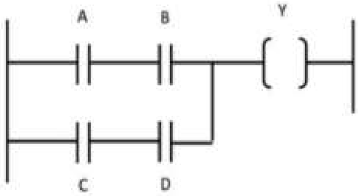
Draw Ladder diagram for given logic diagram



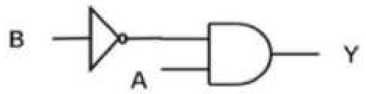


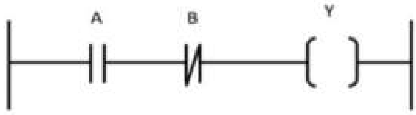
Draw Ladder diagram for given logic diagram



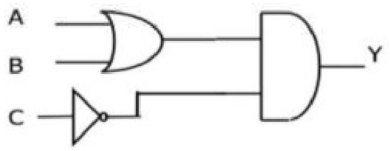


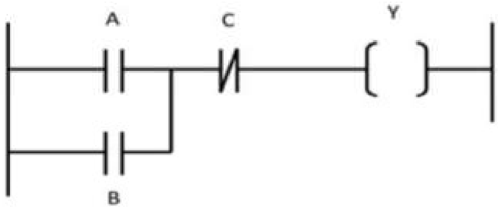
Draw Ladder diagram for given logic diagram





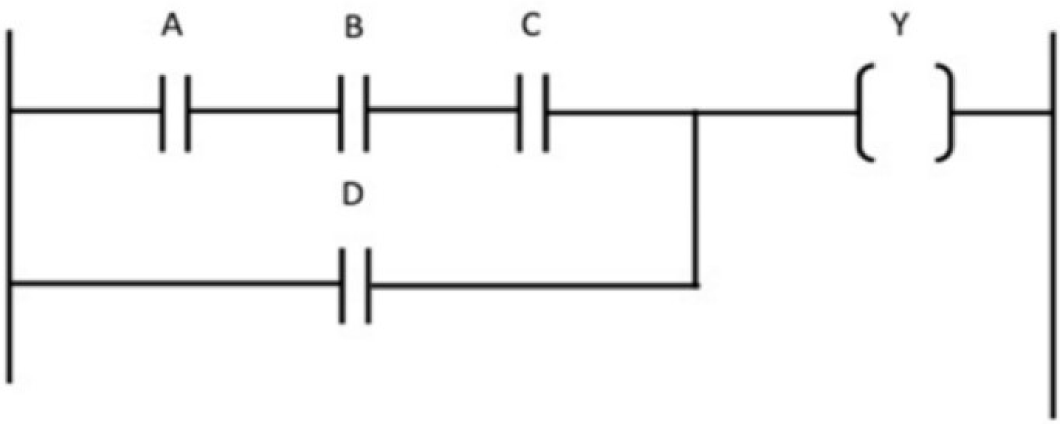
Draw Ladder diagram for given logic diagram





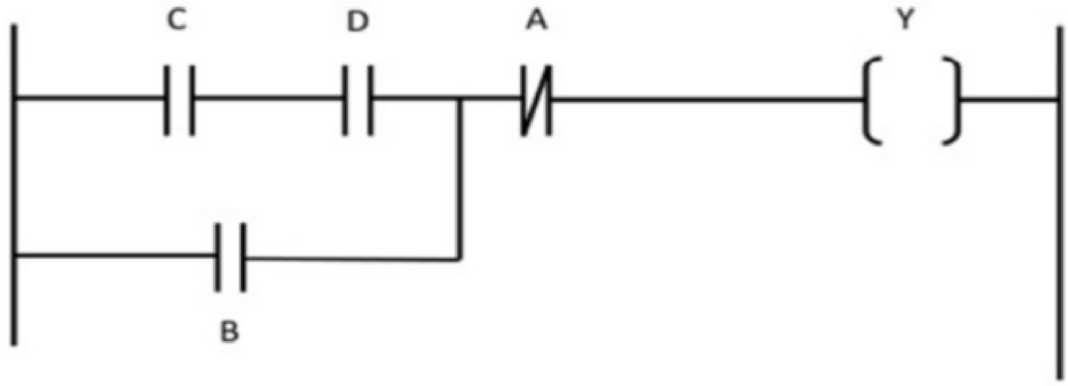
Draw Ladder diagram for given Boolean Expression

$$Y = ABC + D$$



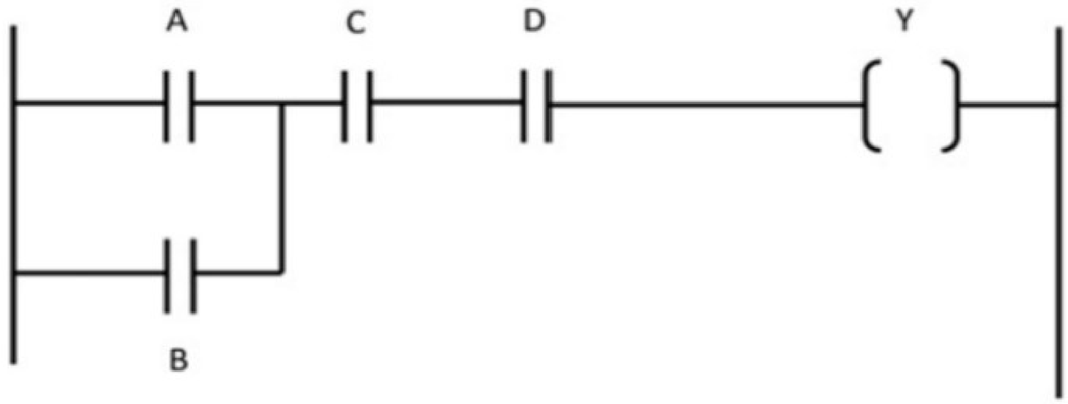
Draw Ladder diagram for given Boolean Expression

$$Y = \overline{A}(B + CD)$$



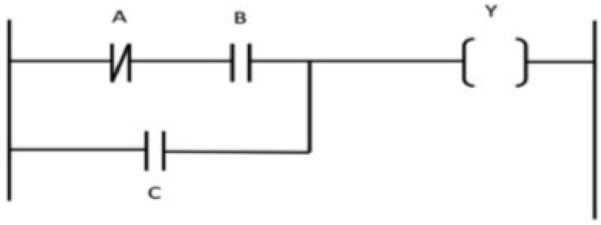
Draw Ladder diagram for given Boolean Expression

$$Y = (A + B)CD$$



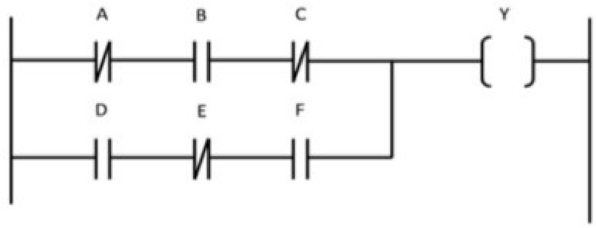
Draw Ladder diagram for given Boolean Expression

$$Y = \overline{A}B + C$$



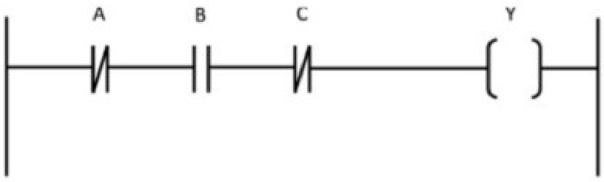
Draw Ladder diagram for given Boolean Expression

$$Y = (\overline{A}B\overline{C}) + (D\overline{E}F)$$



Draw Ladder diagram for given Boolean Expression

$$Y = (\overline{A} + B) + (\overline{A} + B + \overline{C})$$



5.9 TIMERS-I) T ON II) T OFF AND III) RETENTIVE TIMER

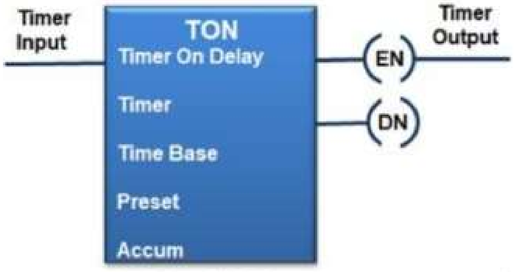
1. On Timer (TON)

What is TON?

TON is called 'On Delay Timer'.

An on-delay timer (TON) is a programming instruction which use to start momentary pulses for a set period of time.

Let's see, a simple construction of the AB PLC On-delay timer programming instruction.

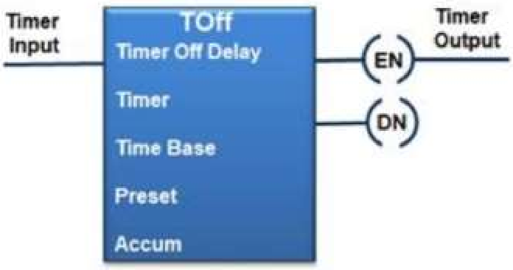


On Delay PLC Timer

In the LD programming, when an On-delay timer is energized (True), it delays turning 'on' the timer's output.
This output will be 'on' until the timer's preset time value is reached.off delay PLC timer instruction. It helps to activate the output (like machine or process) contact based on the delay time.
Example: Running Electric Motor after 10 seconds.
– If you press the button (NC), it starts the momentary pulse. After the 10 seconds, the motor will be 'On'.

2. Off Timer (TOFF)

What is TOFF?
TOFF is also known as an 'Off-Delay Timer'.
A off-delay (TOF) timer is a PLC programming instruction which use to switch off the output or system after a certain amount of time.
See here, a basic structure of AB PLC Off delay timer programming instruction.



Off Delay PLC Timer

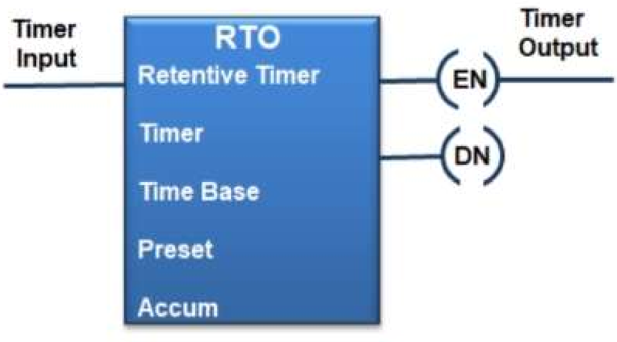
In PLC programming, when the off-delay timer is energized (True), it immediately turns 'on' its output. The output will be 'on' till it reaches the setting time.
When it reaches preset time, the output turns 'off'. Due to the turning 'off' condition, the timer is de-energized (False).
It helps to delay the shut down of machinery or process in automation industries.
Example: Stop electric motor after the 10 seconds.
– Firstly, you should switch press (NC), the motor will 'on' for the 10 seconds. After 10 seconds, the motor will automatically stop (NO).
This is the main function of the off-delay timer.

3. Retentive Timer On/Off (RTO)

The main function of the RTO is used to hold or store the set (accumulated) time.

RTO is used in the case when there is a change in the rung state, power loss, or any interruption in the system.

In the AB PLC, retentive timer instruction looks like this.



Retentive Timer On/Off

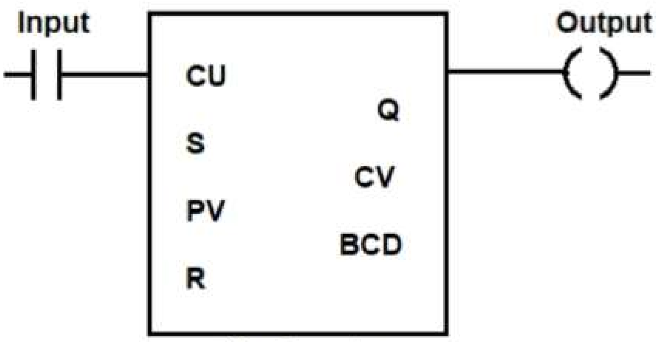
5.10 COUNTERS-CTU, CTD

Up Counter

Up counter counts from zero to the preset value. Basically, it increases the pulse or number.

Up counter is known as the '**CTU**' or '**CNT**' or '**CC**' or '**CTR**'.

Up counter function block diagram:



Up Counter

We can also set the initial and target value as an input to the counter.

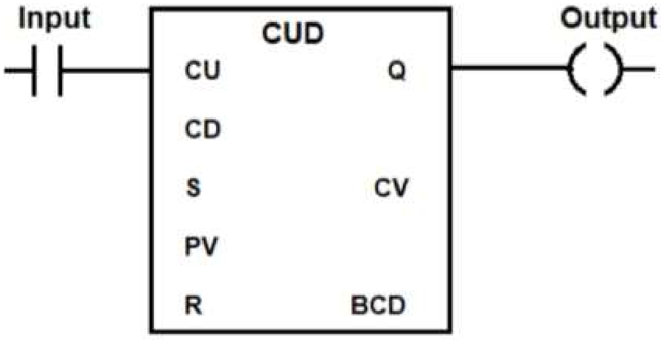
Here, the up-counter in PLC can count the value from the initial value to the target value. This initial value must be less than the target value. Most of the time, it is set as zero.

Down Counter

The down counter counts from the preset value to zero. It decreases the pulse or number.

Down counter is shortly known as the '**CTD**' or '**CD**'.

Down counter function block diagram:



Up-Down Counter

The down counter counts from target value to the initial value by decreasing it. This initial value must be less than the target value.

Counter Instruction Addressing for Siemens PLC

In Siemens PLC, up, down and up-down counters are used. These three PLC counters require some important factors

- S – Set the value of a counter.
- Q – Output of the counter.
- R- Reset value of the counter.
- PV- Preset counter value.
- CV – Count Variable.
- BCD – Current count in binary decimal code.
- Preset counter value (PV) and Count Variable (CV) require the same addressing format. The standard addressing format of the PV and CV in LD.

Summary of PLC Counter Function

- The basic counter function is to count the digital signal pulse or binary system.
- Different PLC brands offer a different range of counter values.
- Counters work as per the supported mode.
- Counter operates in up mode, down mode, bidirectional mode, and quadrature mode.
- Up counting starts from the zero or initial value to the target value.
- Down counting starts from target value down to the initial value.

5.11 LADDER DIAGRAMS USING TIMERS AND COUNTERS

LADDER DIAGRAMS USING TIMERS

In many of the PLC control tasks, there is a need to control the time an example of this will be using a PLC to control a motor. The motor would require to be controlled to operate for a certain interval, and that's why PLCs have timers and the timers are built-in devices in a PLC. By using the internal CPU clock the timer would count the time. Different PLC timers are programmed in different ways, so we can consider a timer to act as a relay with coils, which would open or close when it is energized according to the pre-set time.

Timer instructions

The timer instructions are the output instructions which is used to time the intervals for which the rung conditions are true or false. The timer accuracy will be depended upon the microprocessor which is being used. The timer instruction is composed of two values and they are

- **Accumulated value** – This is a current number of time-based intervals that have been counted from the moment when the timer is energized.
- **Preset value** – This value is set by the programmer, if the preset value is less than or equal to the accumulated value then a status bit is set and this bit is to control an output device.
- Each timer is composed of two status bit
- **Timer enable-bit** – This bit will be set if the rung condition to the left of the timer instruction is true and when this bit is set then the accumulated value will be incremented on each time base interval till it reaches the preset value.
- **Done bit** – This bit will be set if the preset value and the accumulated value are equal and it will be reset if the rung condition is false.

Timer working

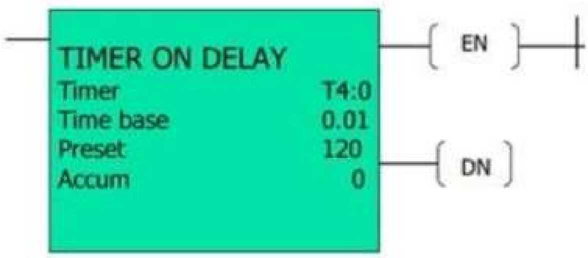
The timer will be activated if the execution condition is started and it will be reset if the execution condition stops or goes OFF. If the execution condition keeps ongoing or if it is long enough for the timer to time down to zero. Then the completion flag will be turned ON and it will remain ON till the execution condition is completed or turn off.

The address of the timer is unique in the PLC memory, the timer instruction is one element and the timer element is composed of 16-bits. The word zero will cover the status bits and it has three state bits such as EN, TT, and DN. The word one is for the preset value and the word two is for the accumulated value.

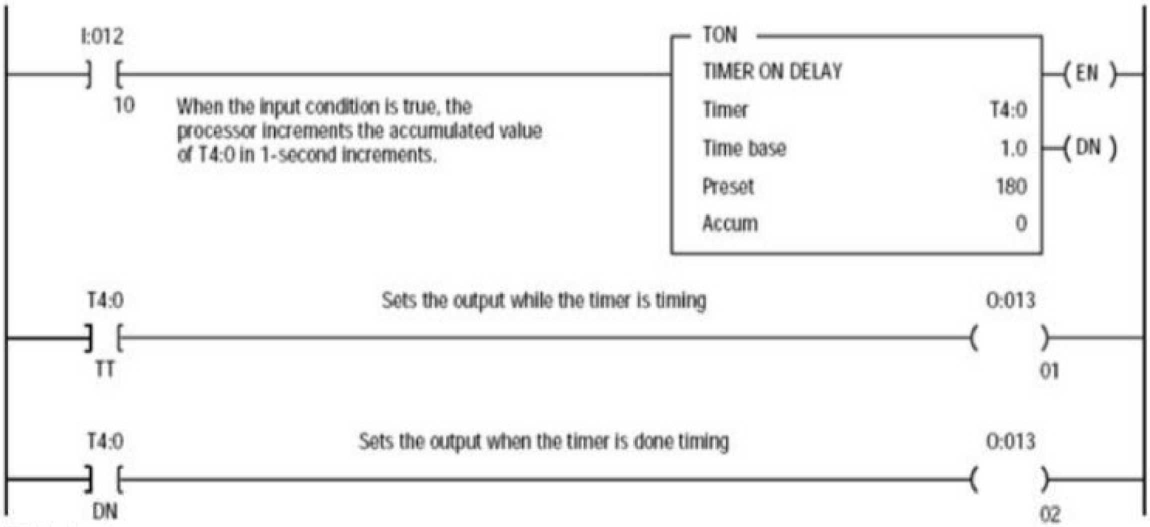
Types of timers

We can see different types of timers in a PLC

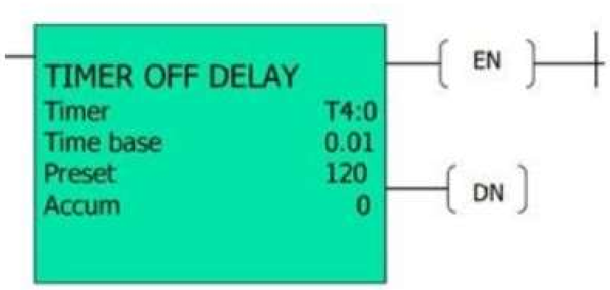
ON delay timer



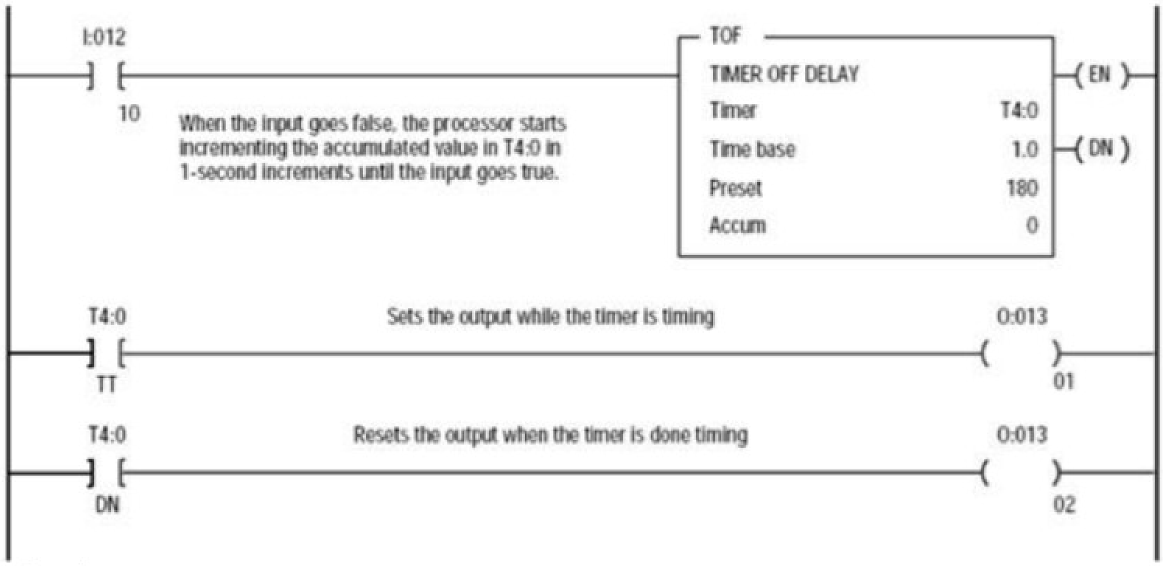
This type of timer can be seen in small PLC's and this timer would be on after a particular time delay. This is widely used for PLC programming we can also create other timer functions by using an on-delay timer. So this timer would delay the turning ON time in a system. This type of timer would count the time base interval if the instruction is true. So if the rung condition becomes true then the on delay timer instructions will start to count the time base intervals. So if the rung conditions stay true then the timer would adjust its accumulated value during each evaluation till it reaches the preset value. So when the rung condition becomes false then the accumulated value is reset. The three timer bits EN, TT, and DN can be used as rung conditions.



OFF delay timer



This is the exact opposite of the on delay timer; this timer would delays the turning off. So these timers are on for a fixed period of time before turning off. The output will be turned off after a delay, so when this timer is turned on then the output is also turned on. So if the output needs to be turned off then it needs to be turned on in the beginning. So this timer won't be activated before we turn the input off again, so if we do that the timer will start the count after the delay and the output will be turned off.



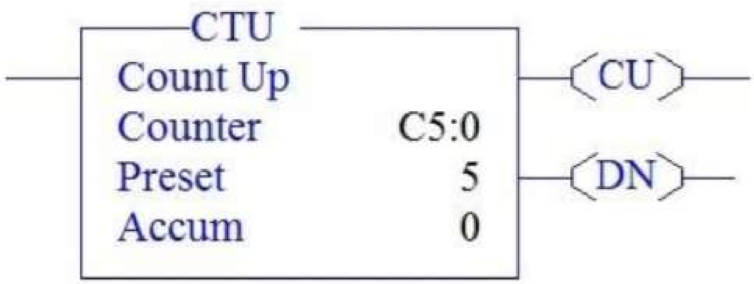
Pulse timer

This timer is not used widely in a PLC it can be very helpful for some PLC operations. The pulse timer is used to generate the pulse and it will be of a specific length. The pulse timer can be activated by turning on the input and when it is turned on then the timer would start counting the time. So basically a pulse timer can switch on or off for a fixed period of time.

LADDER DIAGRAMS USING COUNTERS

To study the working of **Up Counter PLC program** in Allen Bradley Programmable Logic Controller (PLC).

Up Counter

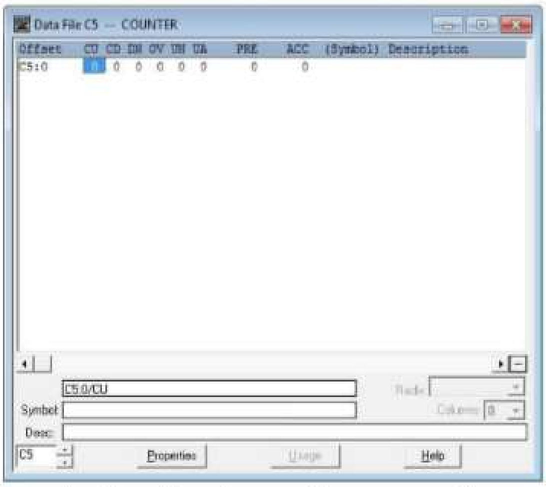


In the above picture, there are totally three parameter,

COUNTER: C4:0 – Counter File name (Timer C5:0, C5:1, C5:2…)

PRESET –PRE: Limit value of COUNT-Up to how much it should count

ACCUMULATOR –ACC: Running Value of counter when condition turn ON.

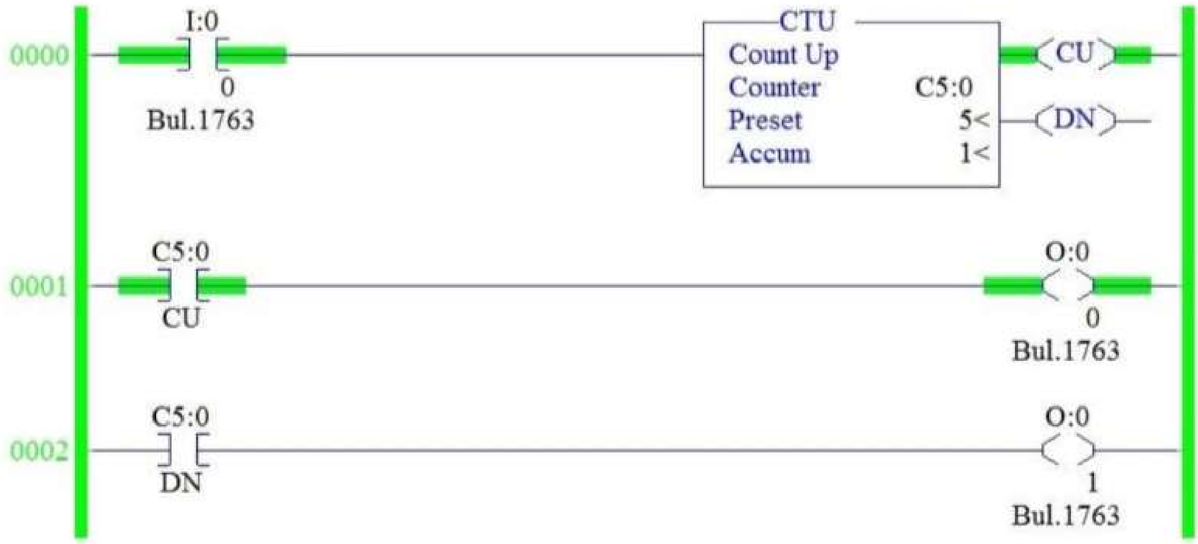


From the data file, along with preset and accumulator, we have few more bits,
CU: Count up Bit-whenever the counter is enable makes this bit to go ON.
DN: Done Bit-When accumulator value reached preset value, done bit turns to ON.
OV: Over Flow Bit-When accumulator value reached the limit value (32767),it rolls back to -32767 for the upcoming counter operation, Overflow bit turns ON, in this condition.

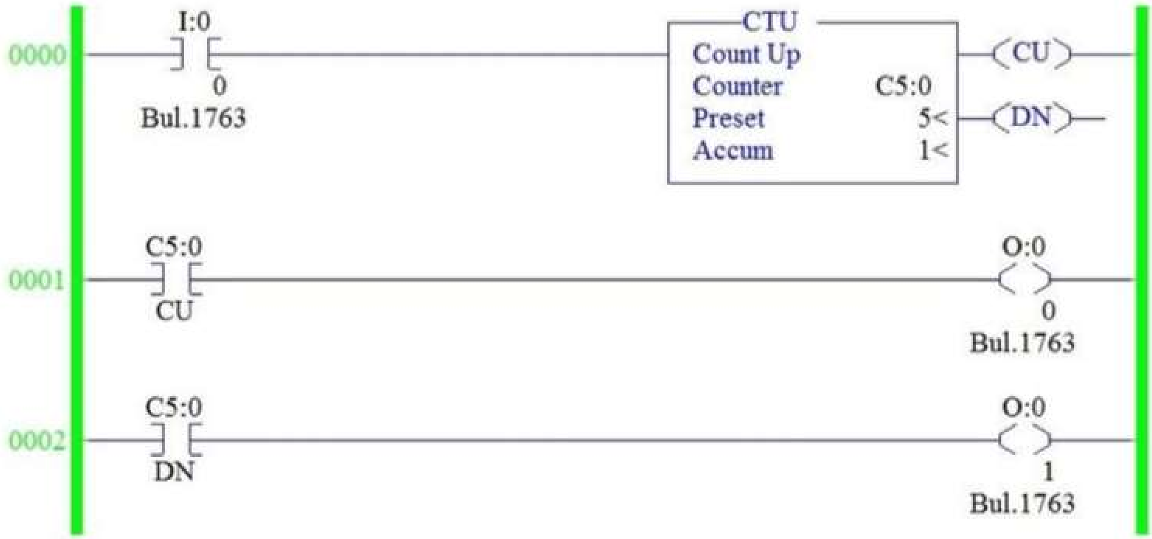
Notes:
UA-Update Accumulator Value-Only used when high speed counters are used in the program.
CD & UN-Used for down Counter Function.

Up Counter Description Using PLC Program

I:0/0 is used to give input to counter and Preset value is set to 5.
Counter Count up Bit (C5:0/CU)
In the below Ladder logic,
Rung 000 – Having condition input I:0/0 which gives input to counter to perform counter function.
Rung 0001 – Having Counter CU Bit which enable only when counter is in function or when input to the counter turns ON.

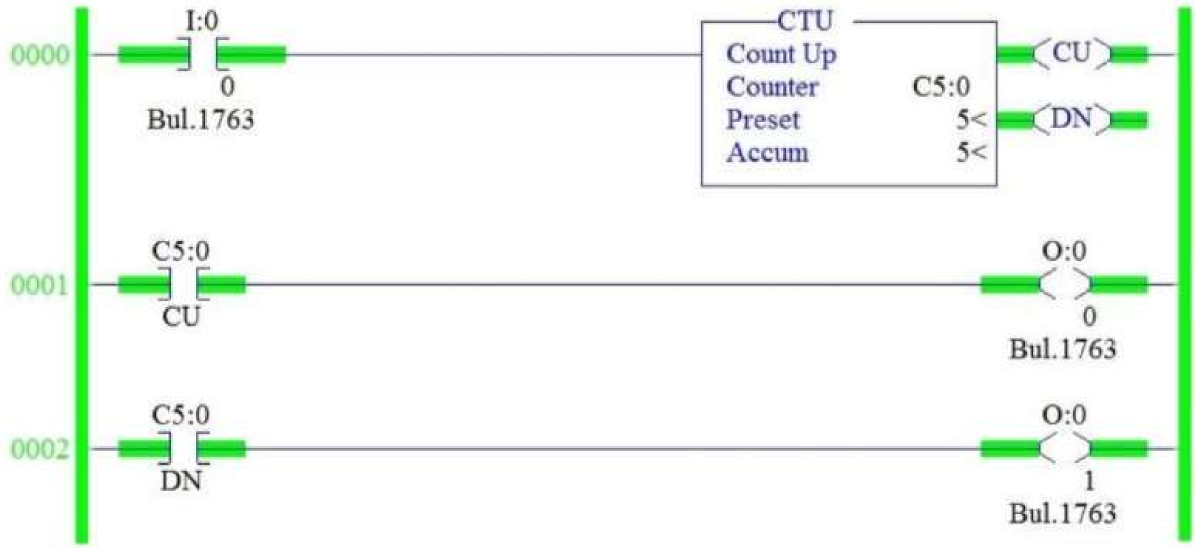


In the below ladder Logic,
When input to the counter turn OFF (I:0/0),Counter CU bit turns OFF. Output O:0/0 turns ON only when C5:0/CU turns ON.

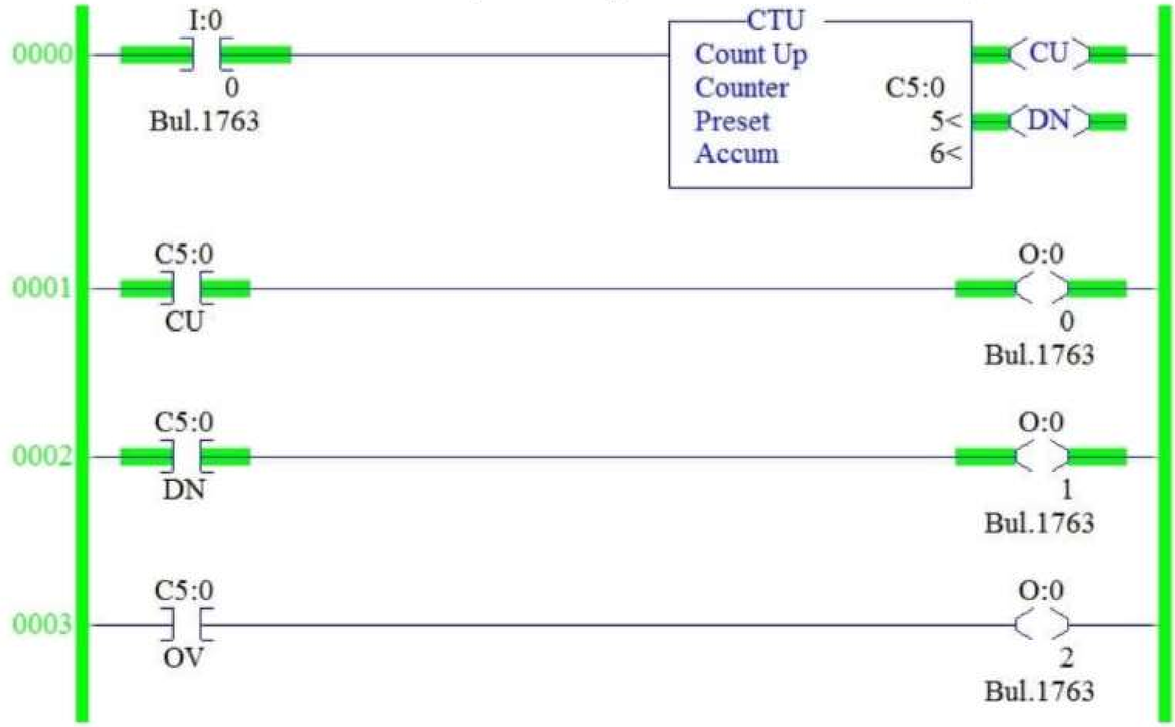


Counter Done Bit (C5:0/DN)

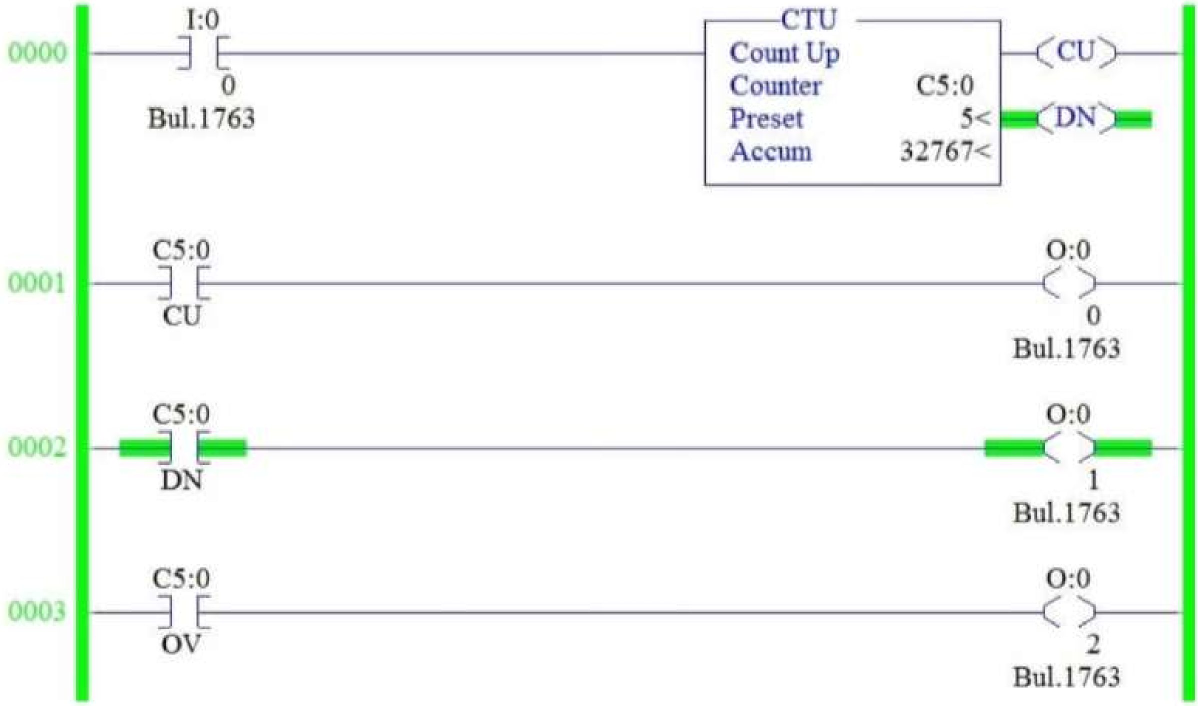
In the Below Ladder Logic,
When accumulator value reaches the Preset, Counter Done bit (Cu5:0/DN) turns ON.



In the below ladder Logic,
Done bits remains in the ON condition, even though accumulator value runs beyond Preset.

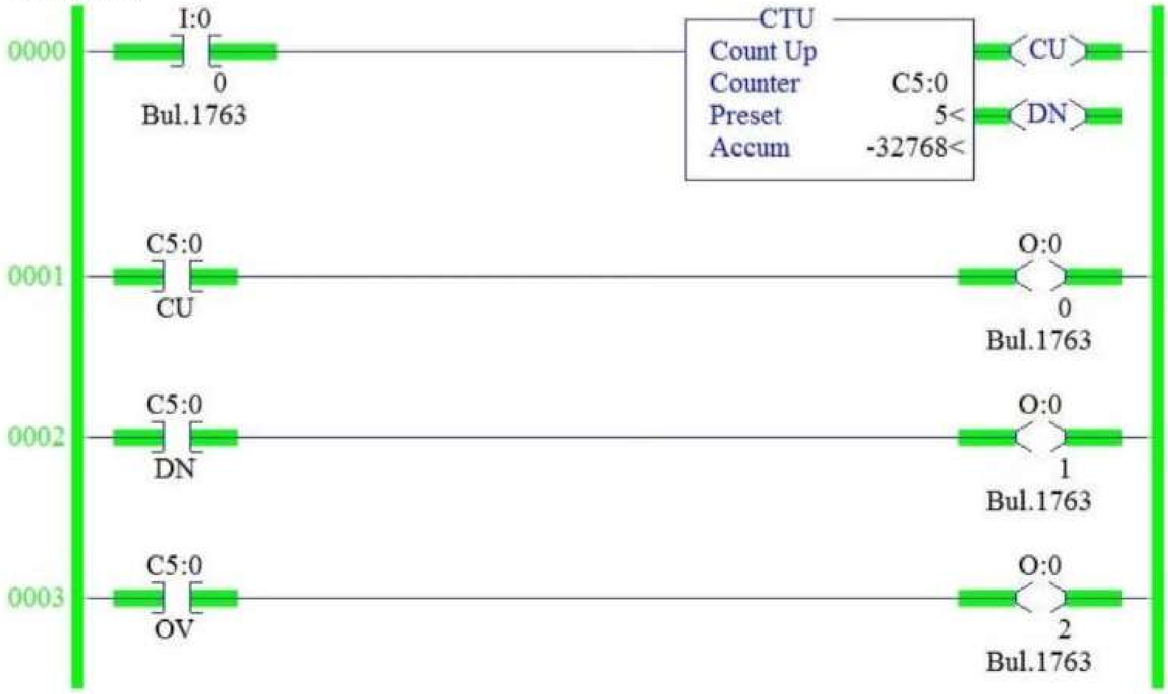


Counter Overflow Bit (C5:0/OV)
In the Below Ladder Logic,
Counter accumulator value overflows when accumulator value reaches 32767 in Allen Bradley PLC Programming.



In the below ladder Logic,

When we turn ON the I:0/0 for the 32768 time, accumulator value rolls back to -32768 and start counting from -32767 to 32767.Counter Overflow bit turns ON when this condition happen (Rung 003).



Conclusion:

We can use this explanation to understand the working of Up Counter function in Allen Bradley Programmable Logic Controller (PLC).

5.12 PLC INSTRUCTION SET

Naming Convention

During the development of a PLC program, we must use specific names to identify the inputs, outputs, memory flags, timers, and counters.

PLC manufacturers use a variety of approaches in naming the inputs, outputs and other resources.

A typical naming convention is to identify inputs with the letter "I" and outputs with the letter "O", followed by a 1-digit number that identifies the slot number and a 2-digit number that identifies the position of the input or output in the slot.

For example:

- I1:00 refers to the first input of slot 1
- O2:00 refers to the first output of slot 2.

Naming Convention

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For example:

- I1:00 refers to the first input of slot 1
- O2:00 refers to the first output of slot 2.

Examine if Closed (XIC)

If the input device is ON or closed, then the corresponding bit in the data memory (input image) is set to true, thus allowing (conceptually) the energy to flow from its left side to its right-hand side.

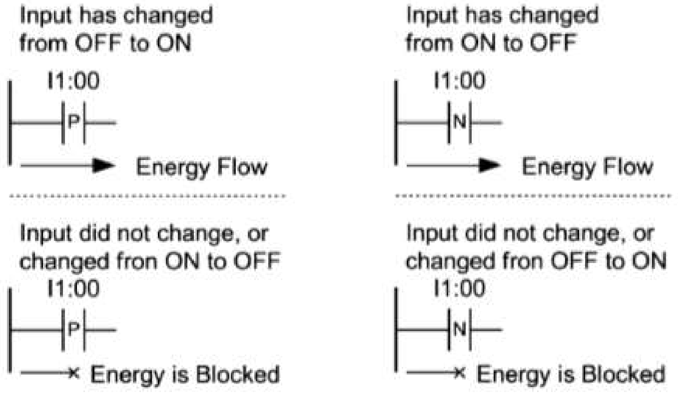
Otherwise, it is set to false, thus blocking the energy.

Examine if Open (XIO)

If the input device is OFF or Open, then the corresponding bit in the data memory (input image) is set to true, thus allowing (conceptually) the energy to flow from its left side to its right-hand side.

Otherwise, it is set to false, thus blocking the energy.

Input Transition Sensing Instructions



Positive Transition Sense (PTS) Negative Transition Sense (NTS)

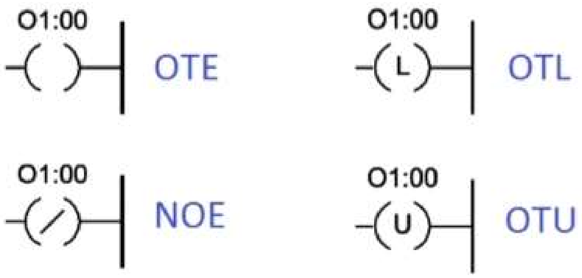
Positive Transition Sense (PTS)

The condition of the right link is ON for one ladder rung evaluation when a change from OFF to ON at the specified input is sensed.

Negative Transition Sense (NTS)

The condition of the right link is ON for one ladder rung evaluation when a change from ON to OFF at the specified input is sensed.

Output Instructions



Output Energize (OTE)

If the condition of the left link of the OTE is ON then the corresponding bit in the output data memory is set. The device wired to this output is also energized.

Negative Output Energize (NOE)

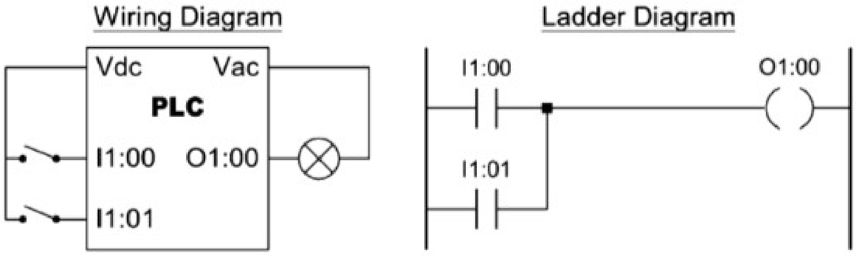
If the condition of the left link of the OTE is OFF then the corresponding bit in the output data memory is set. The device wired to this output is also energized.

Output Latch/Set and Output Unlatch/Reset (OTL), (OTU)

If the condition of the left link of the OTL is momentary ON then the corresponding bit in the output data memory is set, and remains set even if the condition switches to the OFF state. The output will remain set until the condition of the left link of the OTU is momentary ON.

Basic Logic Functions

Two Input OR Function

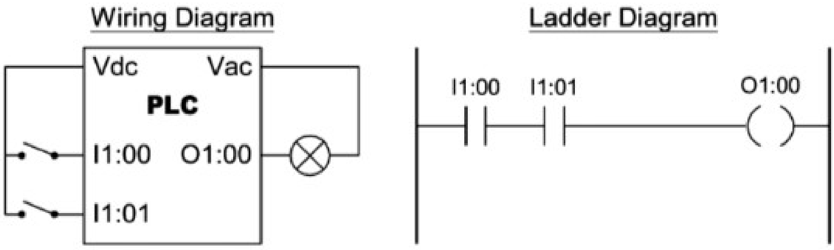


Truth Table

I1:00	I1:01	O1:00
OFF	OFF	OFF
OFF	ON	ON
ON	OFF	ON
ON	ON	ON

The output is ON if any of the two inputs is ON.

Two Input AND Function

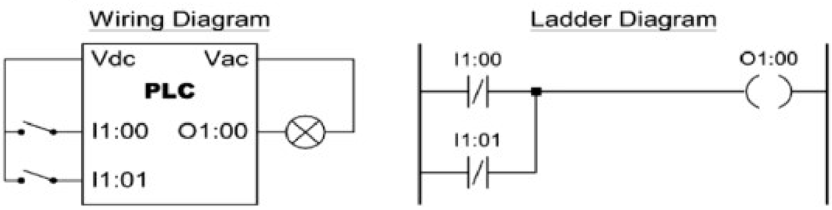


Truth Table

I1:00	I1:01	O1:00
OFF	OFF	OFF
OFF	ON	OFF
ON	OFF	OFF
ON	ON	ON

The output is ON if both of the two inputs are ON.

Two Input NAND Function

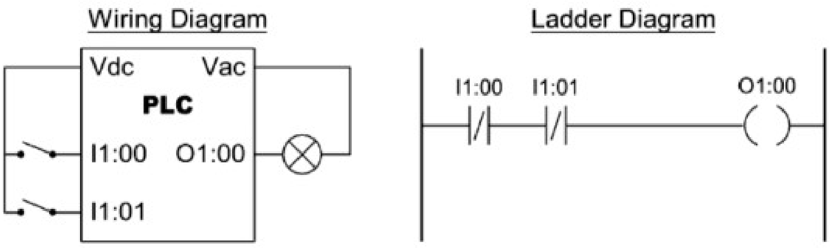


Truth Table

I1:00	I1:01	O1:00
OFF	OFF	ON
OFF	ON	ON
ON	OFF	ON
ON	ON	OFF

The output is ON if any of the two inputs is OFF.

Two Input NOR Function

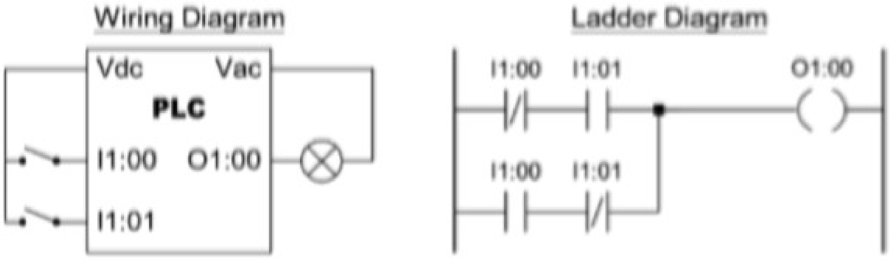


Truth Table

I1:00	I1:01	O1:00
OFF	OFF	ON
OFF	ON	OFF
ON	OFF	OFF
ON	ON	OFF

The output is ON if both of the two inputs are OFF.

Two Input EXOR Function

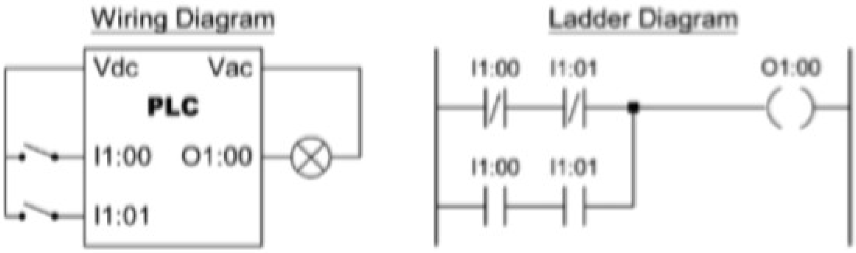


Truth Table

I1:00	I1:01	O1:00
OFF	OFF	OFF
OFF	ON	ON
ON	OFF	ON
ON	ON	OFF

The output is ON if any of the two inputs is ON, but not both.

Two Input EXNOR Function



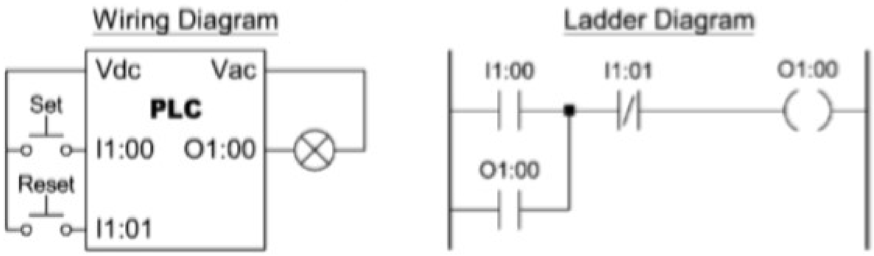
Truth Table

I1:00	I1:01	O1:00
OFF	OFF	ON
OFF	ON	OFF
ON	OFF	OFF
ON	ON	ON

The output is ON if both of the two inputs are either OFF or ON.

Set/Reset Latch Instructions

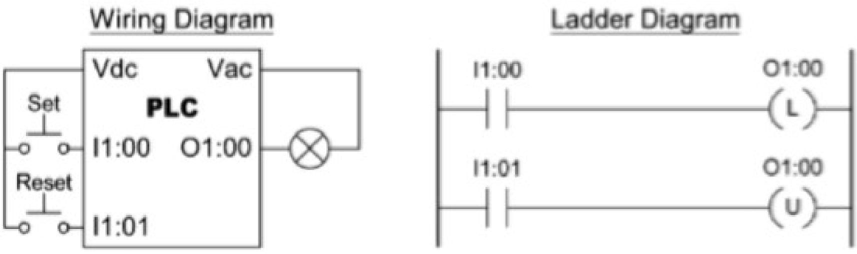
Set/Reset Latch using a Hold-in contact



Truth Table

I1:00	I1:01	O1:00
OFF	OFF	O1:00'
OFF	ON	OFF
ON	OFF	ON
ON	ON	OFF-?

Set/Reset Latch using Latch/Unlatch outputs



Truth Table

I1:00	I1:01	O1:00
OFF	OFF	O1:00'
OFF	ON	OFF
ON	OFF	ON
ON	ON	OFF-?

Notes:

- O1:00' means that the output is unchanged
- If both inputs are ON then normally the output is OFF, since the Unlatch rung appears last in the ladder diagram.

Timer Instructions

Timer Instructions are output instructions used to time intervals for which their rung conditions are true (TON), or false (TOF).

These are software timers. Their resolution and accuracy depend on a tick timer maintained by the microprocessor.

Each timer instruction has two values (integers) associated with it:

- Accumulated Value (ACC): This is the current number of ticks (time-base intervals) that have been counted from the moment that the timer has been energized.
- Preset Value (PR): This is a predetermined value set by the programmer. When the accumulated value is equal to, or greater than the preset value, a status bit is set. This bit can be used to control an output device.

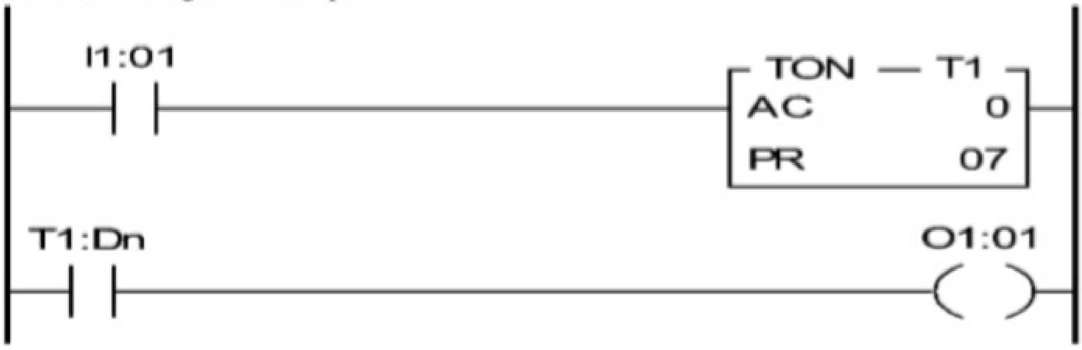
Each timer is associated with two status bits:

- Timer Enable Bit (EN): This bit is set when the rung condition to the left of the timer instruction is true. When this bit is set, the accumulated value is incremented on each time-base interval, until it reaches the preset value.
- Done Bit (DN): This bit is set when the accumulated value is equal to the preset value. It is reset when the rung condition becomes false.

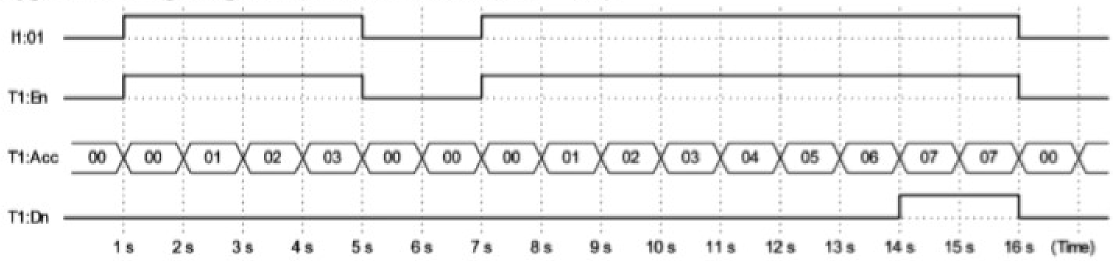
Timer On-Delay (TON) Instruction

The TON instruction begins to count when its input rung conditions are true. The accumulated value is reset when the input rung conditions become false.

Timer ladder diagram example:



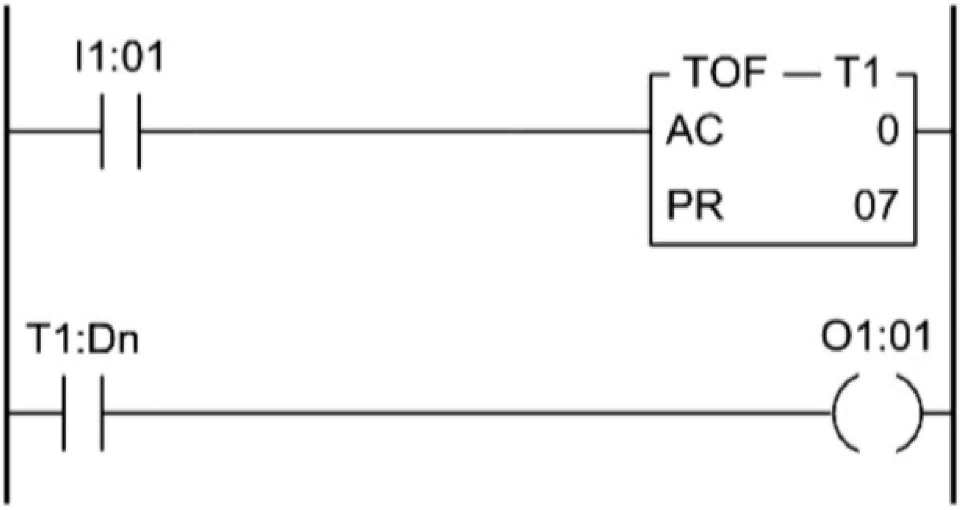
Typical timing diagram (Assume that Preset = 07)



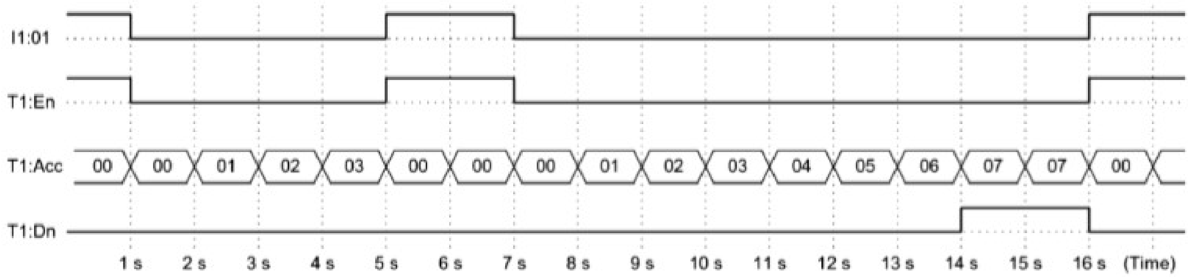
Timer Off-Delay (TOF) Instruction

The TOF instruction begins to count when its input rung makes a true-to-false transition, and continues counting for as long as the input rung remains false. The accumulated value is reset when the input rung conditions become false.

Timer ladder diagram example:



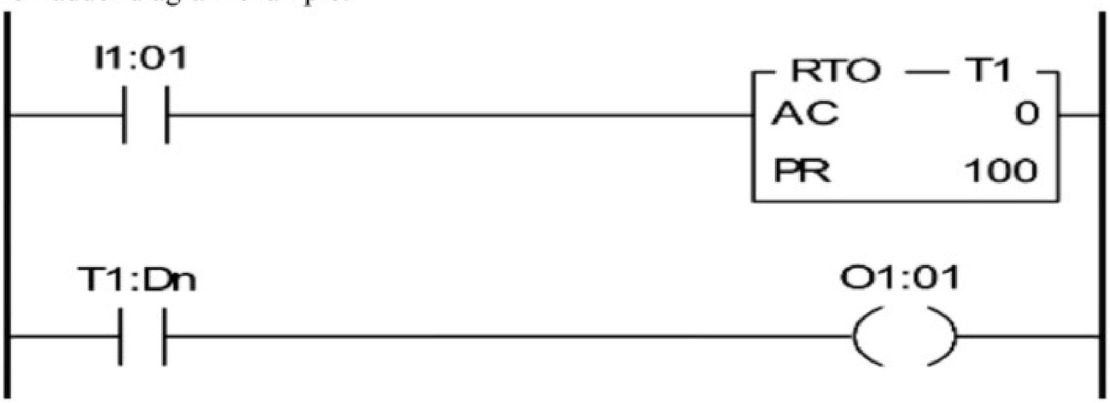
Typical timing diagram (Assume that Preset = 07)



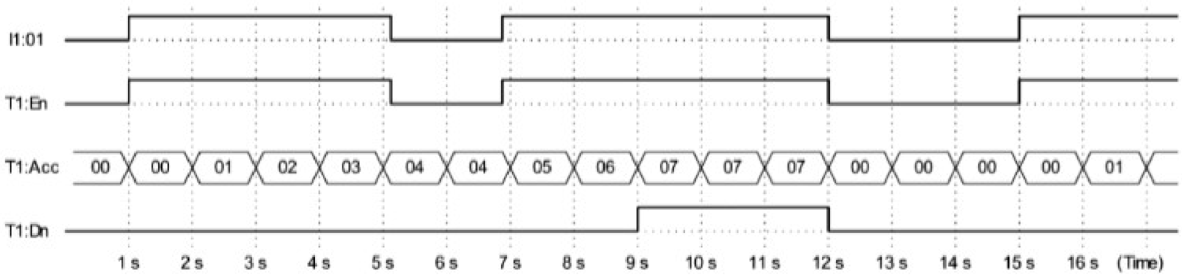
Retentive Timer (RTO) Instruction

The RTO instruction begins to count when its input rung conditions are true. The accumulated value is retained when the input rung conditions become false, and continues counting after the input rung conditions become true.

Timer ladder diagram example:



Typical timing diagram (Assume that Preset = 07)



Counter Instructions

Counter Instructions are output instructions used to count false-to-true rung transitions. These transitions are usually caused by events occurring at an input.

These counters can be UP (incrementing) or DOWN (decrementing).

Each counter instruction has two values (integers) associated with it:

- Accumulated Value (ACC): This is the current number of the counter. The initial value is zero.
- Preset Value (PR): This is a predetermined value set by the programmer. When the accumulated value is equal to, or greater than the preset value, a status bit is set. This bit can be used to control an output device.

Each counter is associated with two status bits:

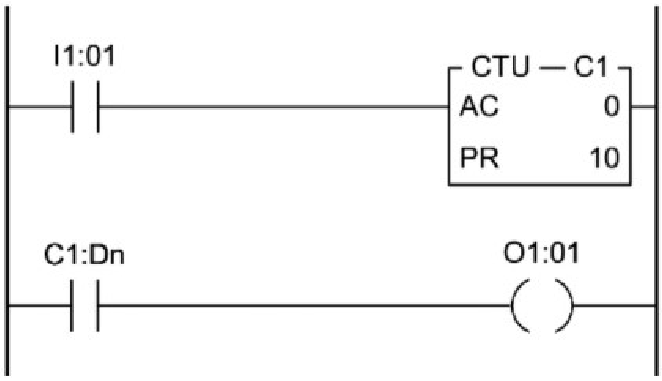
- Counter Enable Bit (EN): This bit is set when a false-to-true rung condition to the left of the counter instruction is detected.
- Done Bit (DN): This bit is set when the accumulated value is equal to the preset value. It is reset when the rung condition becomes false.

The maximum count value is 9999*. After a maximum count is reached, the counters reset and start counting from zero.

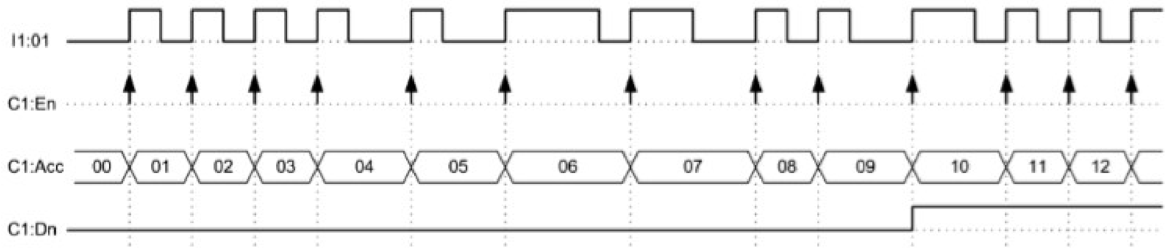
Count-up (CTU) Instruction

The CTU instruction increments its accumulated value on each false-to-true transition at its input, starting from 0.

Counter ladder diagram example:



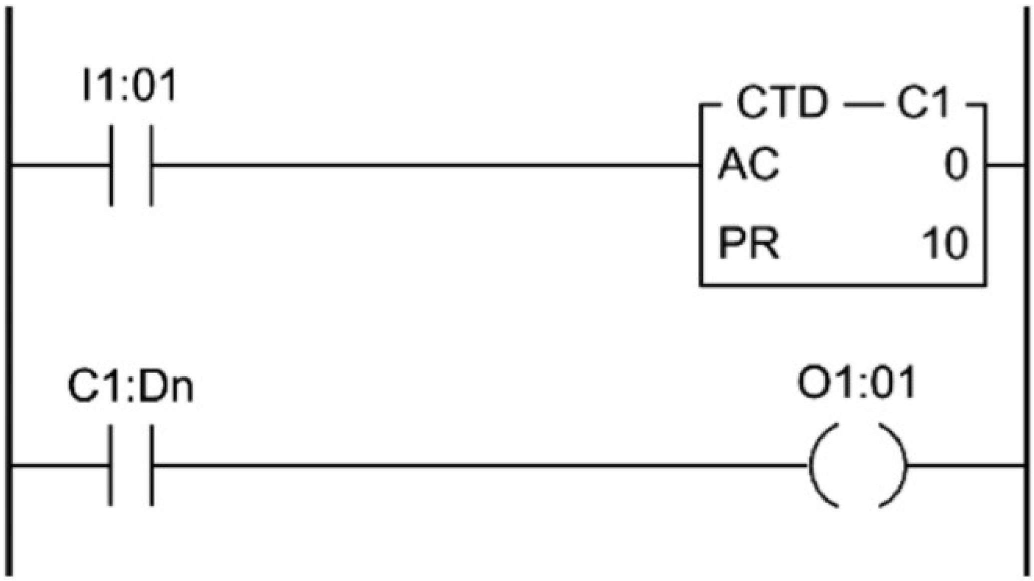
Typical timing diagram (Assume that Preset = 10)



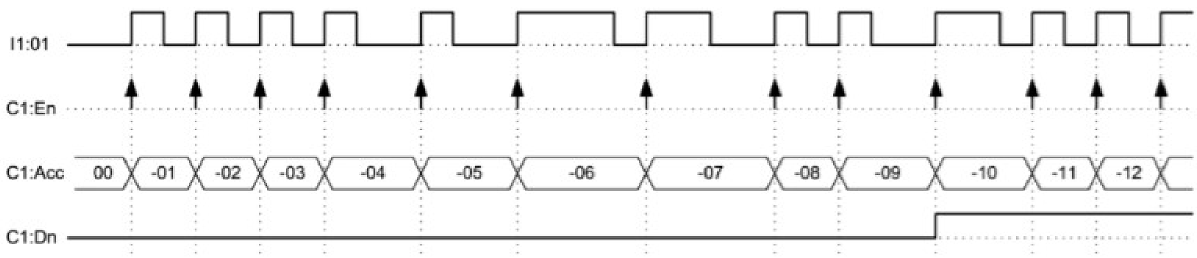
Count-down (CTD) Instruction

The CTD instruction decrements its accumulated value on each false-to-true transition at its input, starting from 0.

Counter ladder diagram example:



Typical timing diagram (Assume that Preset = -10)



The Reset (RES) Instruction

The RES instruction resets timing and counting instructions.

When the RES instruction is enabled it resets the following:

Counters:

- Accumulated value
- Counter Done Bit
- Counter Enabled Bit

Timers:

- Accumulated value
- Timer Done Bit
- Timer Timing Bit
- Timer Enable Bit

Reset ladder diagram example:

Some other PLC Instructions are :

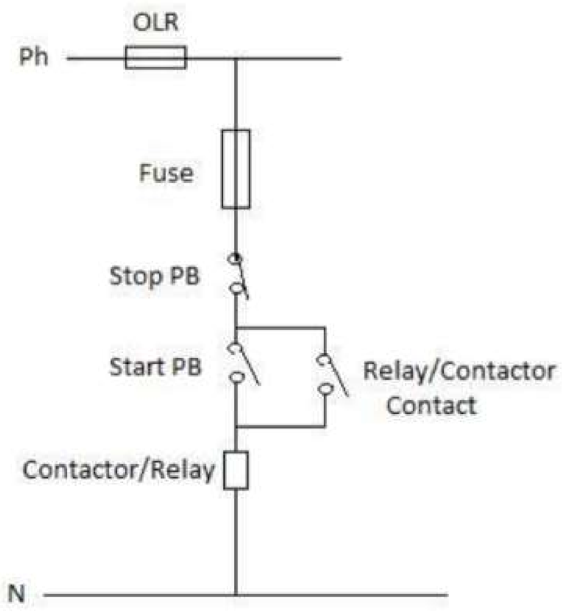
- Relay-type (Basic) instructions: I, O, OSR, SET, RES, T, C
- Data Handling Instructions:
- Data move Instructions: MOV, COP, FLL, TOD, FRD, DEG, RAD (degrees to radian).
- Comparison instructions: EQU (equal), NEQ (not equal), GEQ (greater than or equal), GRT (greater than).
- Mathematical instructions.
- Continuous Control Instructions (PID instructions).
- Program flow control instructions: MCR (master control reset), JMP, LBL, JSR, SBR, RET, SUS, REF
- Specific instructions:
- BSL, BSR (bit shift justify/right), SQO (sequencer output), SQC (sequencer compare), SQL (sequencer load).
- High-speed counter instructions: HSC, HSL, RES, HSE
- Communication instructions: MSQ, SVC
- ASCII instructions: ABL, ACB, ACI, ACL, CAN

5.13 LADDER DIAGRAMS FOR FOLLOWING (I) DOL STARTER AND STAR-DELTA STARTER (II) STAIR CASE LIGHTING (III) TRAFFIC LIGHT CONTROL (IV) TEMPERATURE CONTROLLER

(I) DOL STARTER AND STAR-DELTA STARTER

Working of Direct-On-Line (DOL) starter:

One method of starting electric motors is using direct on line (DOL) or across the line starter. In this method full line voltage is applied to the motor terminals. This is simplest type of motor starter. An electrical wiring diagram for single phase DOL starter is shown below.



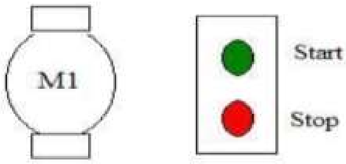
Control Circuit for DOL Starter

A DOL motor starter contains fuse and over load relay (OLR) for protection purpose. The starter can be contain momentary contact or maintained contact push buttons. The example considered here is momentary contact push buttons. For starting purpose normally open (NO) push button is preferred whereas normally closed (NC) push button is used to stop the motor.

The excessive supply voltage drop causing high inrush current is the criteria to limit the use of DOL starter. Conveyor motors, water pumps are the applications where DOL starters are used.

Procedure

Problem Statement: To start a motor using DOL starter. The simple P&I; diagram for this problem is as below.



Listing of Input and Output devices:

Inputs: PB1- To start the motor

PB2- To stop the motor

Output: M1- Motor

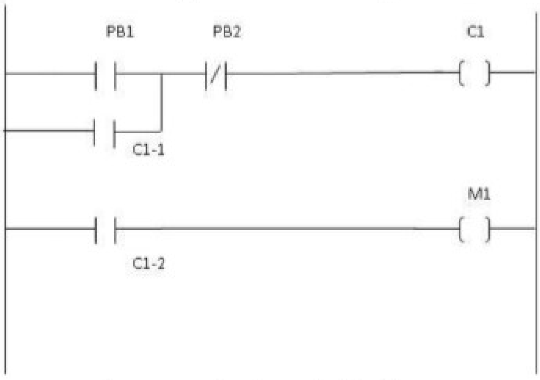
Sequence of Events :

1. When Start push button (PB1) is pressed, Motor (M1) has to start.
2. If Start pushbutton (PB1) is released and Stop pushbutton (PB2) is not pressed, Motor (M1) should remain on.
3. When Stop push button (PB2 is pressed, Motor (M1) has tol stop.
4. If stop push button is released and start is not pressed (released) motor should remain off.

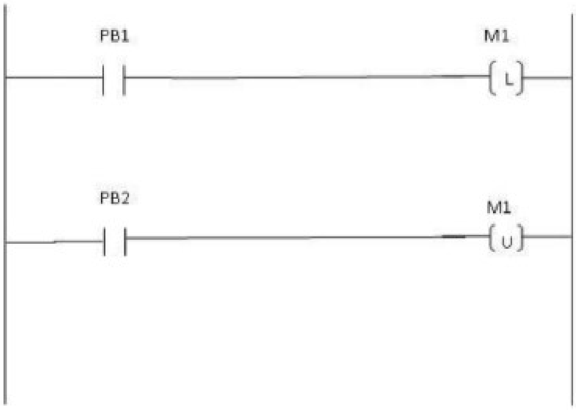
The Boolean equation to represent this sequence is

$$M1 = PB1.\overline{PB2}$$

The ladder diagram to implement these equations is shown below.



As the momentary contact push buttons are used here, the condition of PB1 is maintained through contact of coil C1. This contact is called as latching contact. The same sequence of event can be executed by using latch and unlatch instruction in the following way.



STAR-DELTA STARTER

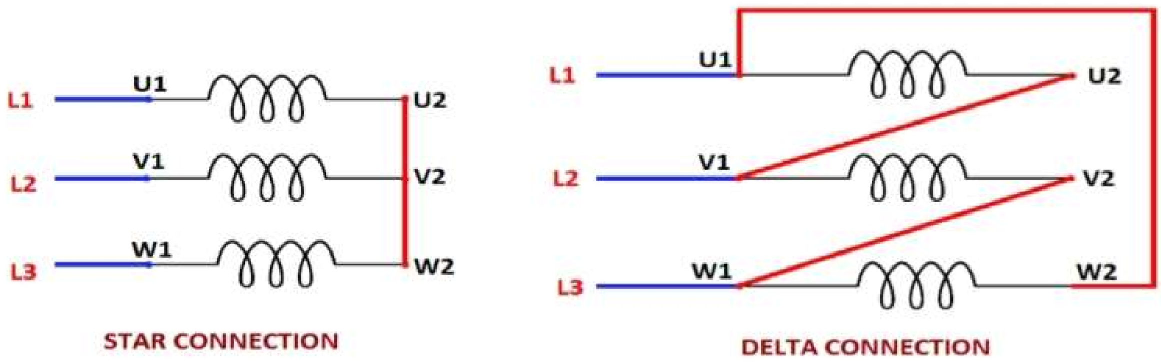
When electric motor is started, it draws a high current typical 5-6 times greater than normal current. In DC motors there is no back emf at starting therefore initial current is very high as compared to the normal current.

To protect the motor from these high starting currents we use a star and delta starter.

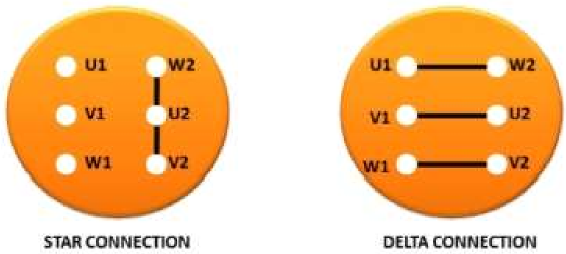
Simply in Star connection, supply voltage to motor will be less. so we use star connection during starting of the motor, after motor running we will change the connection form star to delta to gain full speed of the motor.

Star Delta Motor Starter

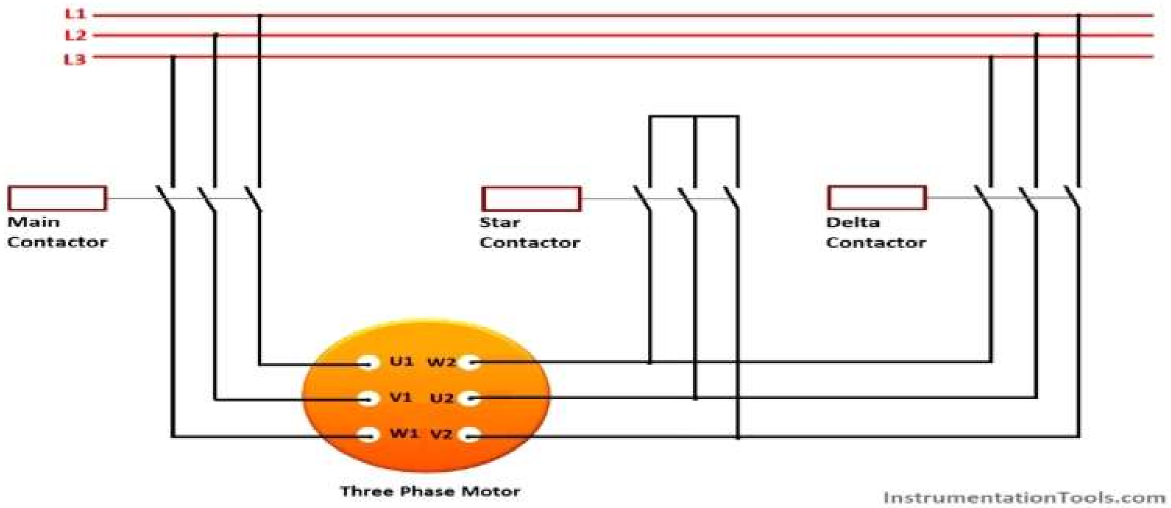
The following figure shows the winding connections in star and delta configuration one by one.



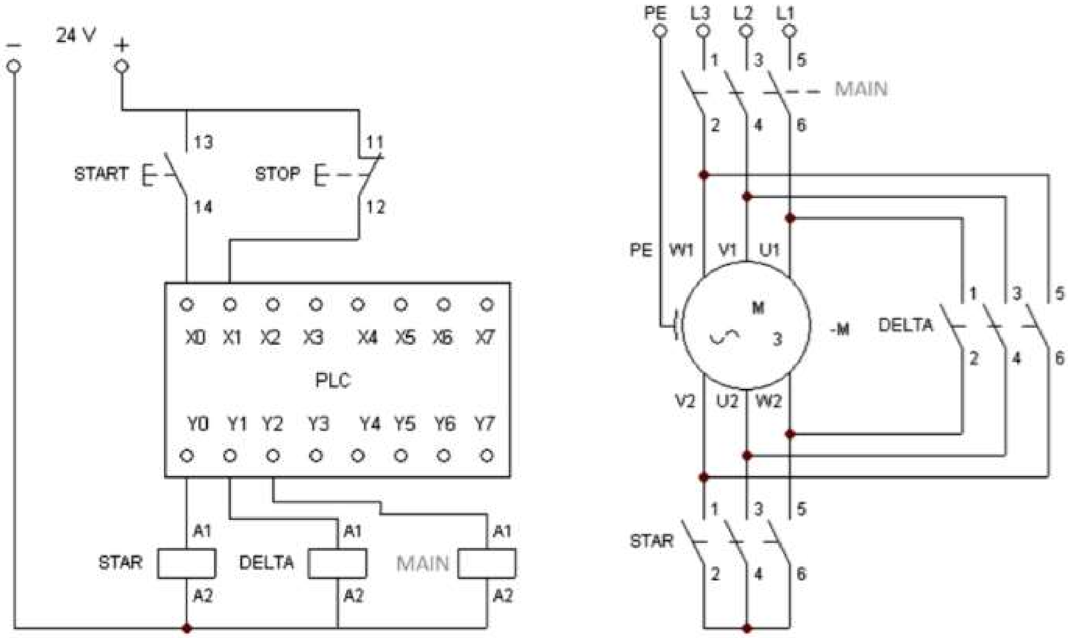
It can be seen that in star connection, one end of all three windings are shorted to make star point while other end of each winding is connected to power supply.It can be seen that in star connection, one end of all three windings are shorted to make star point while other end of each winding is connected to power supply. In delta configuration, the windings are connected such that to make a close loop. The connection of each winding is shown in above figure. In actual motor the three phase connections are provided in the following order as shown



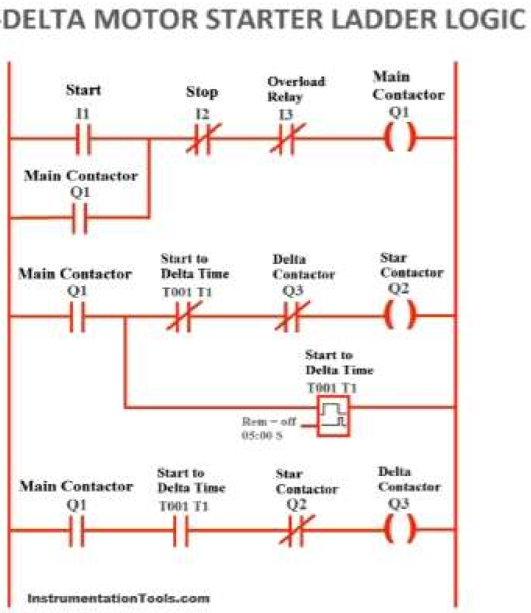
So in order to make winding connection in star and delta style in practical motor, the connection is shown above.



Main contractor is used to supply power to the windings. It must be turned on all the time. Initially the star contactor is closed while delta contactor is open It makes the motor windings in star configuration. When the motor gains speed, the star contactor is opened while delta contactor is closed turning the motor windings into delta configuration. The contactors are controlled by using PLC. The following section of PLC tutorial will explain the ladder programming for star delta motor starter.PLC program for star delta motor starter:



PLC Ladder Logic



Rung 1 Main contractor :

The main contactor depends upon the normally open input start push button (I1), normally closed stop button (I2) and normally closed overload relay. It means that Main contactor will only be energized if start button is pressed, while stop is not pressed and overload relay is not activated.

A normally open input named (Q1) is added in parallel to the start button I1.By doing so, a push button is created which means that once motor is started, it will be kept started even if start button is released

Rung 2 Star contactor:

Star contactor depends upon main contractor, normally close contacts of timer (T1), and normally close contacts of output delta contactor (Q3).So star contactor will only be energized if main contactor is ON, time output is not activated and delta contactor is not energized.

Timer T1:

Timer T1 measures the time after which the winding connection of star delta starter is to be changed. It will start counting time after main contractor is energized.

Rung 3 Delta contactor:

Delta contactor will be energized when main contactor (Q1) is energized, timer T1 is activated and star contactor (Q3) is de-energized.

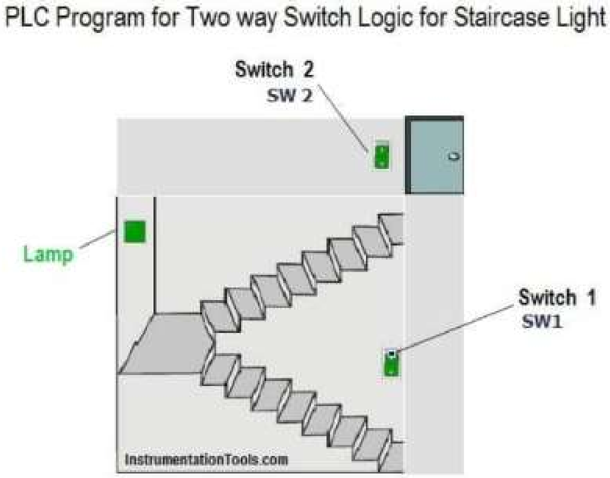
(ii) Stair case lighting

This is PLC Program for Two ways switch logic for staircase light in house

PLC Two Way Switch Logic

- In duplex type house there are ground floor and first floor and sometimes second floor also.
- Sometimes people need to go from ground floor to first floor or from first floor to ground floor by staircase provided in house.
- But in staircase there is no sunlight so people need a lamp/light to see the steps of the staircase easily.
- Here we are using a simple PLC to control this lamp using two switches, one switch at ground floor and second switch at first floor to control one lamp as shown in below figure.
- Note : we can also build the circuit using simple relays/switches also. This article only for understanding the basic concept of 2 way switch using a PLC Ladder Logic.

Problem Diagram



Problem Solution

We will solve this problem by simple automation. As shown in figure consider one simple house with one floor and staircase is provided in the house.

Here we will set lighting system for the users to switch ON/OFF the light whether they are on bottom of the stair or at top.

We will provide separate switch for each floor as shown in above figure.

List of inputs/outputs

Digital Inputs

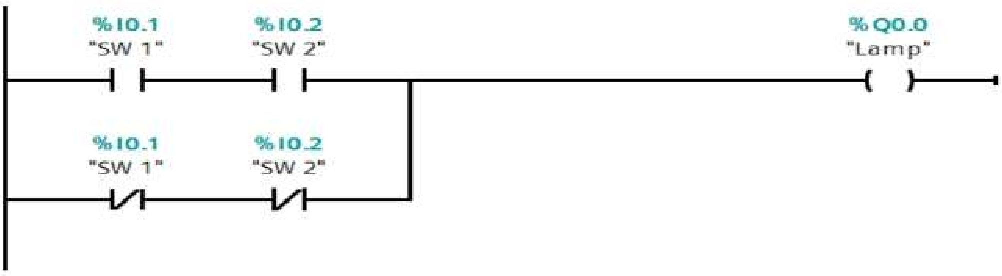
SW1: I0.1

SW2: I0.2

Digital Outputs

Lamp: Q0.0

PLC Ladder diagram for two ways switch logic



Program Description

- For this application, we used S7-1200 PLC and TIA portal software for programming.

- In above program, we have added two NO contacts of SW 1 (I0.1) and SW 2 (I0.2) in series and NC contacts of SW1 (I0.1) and SW2 (I0.2) in parallel of this series SW1 & SW2 NO Contacts.
- If the status of the bottom switch (SW1) and status of the top switch (SW2) are same then lamp will be ON. And if either status of the bottom or top switch is different from other then lamp (Q0.0) will be OFF.
- When lamp (Q0.0) is OFF then user can ON the lamp by changing status of any switch. Also user can turn OFF the lamp by changing the status of one of the two switches.

Runtime Test Cases

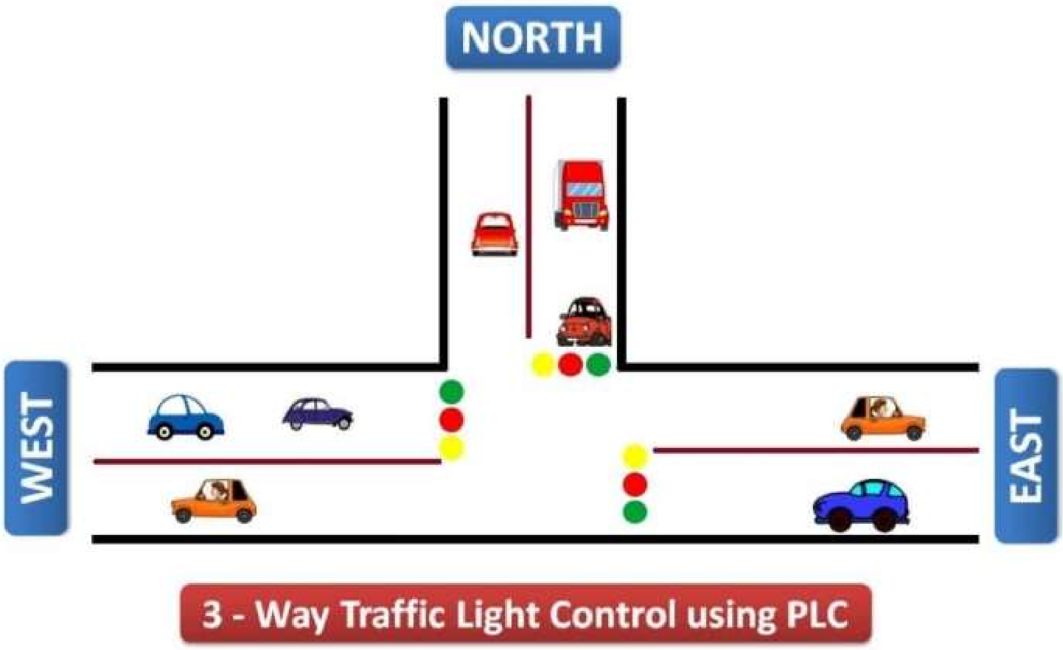
PLC Program for Two Way Switch Logic

Inputs	Outputs	Physical Elements
I0.1=1 & I0.2=1	Q0.0=1	Lamp on
I0.1=0 & I0.2=0	Q0.1=1	Lamp on
I0.1=0 & I0.2=1	Q0.1=0	Lamp off
I0.1=1 & I0.2=0	Q0.1=0	Lamp off

(iii) Traffic light Control

We most often come across a three-way traffic jam in our city. This **PLC program** gives the solution to control heavy traffic jams using programmable logic control.

Traffic Light Control using PLC



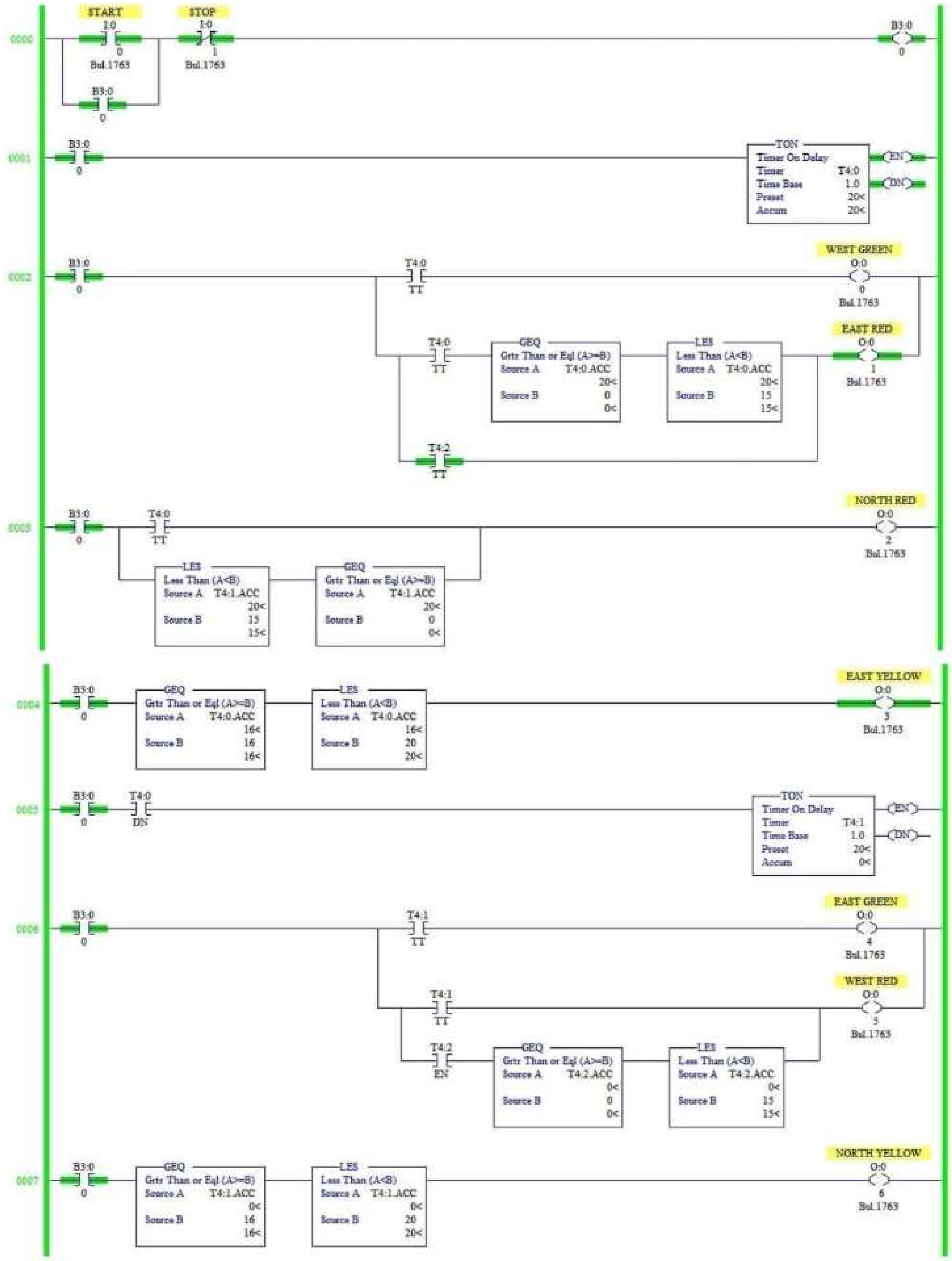
Problem Solution

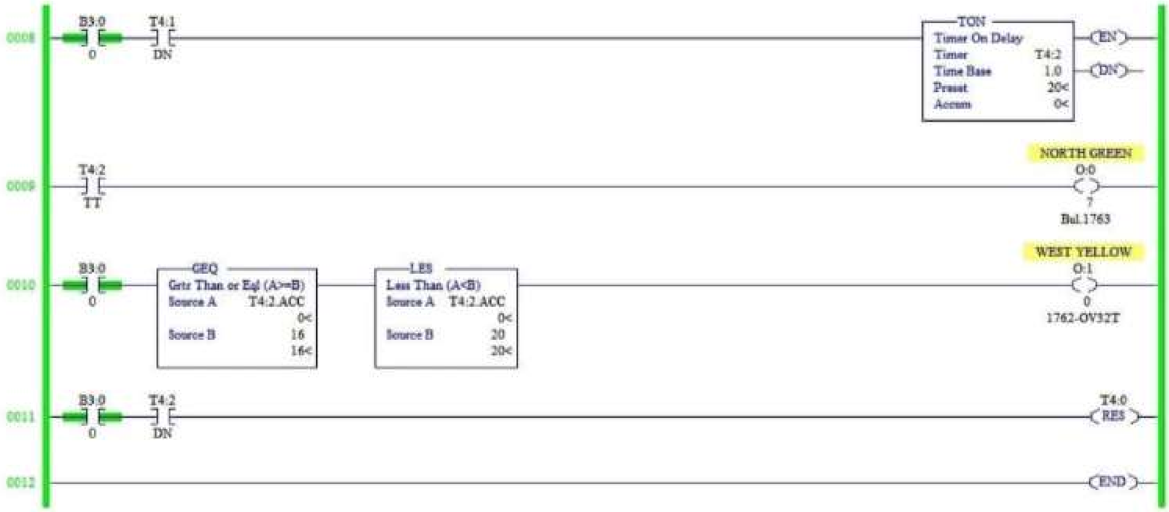
- They are so many ways to write a program for traffic light control ex: sequencer output method but in this normal input, outputs and timers are used.
- Timers are used to give time delay for output to turn ON and OFF.
- Reset coil is used at the end to run the program continuously.
- Comparator blocks are used to reduce the number of timers used.
- Program done in AB RSLogix 500 Software.

List of Inputs and Outputs for Traffic Control System

S.no	Address	Name	Input/Output
1	I:0/0	Start	Input
2	I:0/1	Stop	Input
3	B3.0	Memory	Memory
4	O:0/0	West Green	Output
5	O:0/1	East Red	Output
6	O:0/2	North Red	Output
7	O:0/3	East yellow	Output
8	O:0/4	East Green	Output
9	O:0/5	West Red	Output
10	O:0/6	North Yellow	Output
11	O:0/7	North Green	Output
12	O:1/0	West Yellow	Output

PLC Program for 3-way Traffic control System


0000
START
I:0
0
Bul.1763
STOP
I:0
1
Bul.1763
B3:0
0
0001
TON
Timer On Delay
Timer T4:0
Time Base 1.0
Preset 20<
Accum 20<
EN
DN
0002
T4:0
TT
WEST GREEN
O:0
0
Bul.1763
GEQ
Grtr Than or Eql (A>=B)
Source A T4:0.ACC
20<
Source B 0
0<
LES
Less Than (A<B)
Source A T4:0.ACC
20<
Source B 15
15<
EAST RED
O:0
1
Bul.1763
T4:2
TT
0003
NORTH RED
O:0
2
Bul.1763
LES
Less Than (A<B)
Source A T4:1.ACC
20<
Source B 15
15<
GEQ
Grtr Than or Eql (A>=B)
Source A T4:1.ACC
20<
Source B 0
0<
0004
GEQ
Grtr Than or Eql (A>=B)
Source A T4:0.ACC
16<
Source B 16
16<
LES
Less Than (A<B)
Source A T4:0.ACC
16<
Source B 20
20<
EAST YELLOW
O:0
3
Bul.1763
0005
T4:0
DN
TON
Timer On Delay
Timer T4:1
Time Base 1.0
Preset 20<
Accum 0<
EN
DN
0006
T4:1
TT
EAST GREEN
O:0
4
Bul.1763
WEST RED
O:0
5
Bul.1763
T4:2
EN
GEQ
Grtr Than or Eql (A>=B)
Source A T4:2.ACC
0<
Source B 0
0<
LES
Less Than (A<B)
Source A T4:2.ACC
0<
Source B 15
15<
0007
GEQ
Grtr Than or Eql (A>=B)
Source A T4:1.ACC
0<
Source B 16
16<
LES
Less Than (A<B)
Source A T4:1.ACC
0<
Source B 20
20<
NORTH YELLOW
O:0
6
Bul.1763



Below tabular column gives the Steps or sequence of outputs to turn ON.

S.NO	EAST	WEST	NORTH
1	R	G	R
2	Y	G	R
3	G	R	R
4	G	R	Y
5	R	R	G
6	R	Y	G

PLC Logic Description for 3-way Traffic Control System

RUNG000:

This is a Latching rung to operate the system through Master Start and Stop PB.

RUNG001 and RUNG0002:

Starting the timer to turn ON first output West Green so east and west should be in red. Comparators in Parallel rung are used to turn OFF East red after 15 sec. Timer T4:2 timing bit in parallel contact used to turn ON East red again in 5$^{th\ and}$ 6Th Step. (Refer Above Tabular column for clarification)

RUNG 0003:

Turning ON North Red up to 3rd step using T4:0 and T4:1's timer timing bit and comparator blocks.

Rung 0004:

Turn ON East yellow for 5 sec using comparator blocks. (Step 2nd)

Rung 0005-0006-0007-0008-0009-0010 :

The same procedures followed to turn ON further outputs. (Refer Tabular column for a sequence of operation)

RUNG 0011:
Reset coil is turned ON using T4:2's done bit to restart the cycle from beginning
The program runs continuously until STOP PB is pressed

(IV) TEMPERATURE CONTROLLER

PLC Temperature Control : In a vessel there are Three Heaters which are used to control the temperature of the vessel.

PLC Temperature Control Programming

We are using Three Thermostats to measure the temperature at each heater. Also another thermostat for safety shutoff in case of malfunction or emergency or to avoid over temperatures.

All these heaters have different set points or different temperature ranges where heaters can be turned ON accordingly (below table shows the temperature ranges).

- A temperature control system consists of four thermostats. The system operates three heating units. The thermostats (TS1/TS2/TS3/TS4 are set at 55°C, 60°C, 65°C and 70°C.
- Below 55°C temperature, three heaters (H1,H2,H3) are to be in ON state
- Between 55°C – 60°C two heaters (H2,H3) are to be in ON state.
- Between 60°C – 65°C one heater (H3) is to be in ON state.
- Above 70°C all heaters are to be in OFF state, there is a safety shutoff (Relay CR1) in case any heater is operating by mistake.
- A master switch turns the system ON and OFF.

Solution:

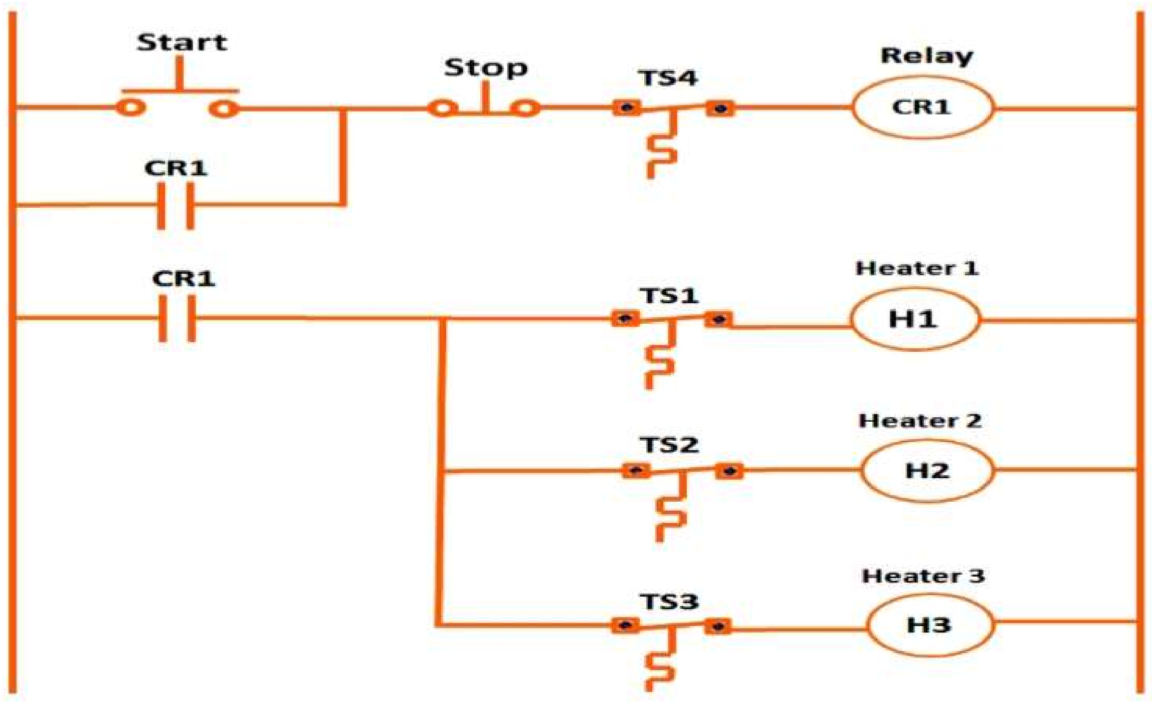
- There are four thermostats; assume them be in NC state when the set point is not reached.
- Let there be a control relay (CR1) to work as a safety shutoff.
- Master Switch: The Start switch is NO and Stop switch NC type.

The below table shows the temperature ranges where Thermostats (TS1,TS2,TS3,TS4) status will be indicated as per the temperature value.

Also the Heaters (H1, H2, H3) status in which either those Heaters will be ON or OFF as per the temperature value.

Temperature	Thermostats	Heater 1	Heater 2	Heater3
Below 55°C	TS1 Closed TS2 Closed TS3 Closed TS4 Closed	ON	ON	ON
55°C-60°C	TS1 Open TS2 Closed TS3 Closed TS4 Closed	OFF	ON	ON
60°C-65°C	TS1 Open TS2 Open TS3 Closed TS4 Closed	OFF	OFF	ON
65°C-70°C	TS1 Open TS2 Open TS3 Open TS4 Closed	OFF	OFF	OFF
Above 70°C	TS1 Open TS2 Open TS3 Open TS4 Open	OFF	OFF	OFF

PLC Ladder Logic



Ladder Logic Operation :

First Rung:

It has START button (default NO contact) and STOP button (default NC contact). A Relay CR1 is used to control the heaters depending on the thermostats status.

A Thermostat TS4 is connected in between STOP & Relay; if TS4 activated (means TS4 contact changes from NC to NO) then all heaters will be OFF.

An NO contact of Relay CR1 is used across the START button in order to latch or hold the START command.

Second Rung:

Second Rung:

An NO contact of Relay CR1 is used to control the Heaters (H1, H2, H3) with the thermostats (TS1,TS2,TS3) status.

After giving START command, This NO contact becomes NC contact. if temperature below 55 Deg C, TS1, TS2 & TS3 will be in Close Status so all heaters will be ON.

If Temperature is in between 55 to 60 Deg C, Then TS1 will be Open, so Heater H1 will be OFF.

Then, if temperature in between 60 to 65 Deg C then TS2 also be Open, so Heater H2 will be OFF

if temperature in between 65 to 70 Deg C then TS3 also be Open, so Heater H3 will be OFF

There is a safety Shutoff which is used to avoid any malfunctions of Thermostats or to avoid over temperatures.

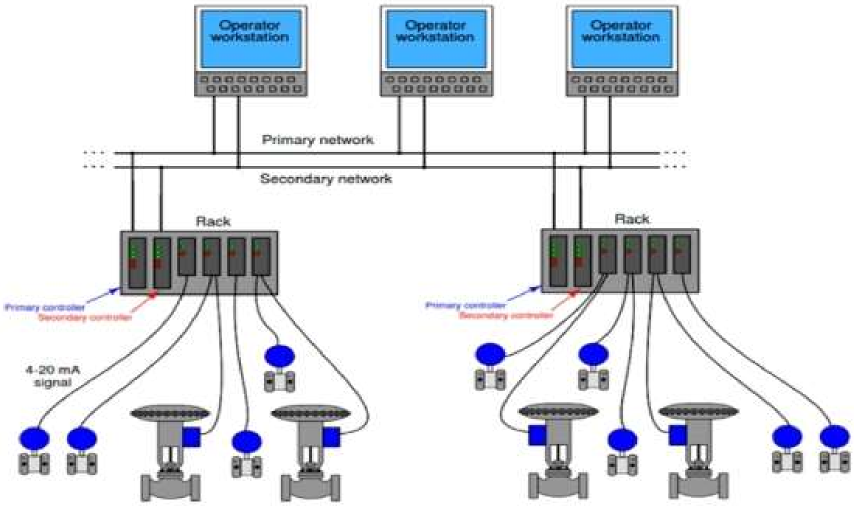
if temperature reaches above 70 Deg C then TS4 will activates and de-energizes the Relay, thus all Heaters will be turned OFF.

Note: Here Heaters H1, H2, H3 are either Relays or Contactors we energizing. so an NO contact of these relays are connected to Electrical Heater feeder circuits (MCC).These Electrical Feeder circuits will be controlled as per these signals and accordingly the heaters will be either ON or OFF.

5.14 SPECIAL CONTROL SYSTEMS- BASICS DCS & SCADA SYSTEMS

Distributed Control Systems (DCS)

The following illustration shows a typical distributed control system (DCS) architecture:



Each "rack" contains a microprocessor to implement all necessary control functions, with individual I/O (input/output) "cards" for converting analog field instrument signals into digital format, and vice-versa. Redundant processors, redundant network cables, and even redundant I/O cards address the possibility of component failure.

DCS processors are usually programmed to perform routine self-checks on redundant system components to ensure availability of the spare components in the event of a failure.

If there ever was a total failure in one of the "control racks" where the redundancy proved insufficient for the fault(s), the only PID loops faulted will be those resident in that rack, not any of the other loops throughout the system.

Likewise, if ever the network cables become severed or otherwise faulted, only the information flow between those two points will suffer; the rest of the system will continue to communicate data normally.

Thus, one of the "hallmark" features of a DCS is its tolerance to serious faults: even in the event of severe hardware or software faults, the impact to process control is minimized by design.

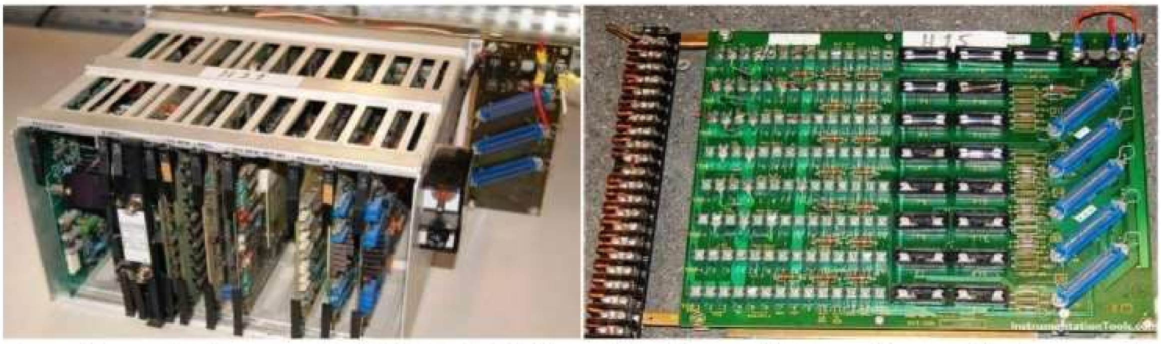
One of the very first distributed control systems in the world was the Honeywell TDC2000 system (Note 1) , introduced in 1975. By today's standards, the technology was crude, but the concept was revolutionary.

Note 1: To be fair, the Yokogawa Electric Corporation of Japan introduced their CENTUM distributed control system the same year as Honeywell.

Each rack (called a "box" by Honeywell) consisted of an aluminum frame holding several large printed circuit boards with card-edge connectors. A "basic controller" box appears in the left-hand photograph.

The right-hand photograph shows the termination board where the field wiring (420 mA) connections were made. A thick cable connected each termination board to its respective controller box:

DCS Hardware



Controller redundancy in the TDC2000 DCS took the form of a "spare" controller box serving as a backup for up to eight other controller boxes. Thick cables routed all analog signals to this spare controller, so that it would have access to them in the event it needed to take over for a failed controller.

The spare controller would become active on the event of any fault in any of the other controllers, including failures in the I/O cards.

Thus, this redundancy system provided for processor failures as well as I/O failures. All TDC2000 controllers communicated digitally by means of a dual coaxial cable network known as the "Data Hiway." The dual cables provided redundancy in network communications.

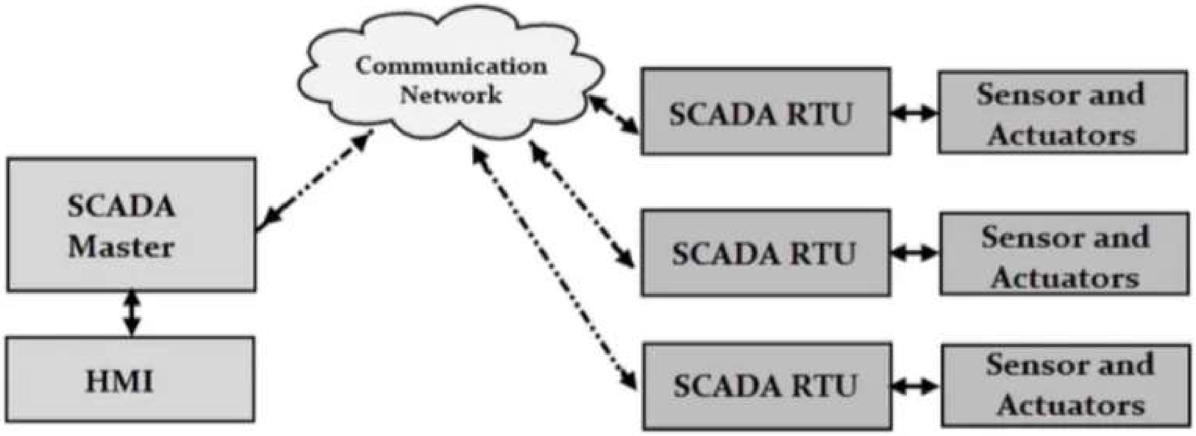
SCADA SYSTEMS

SCADA stands for "Supervisory Control and Data Acquisition". SCADA is a type of process control system architecture that uses computers, networked data communications and graphical Human Machine Interfaces (HMIs) to enable a high-level process supervisory management and control.

SCADA systems communicate with other devices such as programmable logic controllers (PLCs) and PID controllers to interact with industrial process plant and equipment.

SCADA systems form a large part of control systems engineering. SCADA systems gather pieces of information and data from a process that is analyzed in real-time (the "DA" in SCADA). It records and logs the data, as well as representing the collected data on various HMIs.

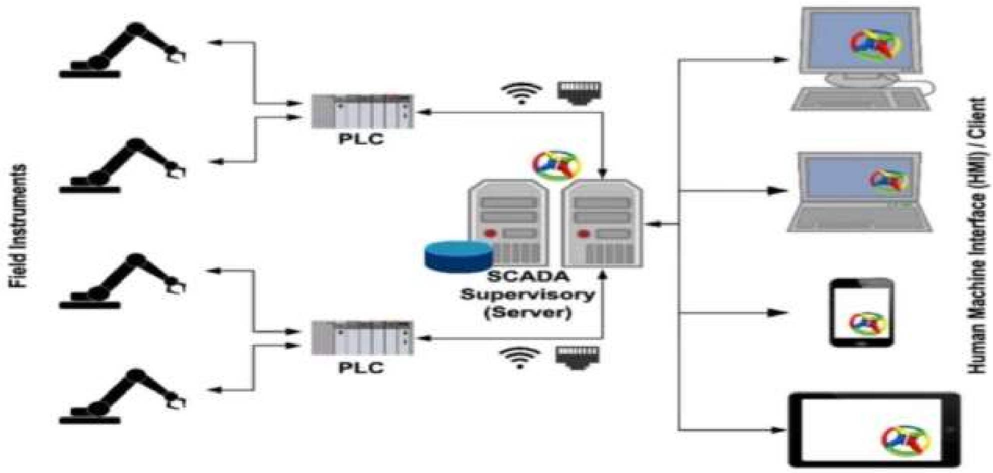
This enables process control operators to supervise (the "S" in SCADA) what is going on in the field, even from a distant location. It also enables operators to control (the "C" in SCADA) these processes by interacting with the HMI.



Supervisory Control and Data Acquisition systems are essential to a wide range of industries and are broadly used for the controlling and monitoring of a process. SCADA systems are prominently used as they have the power to control, monitor, and transmit data in a smart and seamless way. In today's data-driven world, we are always looking for ways to increase automation and make smarter decisions through the proper use of data – and SCADA systems are a great way of achieving this.

SCADA systems can be run virtually, which allows the operator to keep a track of the entire process from his place or control room. Time can be saved by using SCADA efficiently. One such excellent example is, SCADA systems are used extensively in the Oil and Gas sector. Large pipelines will be used to transfer oil and chemicals inside the manufacturing unit.

Hence, safety plays a crucial role, such that there should not be any leakage along the pipeline. In case, if some leakage occurs, a SCADA system is used to identify the leakage. It infers the information, transmits it to the system, displays the information on the computer screen and also gives an alert to the operator.



SCADA Architecture

Generic SCADA systems contain both hardware and software components. The computer used for analysis should be loaded with SCADA software. The hardware component receives the input data and feds it into the system for further analysis.

SCADA system contains a hard disk, which records and stores the data into a file, after which it is printed as when needed by the human operator. SCADA systems are used in various industries and manufacturing units like Energy, Food and Beverage, Oil and Gas, Power, Water, and Waste Management units and many more.

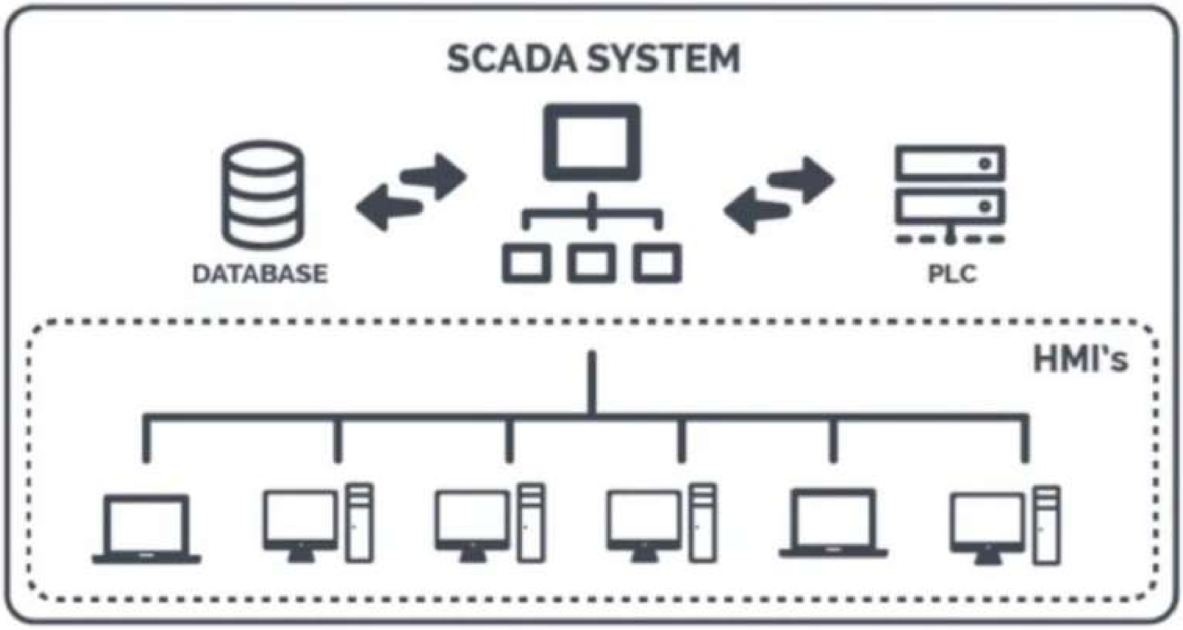
SCADA Basics

Objectives of SCADA

- Monitor: SCADA systems continuously monitor the physical parameters
- Measure: It measures the parameter for processing
- Data Acquisition: It acquires data from RTUs (Remote Terminal Units), data loggers, etc
- Data Communication: It helps to communicate and transmit a large amount of data between MTU and RTU units
- Controlling: Online real-time monitoring and controlling of the process
- Automation: It helps for automatic transmission and functionality

The SCADA systems consist of hardware units and software units. SCADA applications are run using a server. Desktop computers and screens act as an HMI which are connected to the server. The major components of a SCADA system include:

- Master Terminal Unit (MTU)
- Remote Terminal Unit (RTU)
- Communication Network (defined by its network topology)



Master Terminal Unit (MTU)
MTU is the core of the SCADA system. It comprises a computer, PLC and a network server that helps MTU to communicate with the RTUs. MTU begins communication, collects and saves data, helps to interface with operators and to communicate data to other systems.

Remote Terminal Unit (RTU)
Being employed in the field sites, each Remote Terminal Unit (RTU) is connected with sensors and actuators. RTU is used to collect information from these sensors and further sends the data to MTU. RTUs have the storage capacity facility.

So, it stores the data and transmits the data when MTU sends the corresponding command. Recently developed units are employed with sophisticated systems that utilize PLCs as RTUs. This helps for direct transfer and control of data without any signal from MTU.

Remote terminal unit

Communication Network
In general, network means connection. When you tell a communication network, it is defined as a link between RTU in the field to MTU in the central location. The bidirectional wired or wireless communication channel is used for networking purposes. Various other communication mediums like fiber optic cables, twisted pair cables, etc. are also used.
Functions of SCADA Systems
In a nutshell, we can tell the SCADA system is a collection of hardware and software components that allows the manufacturing units to perform specific functions. Some of the important functions include

- To monitor and gather data in real-time
- To interact with field devices and control stations via Human Machine Interface (HMI)
- To record systems events into a log file
- To control manufacturing process virtually
- Information Storage and Reports

5.15 COMPUTER CONTROL–DATA ACQUISITION, DIRECT DIGITAL CONTROL SYSTEM (BASICS ONLY)

DATA ACQUISITION SYSTEMS

Definition

Data acquisition is the process of real world physical conditions and conversion of the resulting samples into digital numeric values that can be manipulated by a computer. Data acquisition and data acquisition systems (abbreviated with the acronym DAS) typically involves the conversion of analog waveforms into digital values for processing.

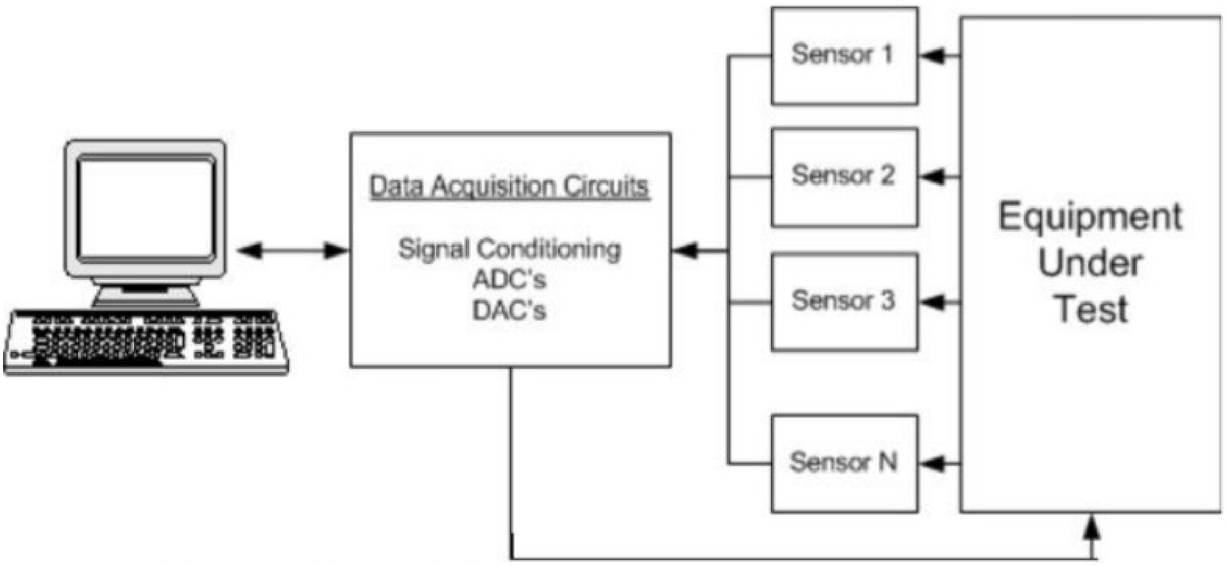
The components of data acquisition systems include:

i) Sensors that convert physical parameters to electrical signals.

ii) Signal conditioning circuitry to convert sensor signals into a form that can be converted to digital values.

iii) Analog-to-digital converters, which convert conditioned sensor signals to digital values.

Diagram



Fundamental elements of data acquisition system

Explanation

Data acquisition is the process of extracting, transforming, and transporting data from the source systems and external data sources to the data processing system to be displayed, analyzed, and stored.

A data acquisition system (DAQ) typically consist of transducers for asserting and measuring electrical signals, signal conditioning logic to perform amplification, isolation, and filtering, and other hardware for receiving analog signals and providing them to a processing system, such as a personal computer.

Data acquisition systems are used to perform a variety of functions, including laboratory research, process monitoring and control, data logging, analytical chemistry, tests and analysis of physical phenomena, and control of mechanical or electrical machinery.
Data recorders are used in a wide variety of applications for imprinting various types of forms, and documents.

Data collection systems or data loggers generally include memory chips or strip charts for electronic recording, probes or sensors which measure product environmental parameters and are connected to the data logger.
Hand-held portable data collection systems permit in field data collection for up-to-date information processing.

Source
Data acquisition begins with the physical phenomenon or physical property to be measured.
Examples of this include temperature, light intensity, gas pressure, fluid flow, and force. Regardless of the type of physical property to be measured, the physical state that is to be measured must first be transformed into a unified form that can be sampled by a data acquisition system.
The task of performing such transformations falls on devices called sensors.
A sensor, which is a type of transducer, is a device that converts a physical property into a corresponding electrical signal (e.g., a voltage or current) or, in many cases, into a corresponding electrical characteristic (e.g., resistance or capacitance) that can easily be converted to electrical signal.

The ability of a data acquisition system to measure differing properties depends on having sensors that are suited to detect the various properties to be measured. There are specific sensors for many different applications.
DAQ systems also employ various signal conditioning techniques to adequately modify various different electrical signals into voltage that can then be digitized using an Analog-to-digital converter (ADC).

Signals
Signals may be digital (also called logic signals sometimes) or analog depending on the transducer used. Signal conditioning may be necessary if the signal from the transducer is not suitable for the DAQ hardware being used.
The signal may need to be amplified, filtered or demodulated.
Various other examples of signal conditioning might be bridge completion, providing current or voltage excitation to the sensor, isolation, and linearization. For transmission purposes, single

ended analog signals, which are more susceptible to noise can be converted to differential signals. Once digitized, the signal can be encoded to reduce and correct transmission errors.

DAQ hardware

DAQ hardware is what usually interfaces between the signal and a PC. It could be in the form of modules that can be connected to the computer's ports (parallel, serial, USB, etc.) or cards connected to slots (S-100 bus, Apple Bus, ISA, MCA, PCI, PCI-E, etc.) in the mother board.

Usually the space on the back of a PCI card is too small for all the connections needed, so an external breakout box is required. The cable between this box and the PC can be expensive due to the many wires, and the required shielding

DAQ cards often contain multiple components (multiplexer, ADC, DAC, TTL-IO, high speed timers, RAM). These are accessible via a bus by a microcontroller, which can run small programs.

A controller is more flexible than a hard wired logic, yet cheaper than a CPU so that it is alright to block it with simple polling loops.

The fixed connection with the PC allows for comfortable compilation and debugging. Using an external housing a modular design with slots in a bus can grow with the needs of the user.

Not all DAQ hardware has to run permanently connected to a PC, for example intelligent stand-alone loggers and oscilloscopes, which can be operated from a PC, yet they can operate completely independent of the PC.

DAQ software

DAQ software is needed in order for the DAQ hardware to work with a PC. The device driver performs low-level register writes and reads on the hardware, while exposing a standard API for developing user applications.

A standard API such as COMEDI allows the same user applications to run on different operating systems, e.g. a user application that runs on Windows will also run on Linux and BSD.

Advantages

Reduced data redundancy

Reduced updating errors and increased consistency

Greater data integrity and independence from applications programs

Improved data access to users through use of host and query languages

Improved data security

Reduced data entry, storage, and retrieval costs

Facilitated development of new applications program

Disadvantages

Database systems are complex, difficult, and time-consuming to design Substantial hardware and software start-up costs

Damage to database affects virtually all applications programs

Extensive conversion costs in moving form a file-based system to a database system Initial training required for all programmers and users

Applications

Temperature measurement

Recommended application software packages and necessary toolkit

Prewritten Lab VIEW example code, available for download

Sensor recommendations

DIRECT DIGITAL CONTROL SYSTEM

Direct Digital Control (DDC) is the automated control of a condition or process by a digital device.

DDC takes a centralized network-oriented approach. All instrumentation is gathered by various analog and digital converters which use the network to transport these signals to the central controller.

The centralized computer then follows all of its production rules (which may incorporate sense points anywhere in the structure) and causes actions to be sent via the same network to valves, actuators, and other HVAC components that can be adjusted.

A microprocessor operating at sufficient clock speed is able to execute more than one PID control algorithm for a process loop, by “time-sharing” its calculating power: devoting slices of time to the evaluation of each PID equation in rapid succession.

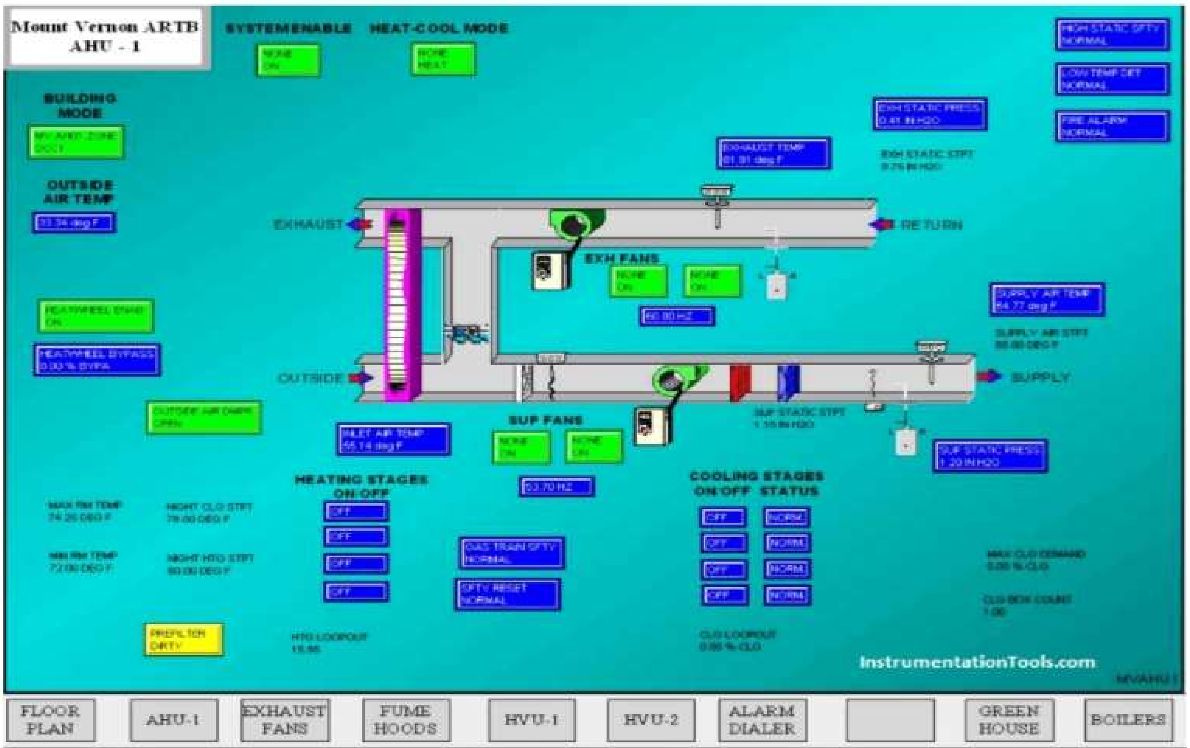
This not only makes multiple-loop digital control possible for a single microprocessor, but also makes it very attractive given the microprocessor’s natural ability to manage data archival, transfer, and networking.

A single computer is able to execute PID control for multiple loops, and also make that loop control data accessible between loops (for purposes of cascade, ratio, feed forward, and other control strategies) and accessible on networks for human operators and technicians to easily access.

Such direct digital control (DDC) has been applied with great success to the problem of building automation, where temperature and humidity controls for large structures benefit from large-scale data integration.

Operators, engineers, and technicians alike must use software running on a networked personal computer to access data in this control system.

An example of the HMI (Human-Machine Interface) software one might see used in conjunction with a DDC controller is shown here, also from a Siemens APOGEE building control system:



This particular screenshot shows monitored and controlled variables for a heat exchanger ("heat wheel") used to exchange heat between outgoing and incoming air for the building.

QUESTION BANK

Short Questions With Answer:

Q: Explain PLC?

A: Robot manufacturing companies use programmable logic controllers. It is a digitized computer device. PLC helps in the automation of a few electromechanical tasks. It can control a device connected to electricity to converting electrical energy into mechanical energy.

Q: What is redundancy in PLC?

A: Redundancy means the state of non-usefulness. For PLCs, when they are out of service or when they have faults, they cannot be used. They then become useless and are said to be redundant. It is called PLCs redundancy.

Q: What is HMI in PLC?

A: The full form of HMI is the Human Machine Interface. It basically allows operators to interface or communicate with the system they are supervising. The HMI provides a graphical overview of the status of the mechanical system and direct control of its operation. Graphical HMI screens can be programmed to allow the operator to view all important status and control information.

Q: What is scan in PLC?

A: SCAN means a performance by any sequential program controller operation. The process produces all updated outputs, which correspond to the supplied inputs.

The SCAN process runs in the ladder diagram. total scan time takes to read the input, process the program logic, and update the corresponding output in a single cycle.

Q: What are Latching Relays?

A: A Latching Relay is a relay that keeps its nation after being actuated. That is why those styles of relays also are referred to as Impulse Relays Keep Relays or Stay Relays. There is an inner magnet in a latching relay.

Q: What's the position of I/O modules in PLC?

A: I/O modules are used to offer I/O signs withinside the shape of easy on and stale commands in PLC, such that an enter module detects the reputation of entering alerts together with push-buttons, switches, temperature sensors, and so on while an output module controls gadgets together with relays, motor starters, lights, and so on.

Q: What do you know about the time counter?

A: It sparks off or deactivates the instrument software language length run out a form has shown defined value. Generally, time commands are taken into consideration inner results. It is like relay-kind commands, which are crucial commands for logic.

Q: Explain CRC?

A: A cyclic redundancy test (CRC) means an extensively used blunders detection characteristic in virtual networks and garage gadgets to hit upon unintended adjustments to uncooked statistics. Blocks of statistics getting access to those systems are linked with a short seek cost primarily based totally on the rest of a polynomial records section.

Long Questions:

Q: Explain the Anatomy of a Ladder Program.

Q: Draw a ladder program of starting of Induction Motor.

Q: Explain Bit type instructions- XIC, XIO, OTE, OTL, OUT, OSR.

Q: Why different types of I/O modules are required to be interfaced with PLC? Explain functioning of PLC input and output module with neat diagram.

Q: Develop the Ladder Logic Diagram for a motor with following: NO start button, NC stop button Thermal overload switch opens on high temperature, green light when running, and red light for thermal overload.