INDUSTRIAL AUTOMATION

COURSE CODE: 5042 (REV 2021)

POWER SEMICONDUCTOR DEVICES

MODULE I NOTES

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Industrial Automation

(This page is not important in exam point of view)

The course Industrial Automation deals with Industrial Electronics and Programmable Logic Controllers. Industrial Electronics is that branch of Electronics which discusses about electronics equipment for Industrial purposes. It includes simple devices such as drives, sensors, switches to more complex equipment like PLCs or Robotics. It is used for the control and diagnosis of systems or for signal processing. Some important fields where Industrial Engineers work, are listed here:

- Power Electronics and motor drives.
- Control and Mechatronics
- Industrial Communication systems
- Intelligent Systems

Power Electronics

Power electronics is a combination of power engineering, solid state electronic devices and control. Power switching devices are used for power control in the following applications

1) Speed controllers for AC and DC motors
2) Temperature and Illumination Controllers
3) Variable frequency DC – AC Converters
4) Variable voltage DC – DC converters
5) Variable frequency AC – AC Converters
6) Variable voltage AC – DC converters
7) HVDC Transmission lines

Thyristor Family

The whole family of high-power switching devices with similar characteristics is termed as the Thyristor Family. It was so named as the characteristics resembled that of its predecessor, gas – tube thyratron. Some devices which belong to the thyristor family are listed here:

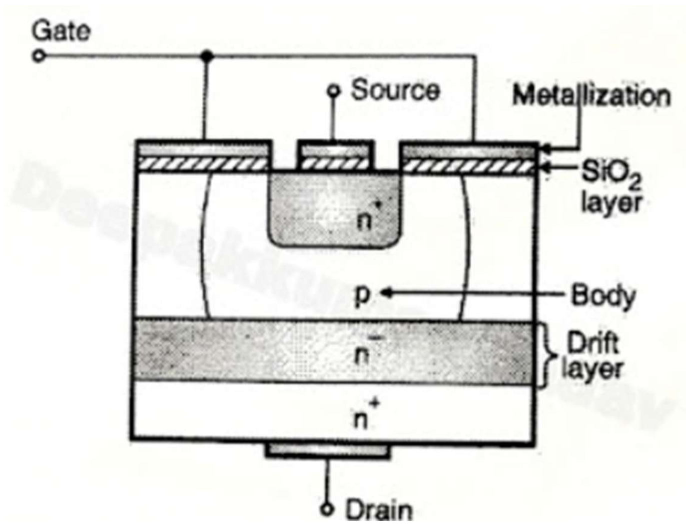
- SCR – Silicon Controlled Rectifier
- SCS - Silicon Controlled Switch
- DIAC
- Triac
- LASCR – Light Activated Silicon Controlled Rectifier

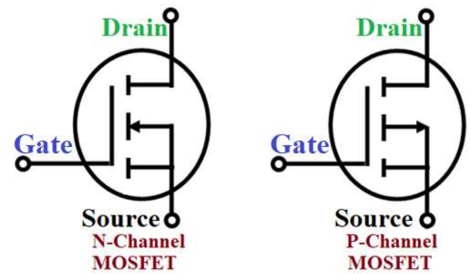
Power Diode, Power Transistor, Power MOSFET etc are also high-power handling devices. These can handle current ranging from few Amperes to 100s of Amperes and voltage ranging from 10s of Volts to 1000s of Volts.

Power MOSFET

Power MOSFET is the high power version of MOSFET (Metal Oxide Semiconductor Field Effect Transistor). It has large voltage and current handling capabilities. N channel power MOSFETs usually have higher rating than the P channel MOSFETs. It is a voltage controlled device and has very high input impedance.

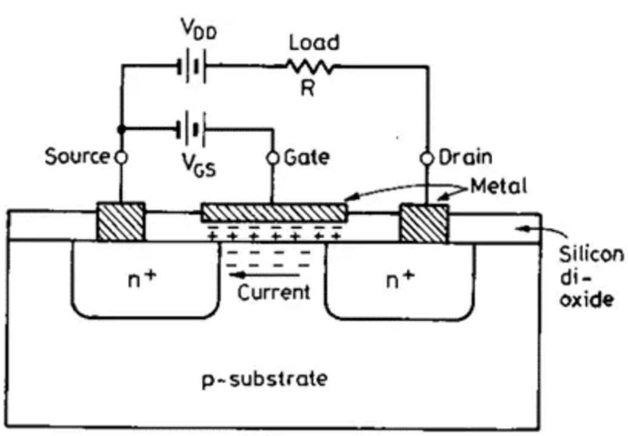
Structure of Power MOESFET





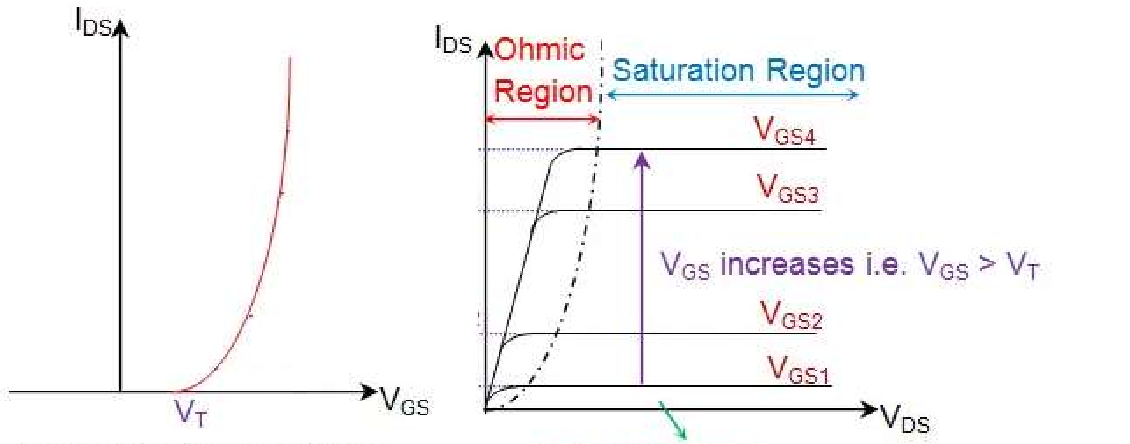
In n-channel Power MOSFET, source and drain are attached with n+layer. There is an n-layer above the n+ layer, which is known as the drift layer. The p layer is known as the body. Gate is connected to p layer through an SiO2 layer. The presence of n- drift layer improves the voltage handling capacity of the device.

Working of Power MOSFET



To understand the working, a simplified structure is used. Supplies V_{GS} and V_{DD} are provided as shown. Due to positive supply at gate, positive and negative charges accumulate at the SiO2 layer as shown in the figure. If V_{GS} is further increased, many electrons will accumulate in the p substrate or body below the SiO2 layer and it forms a channel of electrons. This is the induced N-channel. When the channel is created, current flows from drain to source through the channel. Current flow is due to the presence of N-channel and channel is induced due to V_{GS} . That’s why it is a voltage controlled device

Characteristics of power MOSFET



(a) Transfer Characteristics (b) Output Characteristics

Transfer characteristics is the plot between input voltage V_{GS} and output current I_D. As V_{GS} is increased, I_D increases.

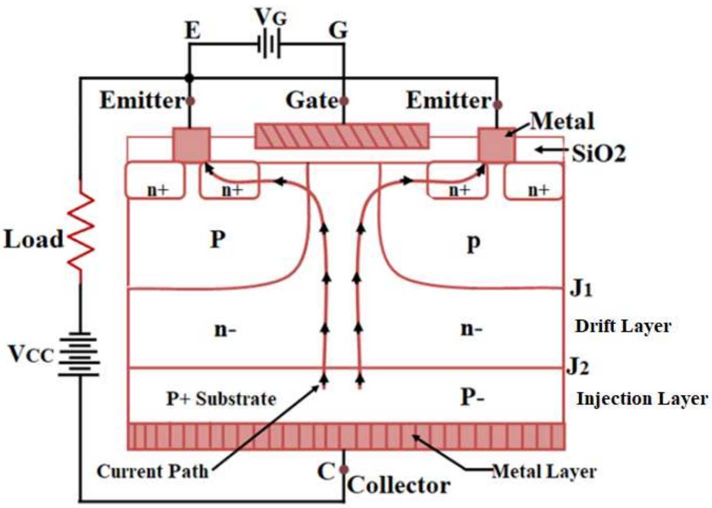
Output characteristics is the plot between output voltage V_{DS} and output current I_D. At constant V_{GS}, if V_{DS} is increased, I_D increases and becomes constant after some time. If V_{GS} is increased, a higher value of I_D is obtained. 3 regions, cut off region, ohmic region and saturation region can be observed in the characteristics as shown in the figure.

Applications of power MOSFET

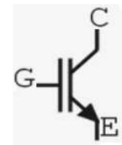
1) Used in UPS (Uninterrupted Power Supply)
2) Used in SMPS (Switched Mode Power Supply)
3) Used in power amplifiers
4) Used in display drivers
5) Used in high frequency based inverters.

IGBT (Insulated Gate Bipolar Transistor)

IGBT is a power electronics device which has got the characteristics of both BJT and MOSFET. The input characteristics are similar to that of MOSFET. It has an insulated gate and hence high input impedance. The output characteristics are similar to that of BJT. It is bipolar in nature, that means, both electrons and holes take part in the conduction. It has 3 terminals, Gate, Collector and Emitter.

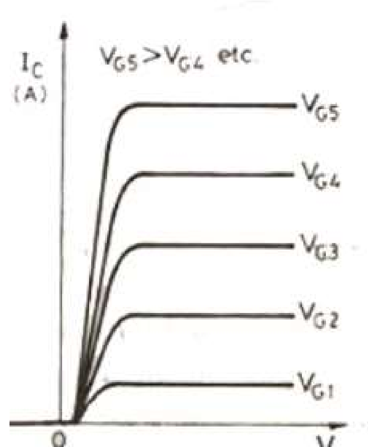


Structure and working of IGBT



IGBT has a 4 layer PNPN structure. The base is a heavily dopped P+ substrate. It injects holes into the drift layer and hence is known as the injection layer. Lightly dopped N- layer is known as the drift layer. The thickness of the Drift Region determines the voltage blocking capability of the IGBT. On top of the Drift Region is the Body Region, which consists of p substrate. It is close to the Emitter. Inside the Body Region, there are n+ layers. The emitter terminal is directly diffused onto the n+ layers. Gate terminal is connected to the body through an insulation layer of SiO2. Collector terminal is connected to the P+ substrate.

When there is no voltage at the gate, no current flows through IGBT. When VG is provided, negative charges start forming in the two p-wells. When V_G is greater than a threshold voltage, an N-channel is formed. This results in flow of electrons from Emitter to Collector and holes from Collector to Emitter. Thus, current flow is established. VI characteristics of IGBT is as shown in the figure.



V-I Characterstic

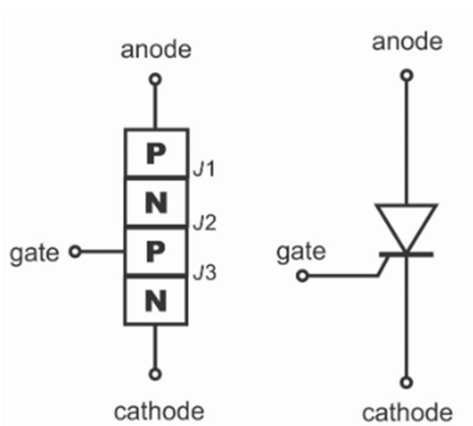
Applications of IGBT

1. It is used in SMPS (Switched Mode Power Supply(
2. It is used in UPS (Uninterrupted Power Supply)
3. It is used in choppers and inverters
4. It is used in solar inverters
5. It is used in AC and DC motor drives

SCR (Silicon Controlled Rectifier)

Introduction

SCR is a uni-directional power switch. It has 4 P-N-P-N layers and 3 terminals. The terminals are Anode, Cathode and Gate. Gate is known as the control electrode. In SCR, current can flow only in one direction. Hence it is a unidirectional, reverse blocking thyristor. The SCR can be turned ON by providing a positive pulse at the Gate. It offers high resistance until the break over point. After break over, SCR behaves just like a normal diode. In the Reverse direction, the working of SCR is similar to that of a diode.



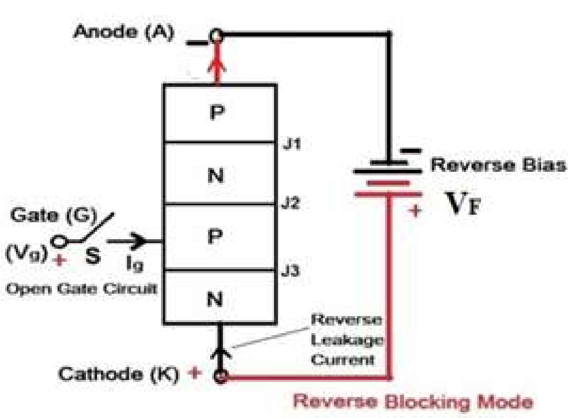
Constructional details of SCR

The SCR is a four layer and three terminal device. The four layers made of P and N layers, are arranged alternately such that they form three junctions J1, J2 and J3. These junctions are either alloyed or diffused based on the type of construction.The outer layers (P and N-layers) are heavily doped whereas middle P and N-layers are lightly doped. The gate terminal is taken at the middle P-layer, anode is from outer P- layer and cathode is taken from N- layer. The SCR is made of silicon, because compared to germanium leakage current in silicon is very small. A heat sink is usually provided for SCR, which provides a thermal path for conducting the internal heat losses to the surrounding medium.

Working or Modes of Operation of SCR

Depending on the biasing given to the SCR, the operation of SCR is divided into three modes.

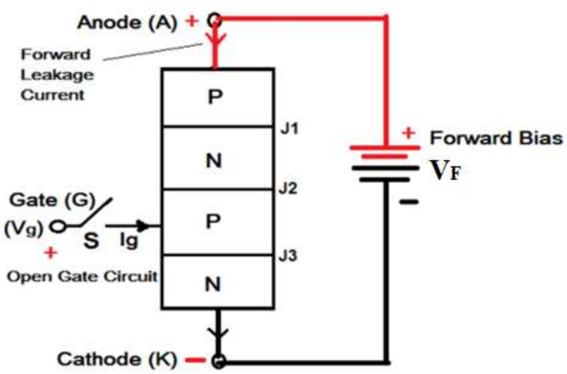
1. **Reverse Blocking Mode**



In this mode of operation, cathode is made positive with respect to anode. Then the junctions J1 and J3 are reverse biased and J2 is forward biased. This reverse voltage drives the SCR into reverse blocking region resulting in flow of small leakage current through it and acts as an open switch as shown in figure.

So, the device offers a high impedance in this mode until the voltage applied is more than the reverse breakdown voltage V_{BR} of the SCR. If the reverse applied voltage is increased beyond the V_{BR}, then avalanche breakdown occurs at junctions J1 and J3 which results to an increase in reverse current flow through the SCR. This reverse current causes more losses in the SCR and even to increase the heat of it. So there will be a considerable damage to the SCR when the reverse voltage applied is more than V_{BR}.

2. **Forward Blocking Mode**

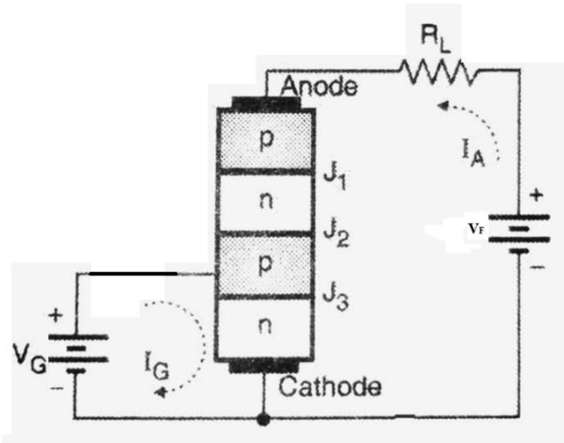


In this mode of operation, the SCR is connected such that the anode terminal is made positive with respect to cathode while the gate terminal is kept open. In this state, junctions J1 and J3 are forward biased and the junction J2 reverse biased. Due to this, a small leakage current due to minority carriers flows through the SCR. Until the voltage applied across the SCR is more than the forward break over voltage, SCR offers a very high resistance to the current flow. Therefore, the SCR acts as an open switch in this mode by blocking forward current flowing through the SCR

3. **Forward Conduction Mode (Figure is same as above)**

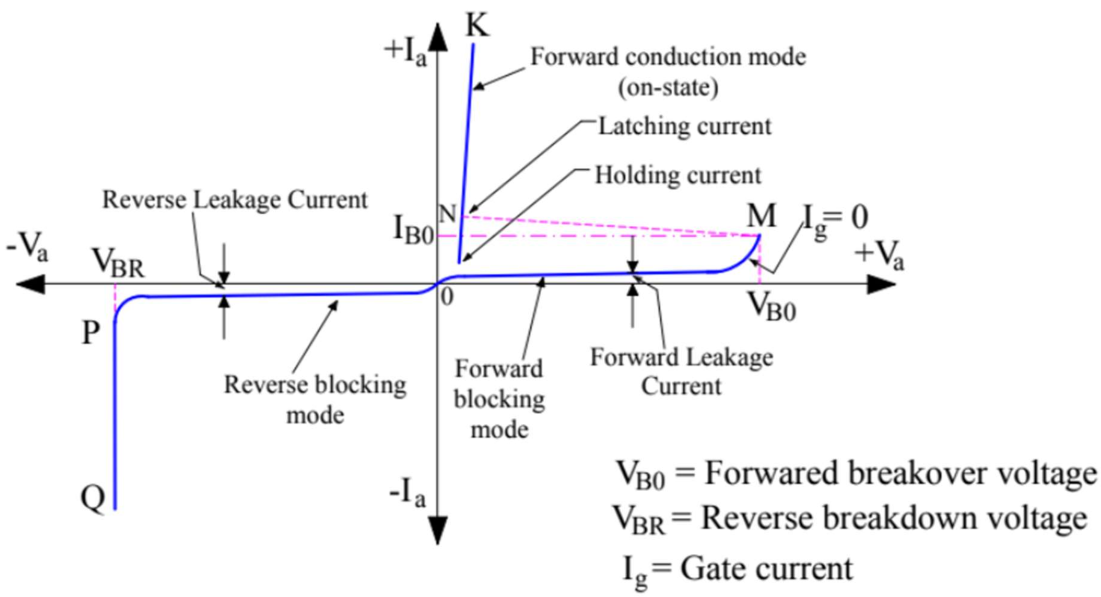
In this mode also, anode is given a positive supply and cathode is given negative supply. Junctions J1 and J3 are forward biased where as junction J3 is reverse biased. If the forward voltage V_F is increased above a particular voltage known as forward breakover voltage, several holes flow from P (anode) to N (cathode). The breakdown of junction J2 occurs and large no. of electron-hole pairs are generated. SCR conducts heavily and is said to be turned ON. Applied voltage at which the forward current increases rapidly is known as the Forward break over Voltage.

4. **Effect of gate voltage in forward conduction mode**



When a small positive voltage is applied to the gate, gate supplies holes to the junction J2. Also, electrons flow from the cathode towards gate. This causes a flow of current at the gate terminal. It lowers the Forward break over voltage and turns the SCR ON. Once the SCR is turned ON, gate loses all the control. Even if the gate voltage is removed, the anode current does not decrease. The turning ON of SCR happens earlier as we increase the gate current.

VI Characteristics of SCR



When the SCR is operating in the reverse blocking mode, there will be small leakage current flowing in the reverse direction of the SCR which is mentioned as the reverse leakage current in the graph. As the reverse voltage is further increased above a particular voltage known as reverse Break down voltage (V_{BR}), avalanche breakdown of Junctions J1 and J3 occurs. Large reverse current flows through the thyristor. Temperature rises and this can damage the SCR. The maximum reverse voltage is usually kept below V_{BR}. In reverse blocking mode, thyristor offers high resistance and acts as an open switch.

If a positive voltage is applied to anode and negative voltage to cathode, the SCR will start operating in the forward blocking mode and a small leakage current will be flowing through the SCR in the positive direction, hence the curve starts rising to a certain level in the positive quadrants of the graph which is mentioned as the forward leakage current. In this mode also, thyristor offers high resistance and acts as an open switch.

Once the graph reaches a certain voltage level called the Forward Breakover voltage or if the gate current Ig is applied to the SCR, the SCR moves to the conduction mode and a high amount of current starts flowing through the SCR. The current flow is represented as the forward conduction in the VI curve. The gate current applied are mentioned as Ig1, Ig2 and Ig3. Higher the applied gate current faster the SCR goes to the conduction state as Ig3 > Ig2 > Ig1. When the SCR is turned ON, the voltage across it drops to a very low value between 1 – 2 volts (1.5 V). The anode current Ia can be limited only by an external resistance.

Important:

Latching Current

Latching current is defined as the minimum value of anode current which must be attained during turn ON process, to maintain conduction, when the gate signal is removed. If the gate signal is removed before the anode current reaches latching current, SCR will not turn ON.

Holding Current

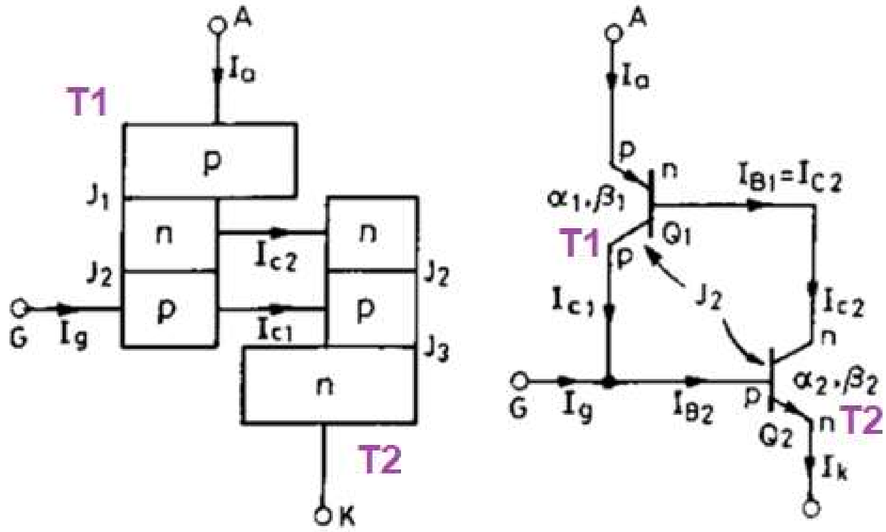
A thyristor can be turned OFF only if the anode current is less than a particular value of current known as the holding current. Holding current is defined as the minimum value of anode current below which an SCR must be brought, in order to turn it OFF.

Note: Latching current is associated with Turn ON where as holding current is associated with turn OFF. Latching current is usually taken as 2-3 times more than the holding current.

Applications of SCR

1. SCR is used as a power switch
2. Used in AC power control
3. Used in controlled rectifier circuits
4. Used in inverter circuits
5. Used in over voltage protection circuits.

Two transistor analogy of SCR



Two transistor analogy of SCR is a method of representing SCR in the form of two transistor model. This represents SCR as the combination of PNP and NPN transistor. The base of the transistor T1 works as the collector of the transistor T2 and collector of the transistor T1 work as the base of the transistor T2.

Case 1: When Gate is open and Forward voltage is less than Forward Break over Voltage

When the gate is open, there is no current flow to the base of T1. T1 is OFF and there is no current flow through its collector. The base of the T2 is connected with the collector of The T1. Therefore, T2 is also OFF and no current flows in the collector of T2. Both T1 and T2 are OFF and so for this condition, SCR is in OFF condition.

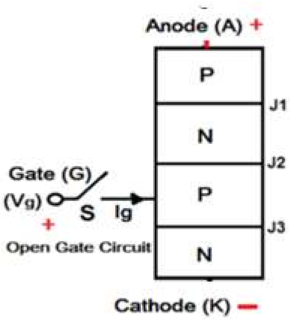
Case 2: When a small positive voltage is applied at the gate

A small gate current will flow through the base of T2 which means its collector current will increase. The collector of the transistor T2 is connected with base of transistor T1. So, the collector current of T2 is the base current of T1. Therefore, the collector current of T1 increases. But collector current of T1 is the base current of T2. This action is cumulative since an increase of current in one transistor causes an increase of current in the other transistor. As a result of this action, both transistors are driven to saturation, and heavy current flows through the externally connected load. SCR is turned ON in this condition.

SCR Turn ON Methods (SCR Triggering)

The SCR can be made to conduct or switched from forward blocking state (non-conducting or OFF state) to forward Conduction (ON) State by any one of the following methods.

1. Forward Voltage Triggering



In forward voltage triggering method, the SCR is forward biased i.e., anode is more positive than cathode but this voltage is increased significantly. The gate terminal is kept open. As the forward voltage increases, at a particular voltage, there will be an avalanche breakdown at the inner junction J2 and there will be release of large number of minority carriers. This voltage is known as Forward Breakover Voltage V_{BO}. At this voltage, the SCR turns into conduction state. A large current flows through the SCR (from Anode to Cathode, which is limited by the load resistance) with a very low voltage drop across it. During the turn ON state, the forward voltage drop across the SCR is in the range of 1 to 1.5 volts.

In practice this method is not employed because it needs a very large anode to cathode voltage. And also once the voltage is more than the V_{BO}, the SCR turns on and a very high current flows through it instantly, which may cause damage to the SCR.

2. dv/dt Triggering

In forward blocking state i.e., anode is more positive than cathode, the junction J2 is reverse biased. So, the junction J2 behaves as a capacitor due to the ionic charges in the depletion region. The charging current of a capacitor is given by,

$$I_C = C\frac{dV}{dt}$$

where C is the capacitance and dv/dt is the rate of change of voltage across the capacitor. From the above equation, if the rate of change of the applied voltage is large (i.e., it is applied suddenly), then the flow of charging current will increase, which causes the SCR to turn on without any gate voltage. We can turn SCR just by increasing the rate of change of voltage across the device rather than applying a large forward voltage. But, this method is also practically avoided because it can cause a false turn ON process and also this can produce very high voltage spikes across the SCR causing damage to it.

3. Temperature Triggering

This type of triggering is also known as Thermal Triggering as the SCR is turned on due to rise in temperature. There is a leakage current flowing through the reverse biased J2 junction of SCR. This causes a slight increase in temperature. The reverse leakage current depends on the temperature. As temperature increases, leakage current also increases, which further increases the temperature. This becomes a cumulative action and at some point, due to the generation of large number of charge carriers, the depletion layer at J2 disappears and current starts flowing through the SCR. Thus, the SCR is turned ON. This type of triggering is practically not employed because the SCR may be damaged.

4. Gate Triggering

This is the most common and most efficient method to turn ON the SCR. When the SCR is forward biased, a sufficient positive voltage at the gate terminal injects some holes into the junction J2. Also, more electrons flow from the cathode towards J2. This results in an increase in the reverse leakage current and hence the breakdown of junction J2 occurs even at a voltage lower than the V_{BO}. Depending on the size of the SCR, the gate current varies from a few milli-amps to 250 milli-amps or more. If the gate current applied is more, then SCR enters the conduction state at a much lower applied voltage.

Once the SCR is turned ON, gate loses all the control. Even if the gate voltage is removed, the anode current does not decrease. (Note: if the gate voltage is removed before the Anode current reaches Latching current, then SCR will not be turned ON)

5. Light Triggering

An SCR turned ON by light radiation is also called as Light Activated SCR (LASCR). In such SCRs, a recess or Niche is provided at the inner P-layer. In this method, light rays with appropriate wavelength and intensity are allowed to strike the junction J2. The bombarded energy particles from the light (neutrons or photons) causes to break electron bonds and as a result, new electron – hole pairs are formed in the device. As the number of charge carriers are increased, there is a sudden increase in the flow of current, causing the SCR to turn ON. Light Triggering is also known as Radiation Triggering. Generally, this type of triggering is used in HVDC transmission systems.

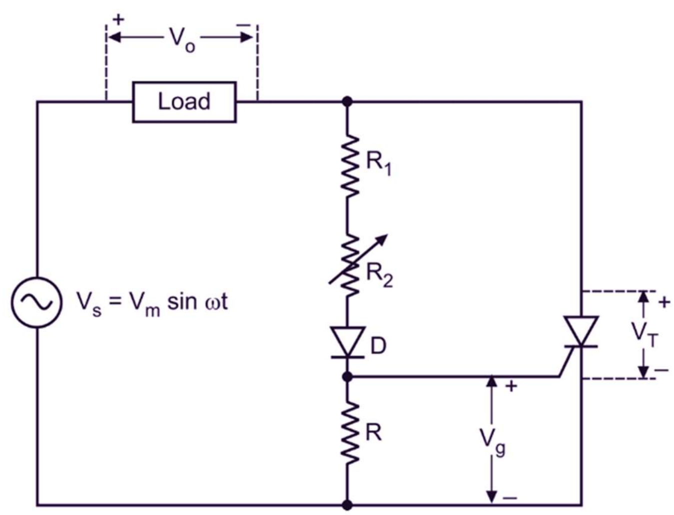
Firing circuits for SCRs / Gate triggering methods

There are many ways to turn ON a thyristor, like forward-voltage firing, dv/dt triggering, temperature triggering, light triggering, and gate triggering. But other than these methods, the most commonly employed method to turn-ON a thyristor is by controlling the gate pulse.

In forward voltage triggering, dv/dt triggering and temperature triggering, we cannot decide the instant of triggering. Through gate triggering, we can accurately turn ON the thyristor at the desired instant.

The circuit used for turning ON the thyristor by giving gate pulses is called the Firing or Triggering Circuit of SCR. Resistance triggering, RC triggering and UJT triggering are some basic firing circuits used to trigger the SCR.

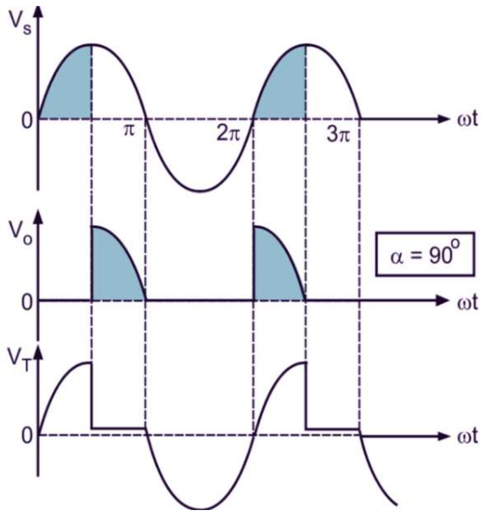
1. Resistance Triggering

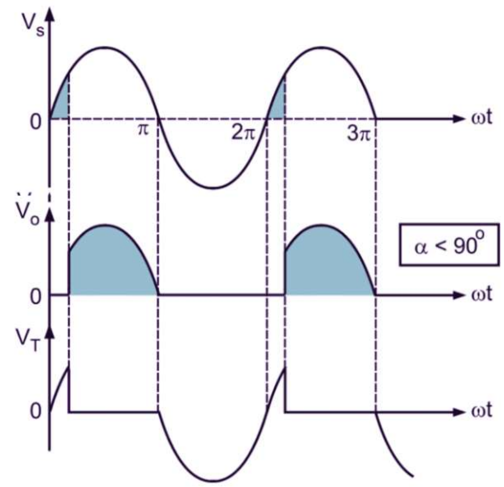


Resistance firing circuit is the simplest method of controlling the firing angle of SCR. In this firing circuit, the firing angle can vary over a limited range of 0° to 90°. The resistance R is known as the stabilising resistance. It ensures that the voltage across gate does not exceed the maximum permissible voltage at Gate. Diode D ensures that only positive pulses are delivered to the gate. Resistance R1 limits the gate current to a safe value. The amplitude of gate pulse is controlled by varying the resistance R2.

During negative half cycle of the input, SCR is reverse biased and hence it is OFF. There will not be any current flow through the load or SCR. Thus, the load voltage V_o becomes zero and Voltage across SCR will be equal to the source voltage Vs.

During positive half cycle, if R2 is at maximum, gate current Ig will be minimum and will not be sufficient to turn the SCR ON. Hence SCR will be OFF. (when firing angle is more than 90)

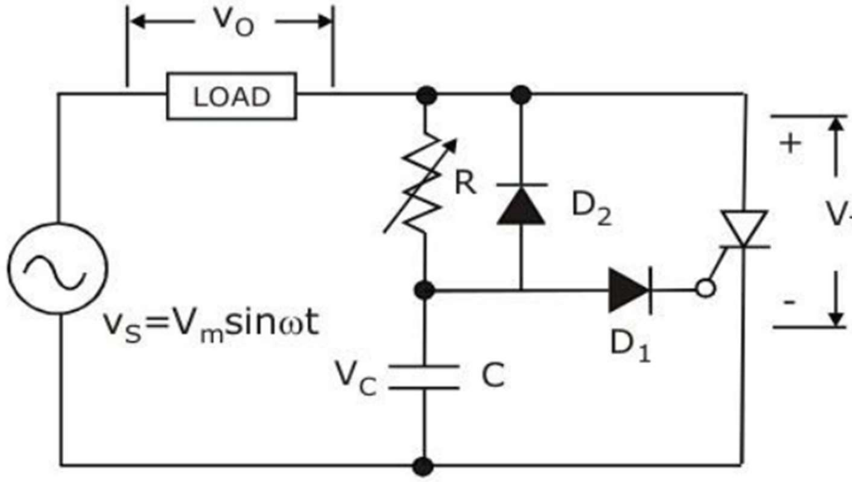




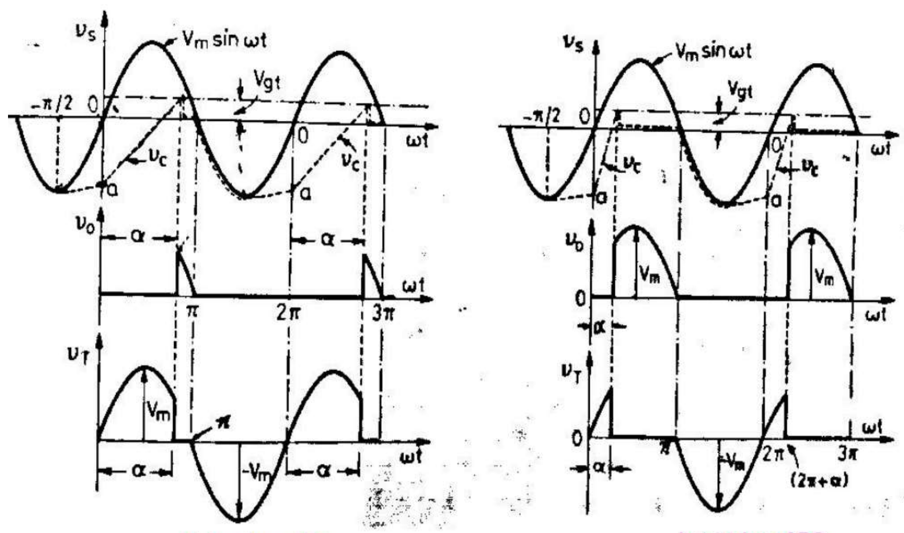
During positive half cycle, if R2 is reduced, Ig will increase. At some point, gate voltage will be equal to the gate threshold voltage required to turn the SCR ON. Then the SCR turns ON with a firing angle of 90º and current flows through the load.

During positive half cycle, if R2 is further reduced, Ig increases again and SCR turns ON earlier. That is, the SCR turns ON at a firing angle less than 90º and current flows through the load. When SCR is ON, the output voltage will be same as the source voltage and the voltage across SCR will be almost zero. In short, the firing angle of SCR can be varied between 0º and 90º by adjusting the value of resistor R2.

2. RC Triggering



RC triggering circuit consists of two diodes with an RC network connected to turn ON the SCR. By varying the variable resistance, firing angle is controlled from 0º to 180º. During the negative half cycle of the input signal, capacitor charges with lower plate positive through diode D2 up to the maximum supply voltage -Vm. SCR will not turn ON. In this, diode D1 prevents the negative voltage between the gate and cathode during the negative half cycle of the input.

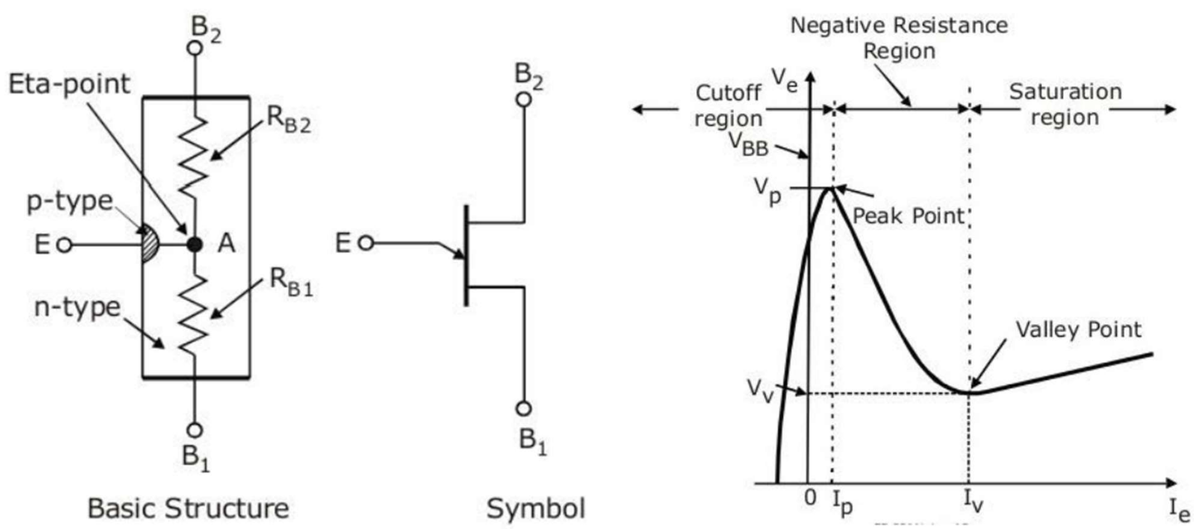


During the positive half cycle of the input, the SCR becomes forward biased and the capacitor starts charging through variable resistance to the gate threshold voltage value of the SCR. When the capacitor charging voltage is equal to the gate threshold voltage, SCR is turned ON and the capacitor holds a small voltage. Therefore, the capacitor voltage is helpful for triggering the SCR even after 90 degrees of the input waveform. The charging of capacitor during positive half cycle is dependent on the time constant RC. If RC is lower, charging time will be low and SCR turns ON at a smaller firing angle. If RC is higher, charging will be more and SCR turns ON at a larger firing angle.

3. UJT Triggering

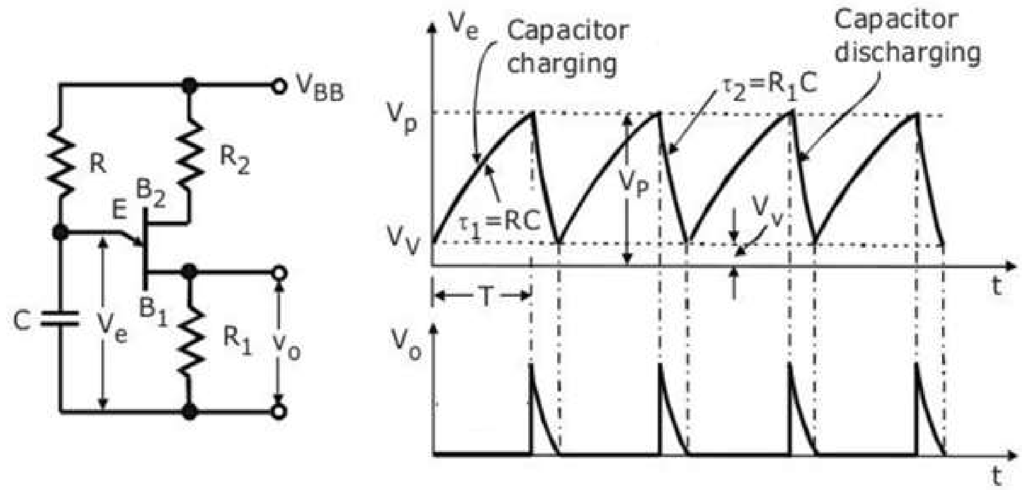
The R and RC triggering circuits give prolonged pulses. It causes more power dissipation in the gate circuit. They cannot be used for automatic control systems. In order to overcome this, UJT triggering circuits are used. These circuits use pulse triggering, in which the width of the pulses can be adjusted. Power level will be low and hence UJT triggering is more efficient.

UJT basics (Not important in exam point of view)



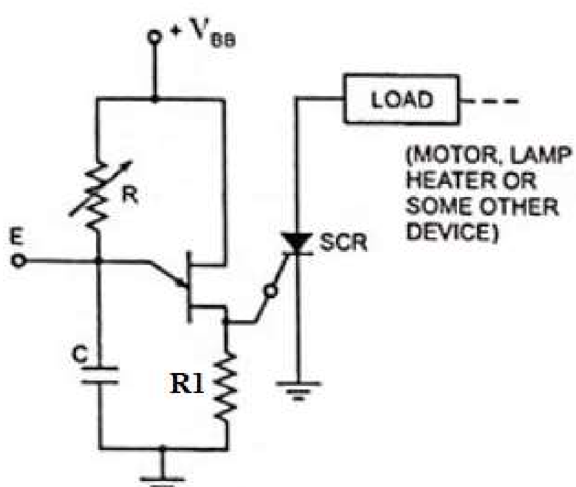
A UJT has an n type base made of Silicon in which a P type Emitter is embedded. 2 Ohmic contacts are given on the n type base and they are B1 and B2. Between B1 and B2, UJT acts like an ordinary resistance. UJT turns ON when the emitter voltage V_e is more than a particular voltage. The point at which UJT turns ON is known as the peak point. Once it is ON, the emitter current Ie increases and emitter voltage Ve reduces. This continues until a point known as the valley point. Between the peak point and valley point, UJT exhibits negative resistance characteristics.

UJT Relaxation Oscillator for SCR triggering



UJT relaxation oscillator can be used to trigger the SCR gate circuit. In this circuit, the UJT is biased to operate between its peak point and valley point. The RC network is connected to the emitter terminal of the UJT which forms the timing circuit. The capacitor is fixed while the resistance R is variable and hence the charging rate of the capacitor depends on the variable resistance. When the voltage V_{BB} is applied, the capacitor starts charging through resistance R with a time constant $\tau_1 = RC$. When the capacitor voltage V_e becomes equal to the peak point voltage V_p, UJT is turned ON. Now the capacitor starts discharging through resistance R1 with a time constant $\tau_2 = R_1C$. Usually discharging time constant $\tau_2 < \tau_1$. During discharging, when the capacitor voltage V_e is less than the valley point voltage V_v, UJT is turned OFF.

When the capacitor is discharging, UJT is ON and output voltage will be same as the capacitor discharge voltage. When the capacitor is charging, UJT is OFF, and hence output voltage will be zero. The output of the UJT is zero for some time (rests) and produces a positive voltage only for a short duration of time. Hence the circuit has the name ‘UJT Relaxation Oscillator’.



For firing the SCR using the UJT, the output of the oscillator circuit taken across resistance R1 is connected to the gate of SCR. When the pulse is received, gate is triggered and the SCR turns ON.

Commutation of thyristor

Thyristors are high power handling devices. It is difficult to turn them OFF. Once the thyristor is turned ON, the gate has no control over the current conduction. In order to turn OFF the SCR, the forward current has to be brought below the holding current by means of some external circuit. Commutation of SCR is defined as the process of turning off an SCR / thyristor. It is the process by which an SCR or thyristor is brought to OFF state from ON state. In commutation, the thyristor is brought from the forward conduction state to the forward blocking state. There are mainly two types of SCR commutation techniques, based on how the anode current is reduced to zero: Natural Commutation and Forced Commutation.

Natural Commutation of SCR: Natural Commutation of SCR is the process of turning off an SCR without using additional commutation circuitry. This commutation technique occurs only in AC circuits. E.g. Class F Commutation

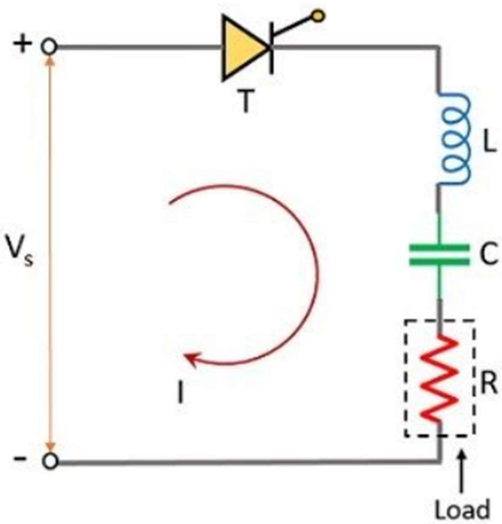
Forced Commutation: In case of DC circuits, there is no natural current zero to turn OFF the SCR. In such circuits, forward current must be forced to zero with an external circuit (known as Commutating Circuit) to commutate the SCR. Hence the name, Forced Commutation.

The commutating circuit consist of components like inductors and capacitors and they are called commutating Components. These components cause to apply a reverse voltage across the SCR that immediately bring the current in the SCR to zero. Depending on the process for achieving zero current in the SCR and the arrangement of the commutating components, Forced Commutation is classified into different types. They are:

- Class A – Self Commutation by Resonating the Load
- Class B – Self Commutation by Resonating the Load
- Class C – Complementary Commutation
- Class D – Auxiliary Commutation
- Class E – Pulse Commutation

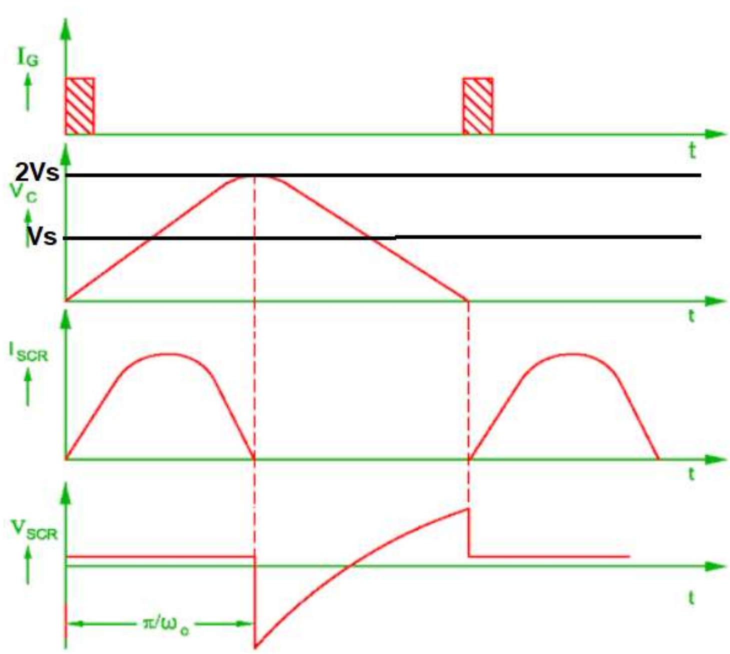
Forced commutation is mainly used in chopper and inverter circuits.

1. Class A Commutation



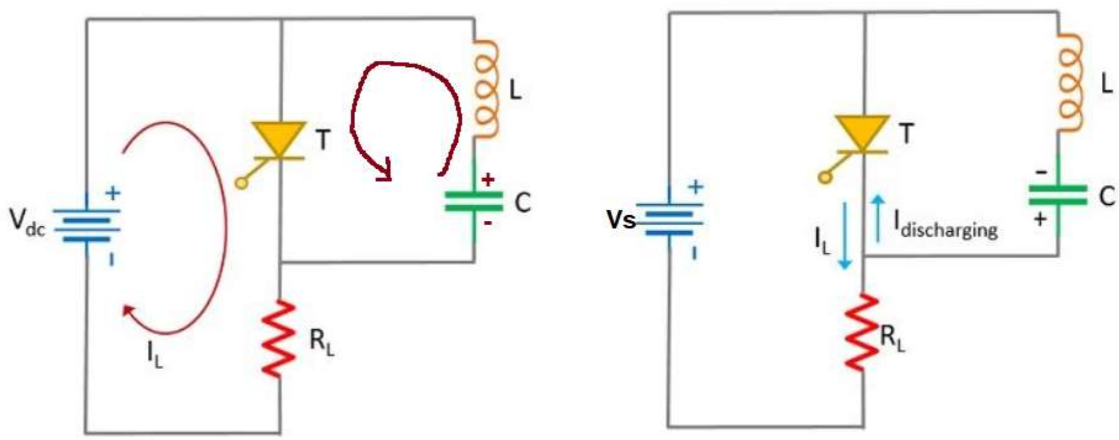
Class A commutation is also known as series resonant commutation or self-commutation or load commutation. In this type, L and C are known as the commutating elements and are connected serially with the load. In this type, once the SCR is turned ON, it gets turned OFF automatically after sometime due to the effect of commutating elements - hence the name self-commutation.

The principle of 'underdamping' in RLC circuits is used in this commutation. Initially, let the thyristor is turned ON. The capacitor starts charging towards the supply voltage. The inductor also gets charged. Once the capacitor gets charged to Vs, the inductor starts releasing its stored energy, which further charges the capacitor up to 2Vs. Now the voltage across SCR is Vs-2Vs=-Vs. That means, there is a negative voltage across SCR, which reverse biases and turns it OFF. In other words, the voltage at the cathode of SCR is higher than that at the anode, due to charging of capacitor up to 2Vs. This turns OFF the SCR. The current through SCR is oscillatory in nature due to the underdamping property. Waveforms are shown here:

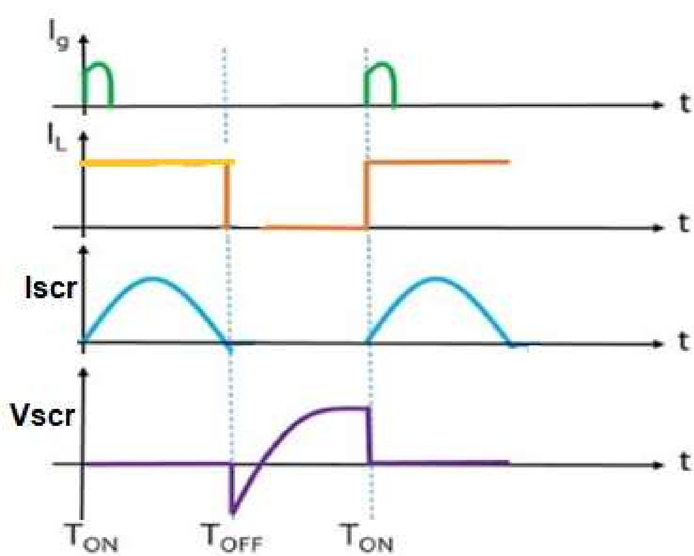


2. Class B commutation

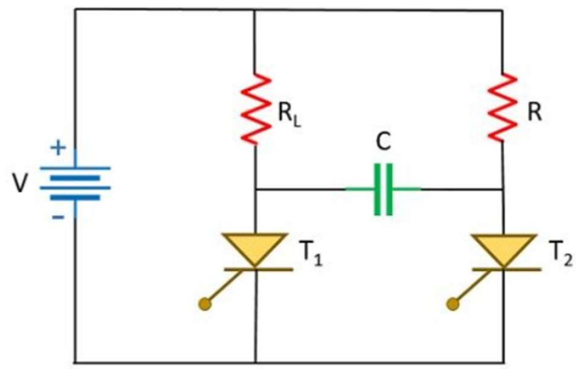
This is also a self-commutation circuit in which commutation of SCR is achieved automatically by L and C components, once the SCR is turned ON. In this, the LC resonant circuit is connected across the SCR but not in series with load as in the case of class A commutation. Hence the L and C components do not carry the load current. When the DC supply is applied to the circuit, the capacitor charges with the upper plate positive and lower plate negative up to the supply voltage Vs.



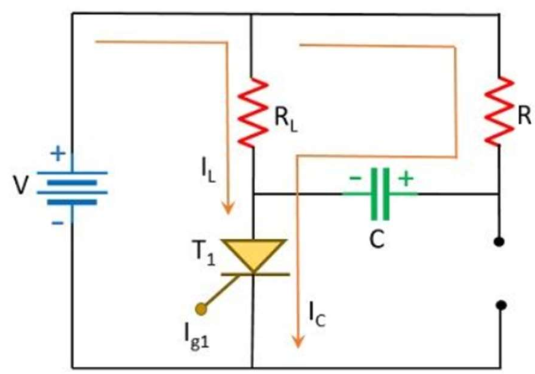
When the SCR is triggered, the current flows in two loops (first figure). One loop is through Vs – T – R_L – Vs. The other loop is through L and C components and the thyristor due to capacitor discharging. When the SCR is ON, discharging of capacitor through the thyristor occurs and capacitor starts charging in the reverse direction. When the capacitor is fully charged in reverse direction with polarity as shown in the second figure, it results in a current flow in the direction opposite to that of load current, through the SCR. Now there are two currents I_L and $I_{discharging}$ in opposite directions through the SCR. When the net current falls below the holding current, SCR gets turned OFF. The waveforms are as shown here:



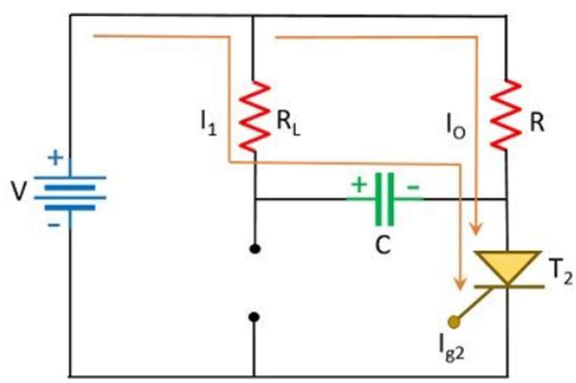
3. Class C Commutation



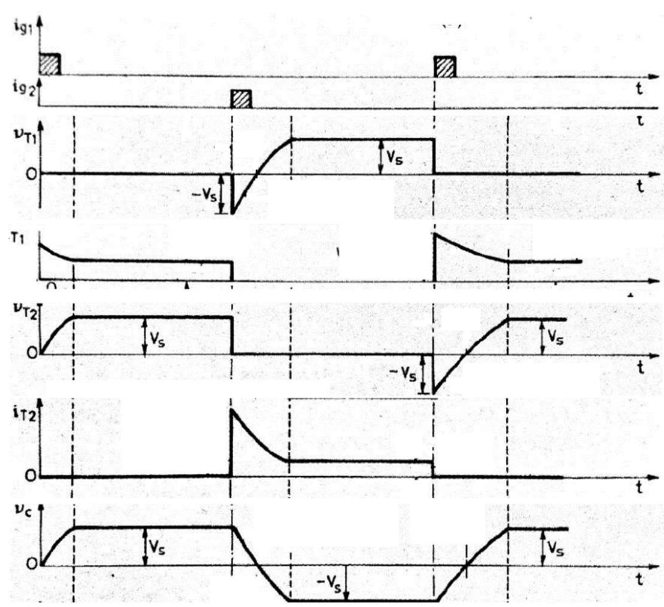
Class C commutation is also known as impulse commutation or complementary commutation. Two thyristors are used in this commutation. When thyristor T1 is turned ON, T2 will be turned OFF and when thyristor T2 is turned ON, T1 will be turned OFF. Hence the name, complementary commutation. Initially assume that both the thyristors are OFF. Then T1 is turned ON. Now current flows through 2 loops as shown:→



Capacitor charges to V with polarity as shown. Now if T2 is turned ON, the capacitor voltage appears as reverse voltage across T1. This turns T1 OFF. Now with T2 ON and T1 OFF, current again flows in two loops with capacitor charging in the reverse direction as shown:↓

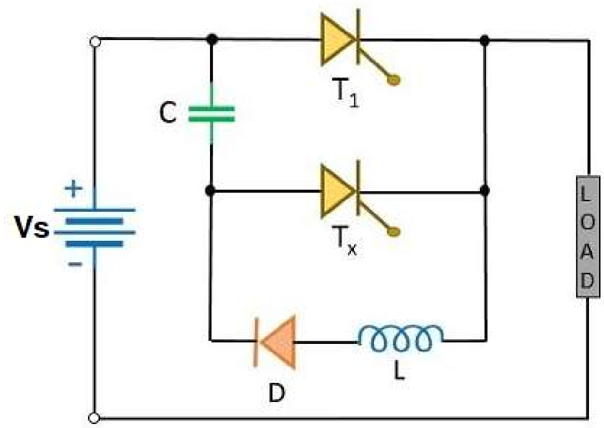


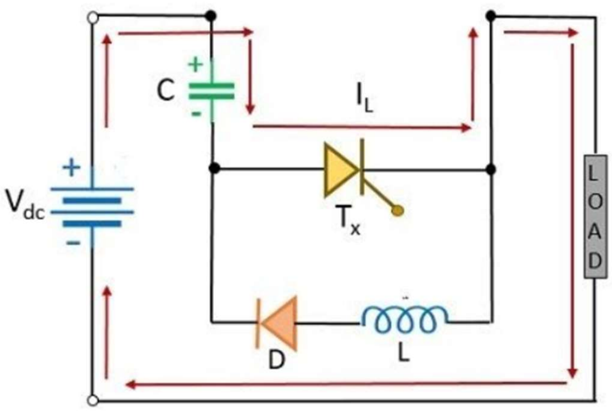
Now if T1 is turned ON, capacitor voltage appears as reverse voltage across T2, and it turns OFF T2. Thus, one thyristor can be turned OFF by turning ON the other thyristor. The waveforms are as shown here:



4. Class D Commutation

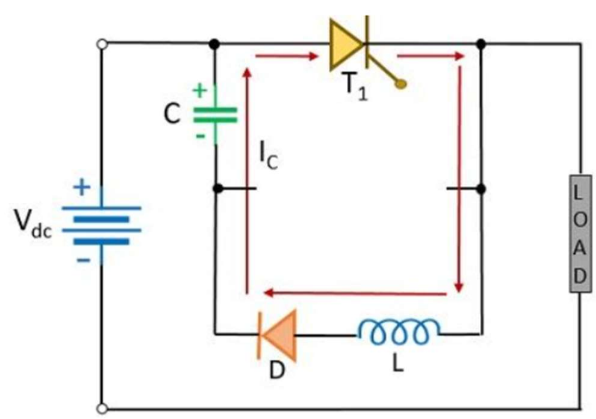
It is also referred to as voltage commutation or auxiliary commutation. In this type, the main thyristor T1 is turned OFF by turning the auxiliary thyristor ON. The circuit for class D type of commutation is shown here:



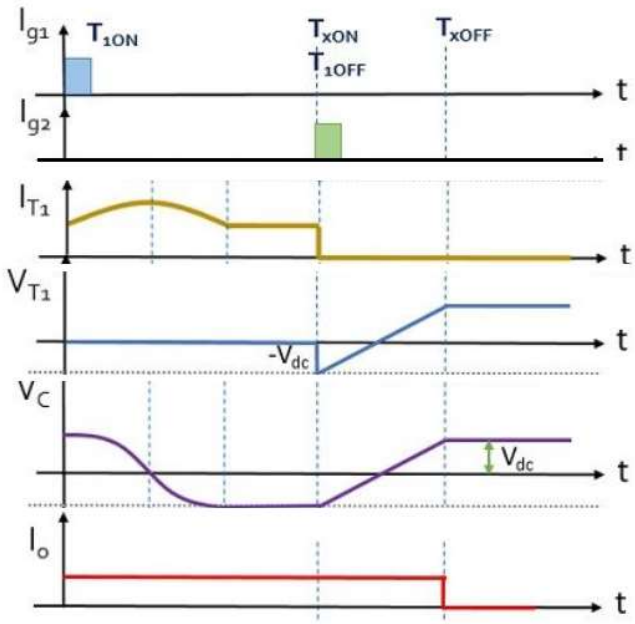


It is assumed that load current is a constant. Initially, the thyristor Tx is turned ON. Capacitor is charged to Vs through the thyristor Tx, with positive polarity on the upper plate. Once the capacitor is fully charged, the thyristor Tx is automatically turned OFF, because the voltage across it will be Vs-Vs=0.

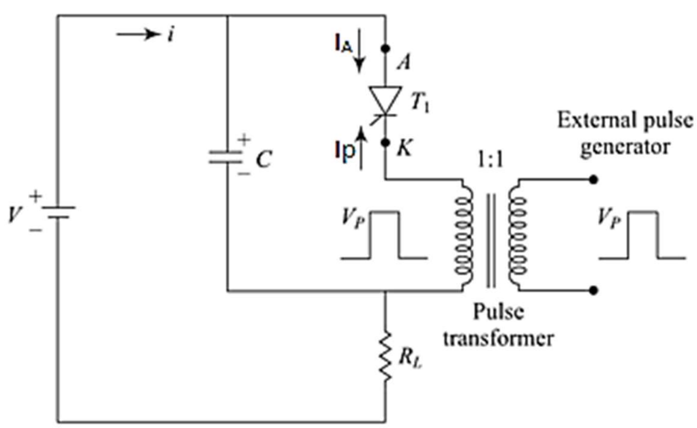
Now T1 is turned ON. Current will flow through 2 loops. First loop is from Vs-T1-Load-Vs and the second loop is through C-T1-L-D. Due to the second loop, capacitor charges in reverse direction.



Now if the main thyristor T1 is to be turned OFF, the auxiliary thyristor Tx has to be turned ON. When Tx is ON, the capacitor voltage appears immediately across the T1 as a reverse voltage. This reverse biases T1 and hence it is turned OFF. Now the capacitor once again charges through Tx with positive polarity on the upper plate. After some time, Tx turns OFF automatically since the voltage across it is zero as described earlier. The waveforms are as shown here:



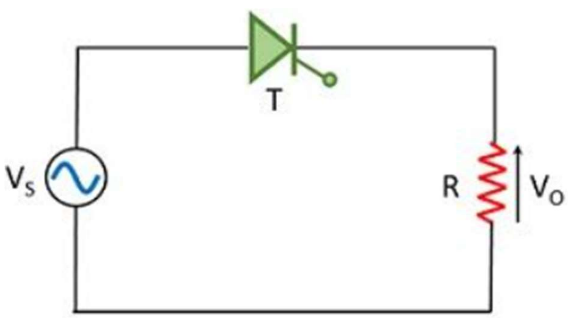
5. Class E commutation

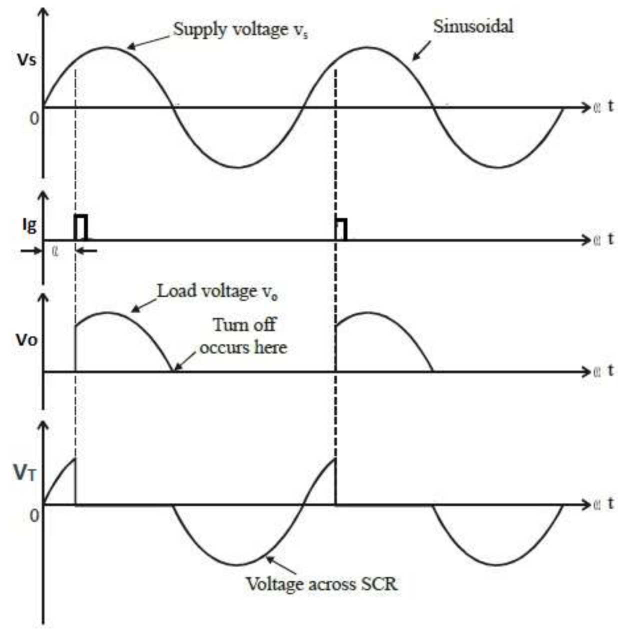


This is also known as external pulse commutation. In this, an external pulse source is used to produce the reverse voltage across the SCR.

The DC source V forward biases the SCR. When a trigger is given at the gate, SCR turns ON and current I_A flows from Anode to Cathode and it flows through the load. If the SCR is to be commutated, a pulse is applied to the primary of the pulse transformer. An emf is induced in the secondary of the pulse transformer. This causes a pulse current Ip to flow in the direction opposite to I_A. Now current flowing through the SCR is I_A-Ip. When this current is less than the holding current, SCR gets turned OFF. The capacitor is provided in the circuit to provide dv/dt protection, to prevent the accidental turn ON of SCR. Pulse transformer is also useful in providing the di/dt protection for SCR.

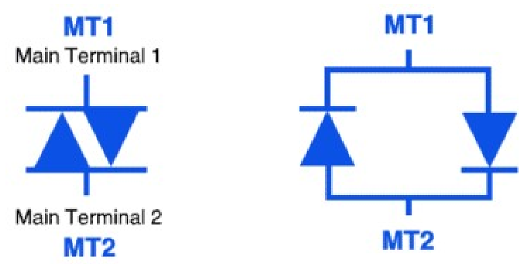
6. Class F Commutation



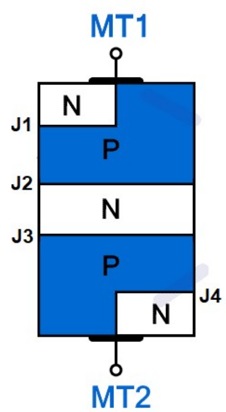


It is also referred to as Natural Commutation or Line commutation. There are no external commutating elements used in this type of commutation and can be used only in AC circuits. Here the input is an AC signal, which has positive and negative half cycles. During positive half cycle, SCR is forward biased. When a trigger is given at the gate, SCR turns ON. During negative half cycle, SCR is reverse biased. Hence when the current falls below the holding current, SCR is turned OFF. Thus, the SCR is naturally turned OFF during the negative half cycle. This type of commutation is used in rectifiers, inverters etc.

DIAC



Diac stands for as Diode for Alternating Current. It is a 2 terminal, bidirectional device (conducts current in both the directions). The two terminals are termed as MT1 and MT2. It can be turned ON during both positive and negative half cycles of an AC signal.

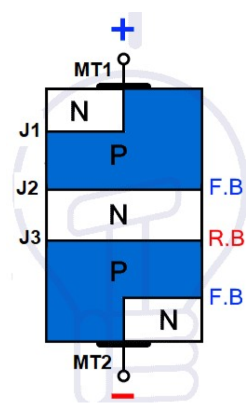


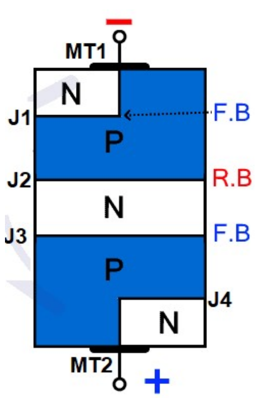
Structure of Diac

Diac has 2 PNPN structures connected in anti-parallel. There is no gate terminal. It can be considered as the anti-parallel connection of two SCRs without gate. MT1 is connected to an N layer and P layer on one side. Similarly, MT2 is connected to N and P layers on the other side. There are 4 PN junctions namely, J1, J2, J3 and J4.

Working of Diac

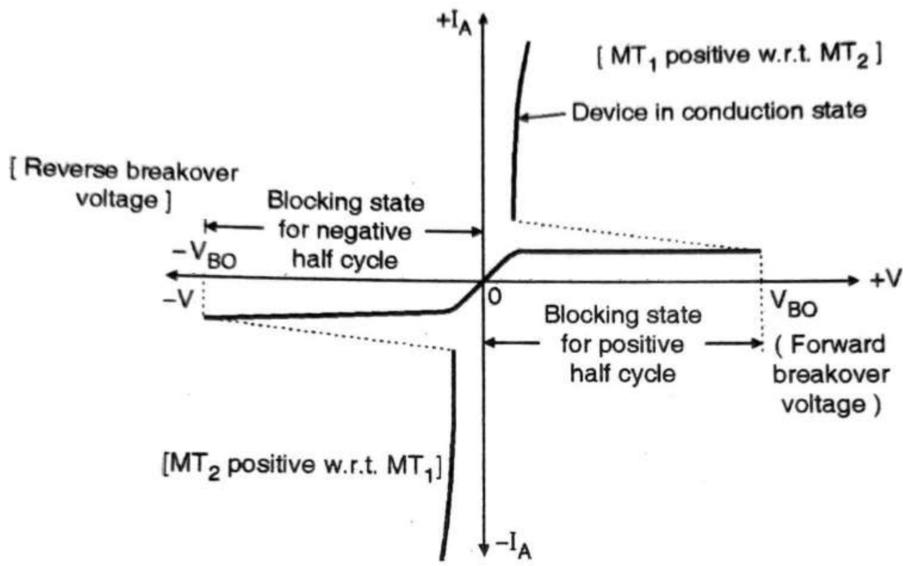
When MT1 is positive with respect to MT2, junctions J2 and J4 are forward biased, where as junctions J3 and J1 are reverse biased. There will be small leakage current through the device. When the external voltage is further increased above the forward breakover voltage, avalanche breakdown of junction J3 occurs. As a result, large number of charge carriers will be generated and current flows through the Diac. The Diac is said to be turned ON.





When MT2 is positive with respect to MT1, junctions J1 and J3 are forward biased, where as junctions J2 and J4 are reverse biased. There will be small leakage current through the device. When the external voltage is further increased above the forward breakover voltage, avalanche breakdown of junction J2 occurs. As a result, large number of charge carriers will be generated and current flows through the Diac. The Diac is said to be turned ON.

Characteristics of Diac

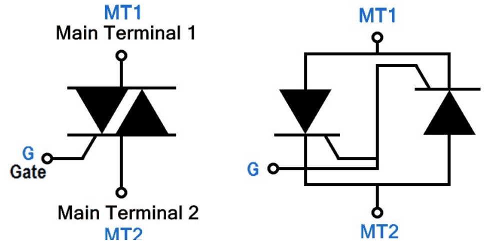


In 1st quadrant, the voltage and current are positive. When the voltage is below the break over voltage V_{BO}, the DIAC blocks the current except for the leakage current. The device remains in OFF-state. Once the voltage increases, the DIAC triggers into ON-state and the current rises. Once Diac is ON, the voltage across it drops to the ON-state voltage. The device operates similarly in the 3rd quadrant. In 3rd quadrant, the voltage and current are reverse.

Applications of Diac

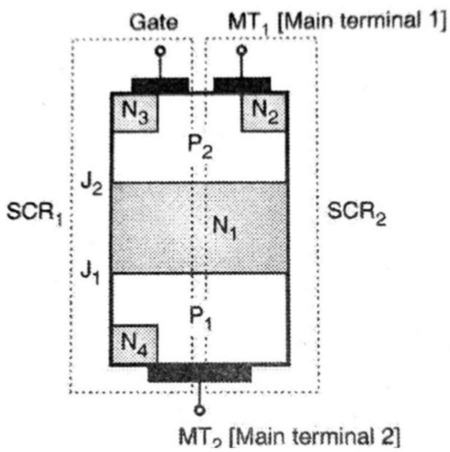
1. Diac is used for controlling SCR
2. Diac is used for the triggering of triac
3. In lamp dimmers
4. In heat control of furnaces
5. In motor speed control

Triac



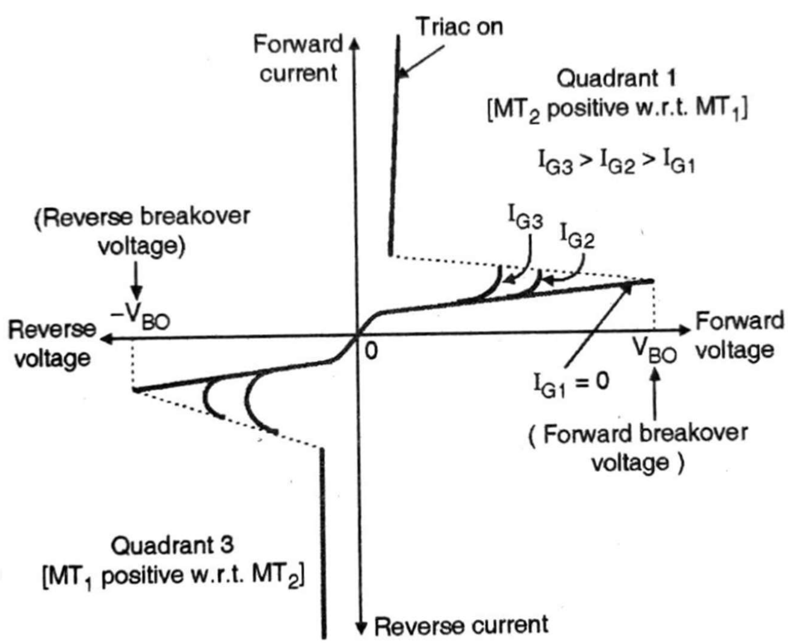
Triac stands for Triode for Alternating Current. It is a bidirectional switching device and can be turned ON with positive or negative gate pulses. It can conduct during both the half cycles of AC.

Structure of triac



Triac is a three-terminal device, with the terminals named as main terminals 1, 2 (MT1 and MT2) and gate, out of which gate is the control terminal. It can be considered as the anti-parallel connection of two SCRs with the gate shorted. Both main terminals (MT1 and MT2) electrodes are connected with both P and N regions of both SCRs. So that it can conduct current in both directions. The gate metallic electrode is also connected with both P and N regions.

Operation of Triac and VI characteristics



When MT2 is positive with respect to MT1, initially, only leakage current flows through the triac. If the forward voltage is increased above the forward break over voltage, breakdown of the reverse biased junction J2 occurs. Current flows through triac and it is said to be turned ON.

Once the triac is turned ON, the voltage across it drops to a low value of around 1 V. The operation of SCR is similar when MT1 is positive with respect to MT2. In this case, the current flows in the reverse direction.

When gate voltage is applied to the triac, the breakdown of triac occurs at a lower voltage and triac is turned ON earlier. As gate current is increased, the triac is turned ON sooner. This can be seen from the VI characteristics. One peculiarity of triac is that, it can be triggered using either positive or negative gate pulses.

Triac has some advantages over using two separate SCRs. If DC is used, SCR needs a diode for protection, which is not needed for triac. Two SCRs connected anti-parallel requires more space and two separate heat sinks. Space acquired by triac is less and it needs only one heat sink.

Applications of triac

1. In dimmer switched for lamps
2. In heat controllers
3. In motor speed controllers
4. For speed control of electric fans
5. In high power lamp switching.