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What Is A Thyristor (SCR)? How Do They Work, Their Types & Applications

A thyristor is a solid-state semiconductor switching device. It is a **bistable** switch that operates in two stable states; non-conducting and conducting state. They are said to be an ideal switch but practically they have some limitations based on their characteristics. They are mostly used in high power circuits.

The thyristors are a family of semiconductor devices that consists of four layers of alternating P-type and N-type substrate. **SCR** is a member of the thyristor's family. Conventional thyristors (SCR) are designed without gate turn-off function, due to which, they switch from conducting to non-conducting state only when the current is brought to zero. However, gate turn-off thyristors are designed to control its both states.

Thyristors have lower on-state losses and high power handling capabilities as compared to transistors. However, they have low switching speed and higher switching losses.

Thyristor

It is a four-layer PNPN semiconductor switching device with three P-N junctions. It has three terminals; the two main terminals **Anode** and **Cathode** & the control terminal called **gate**.

Symbol

The symbol of thyristor resembles diode because both of them allow current flow in one direction except thyristors are controlled by external gate input.

Thyristor Symbol

Structure

It is made up of four layers of alternating P-type and N-type substrate as shown in fig1. The anode terminal is attached to the outermost P-type material and cathode terminal to the N-type material at the opposing end. The gate terminal is attached to the P-type material near the cathode terminal. There are three junctions **j1, j2 & j3** in series from Anode shown in fig1.

Structure Of Thyristor

Read more about : Differences Between Capacitor & Battery

The thyristor's structure can be split into two **NPN** and **PNP BJTs** as shown in fig 2. This structure represents two BJT's whose gate and collectors are connected with each other in a loop as shown in fig 3.

States Of Thyristor:

There are three states of thyristors.

1. **Forward blocking mode**: when there is positive anode-to-cathode voltage, but there is no gate input to triggered the thyristor into the conduction state.

2. **Forward conduction mode:** when the thyristor is triggered into the conduction state and the forward current is maintained above the 'holding current'.

3. **Reverse blocking mode:** When there is a negative voltage applied to the anode with respect to the cathode, the thyristor blocks the current flow like a normal diode.

Working Of Thyristor

Forward Blocking

When a positive voltage is applied to its anode with respect to its cathode, the junction J1 and J3 becomes forward biased. The junction J2 becomes reverse bias. As the junction J2 is reverse biased, the thyristor does not conduct and remain in the off-state current. This is known as '**Forward Blocking Mode**'. However, there is still leakage current known as '**off-state current**'.

Forward Breakdown

If the applied anode-cathode voltage increases very high up to a certain limit, it will break the reversed bias junction j2. This phenomenon is known as '**avalanche breakdown**' and this voltage is called '**forward breakdown voltage**'.

After breakdown, the thyristor will switch-ON resulting in the conduction of a large forward current because junction J1 and J2 were already in forward bias. Practically, this type of switching could be destructive and forward voltage should be maintained below breakdown voltage.

Gate Switching

The proper way of switching on a thyristor is by applying a positive voltage pulse to its gate with respect to the cathode. The junction J2 will become forward bias. The thyristor will switch into conduction state because all three junctions J1, J2, and J3 are forward biased.

During the conduction state, the thyristor acts like a diode. It will conduct current continuously without having any external control. It cannot switch off unless **(a)** the forward voltage is removed or **(b)** the current through the thyristor decreases then a level known as '**holding current**'.

A thyristor is a latching device. When it is triggered using gate input, the device remains latched in on-state. It does not need the continuous gate supply to remain in the conduction state. However, there is a catch; the anode current should not decrease from a limit known as '**latching current**'. The '**latching current**' is greater than the '**holding current**'.

Reverse Blocking

When a negative voltage is applied to the anode with respect to the cathode, the junction J2 becomes forward bias but junction J1 and J3 remain reverse biased. Therefore, the thyristor does not conduct current. This state is known as '**reverse blocking state**'. However, there is still a leakage current known as '**reverse leakage current**'.

Turn On Methods

Generally, a thyristor turns-on by increasing its anode current. This can be achieved using many ways. These turn-on techniques depend on various parameters of a thyristor & it characteristics them for specific applications. But some of them are destructive and should be avoided or protect the device from it.

1) High Voltage

By increasing the forward anode-to-cathode voltage greater than its '**forward breakdown voltage**', the thyristor junction will break. It results in a large current flow, which will turn it into the conduction state. This type of turn-on is destructive and should be avoided.

2) Gate Current

When the thyristor is forward biased i.e. anode terminal voltage is greater than the cathode terminal. Applying a positive gate voltage with respect to the cathode terminal will provide enough gate current to turn on the device.

3) Thermal

Heat can switch a thyristor into the conduction state. If its temperature is high enough, it will produce electron-hole pairs, which results in an increase in the leakage current. This type of turn-on is normally avoided. Because it may cause **thermal runaway**; the process in which a heavy current flow due to high temperature, in turn, releases more heat energy & construct a positive feedback in an uncontrolled manner.

4) Light

Just like photodiodes, if light (photons) reaches the junctions of a thyristor, it will produce electron-hole pairs. These electron-hole pairs result in an increase in current flow & ultimately switching the thyristor into the conduction state.

5) dv/dt

dv/dt is the time rate of change of voltage. As we know that the junctions have capacitance. So, if the anode-to-cathode voltage rising rate is sufficiently high enough, it may charge the capacitive junction to turn the thyristor into the conduction state. However, they have a maximum allowable limit for dv/dt. Increasing the dv/dt from that specified limit might destroy the device.

Thyristor Failure & Its Protection

di/dt Protection

Di/dt is the time rate of change of current. The thyristor needs to be protected against fast-rising current spikes. After switching, It requires a minimum time to establish the current uniformly throughout the junctions. Otherwise, the fast-rising current during switching may damage the junction due to excessive heat and the device will fail eventually.

SCR didt protection

The di/dt can be limited by using an inductor. So an **inductor** is used in **series** to limit the di/dt of the anode current.

dv/dt Protection

As we know that if we apply a fast rising voltage between the anode and cathode of a thyristor, it may turn ON without the gate input. But we don't want to switch ON the device yet.

SCR dvdt protection

In such a case, a **capacitor** is used in parallel which will limit the fast-rising voltage. The capacitor will charge & it will discharge when the thyristor turns on. To limit the discharging current of the capacitor, a **resistor** is used with it in series. Such kind of circuit that suppresses a voltage spike is known as **Snubber**.

Types Of Thyristor

1) Phase-Controlled Thyristor (SCR)

Phase-controlled thyristor also known as a **Silicon Controlled Rectifier** (**SCR**) is turned on by applying the gate current, when it is in forward bias. it does not have a turn-off capability. So, it turns off when the anode current reaches zero.

SCR Symbol

2) Bidirectional Phase-Controlled Thyristor (BCT)

BCT uses two thyristors (**SCR**) in an anti-parallel configuration in a single device. It has two separate gate terminals; one for each thyristor. One of the gate terminals turns on the current in forward direction.& the other gate terminal turns on the current flow in reverse.

BCT Symbol

3) Fast Switching Thyristor (SCR)

They are generally silicon-controlled rectifier (SCR) but they have fast switching speed. It uses the resonant inverter for forced commutation.it is also known as **inverter thyristor**.

4) Light-Activated Silicon-Controlled Rectifier (LASCR)

LASCR is triggered by using a **light source** such as **LED** etc. The light (photon) particles upon hitting the junction produce electron-hole pairs, which triggers the current flow throw the device.
LASCR electrically **isolate** the high power circuit form the light source circuit.

LASCR Symbol

5) Bidirectional Triode Thyristor (TRIAC)

The TRIAC uses two SCR connected in antiparallel configuration with a common gate terminal. It can conduct in both direction and they are used for phase control in AC applications. It has no Anode & Cathode terminals. So it can be used in either direction.

TRIAC Symbol

The TRIAC switches-on by applying a positive & negative gate pulse. When the TRIAC is connected to an AC source, a positive gate pulse will trigger the device for half cycle & a negative gate pulse for the other half cycle.

6) Reverse-Conducting Thyristor (RCT)

RCT Symbol

RCT can conduct in reverse direction without any control input. Its made of an **SCR** with a **diode** in an antiparallel configuration for the reverse conduction of the reactive load currents. It is used in applications where reverse blocking is not necessary. However, it has low reverse voltage rating than its forward voltage rating. Because of the reverses current flow, it allows the RCT to drain its carriers from its junction relatively fast, providing much **fast switching speed**.

7) Gate Turn-off Thyristor (GTO)

GTO turn on like any normal SCR by applying positive gate voltage. However, it can be turned off by applying negative gate voltage. It is a non-latching device; it requires a minimum of 1% of the turn-on pulse to maintain its conduction state.

GTO Symbol

8) FET-Controlled Thyristor (FET-CTH)

FET-CTH uses an **SCR** with a **MOSFET**. The MOSFET is connected to its gate terminal. When sufficient voltage about **3v** is applied to the gate of MOSFET, it provides the necessary triggering current to the gate of the **SCR**.

FET-CTH

FET-CTH has no gate turn-off capability. It provides electrical isolation between control input and the output circuit.

9) MOS Turn-off Thyristor (MTO)

Such type of thyristor uses the combination of **GTO** & **MOSFET**. The **MTO** operates same as the **GTO** but the limitation of **GTO** is the requirement of high pulse current for its off-state. The MTO overcome this limitation by using a MOSFET for its turn-off function. The MOSFET is activated by providing only signal voltage level.

MTO Symbol

MTO has two gate terminals; turn-on gate & turn-off gate. To turn-on MTO, a current pulse is applied to the turn-on gate, which latches the device. To turn off the device, a voltage pulse is applied to the turn-off gate.

10) Emitter Turn-off Thyristor (ETO)

ETO also uses **GTO & MOSFET** combination. It consists of two N-MOSFET & P-MOSFET & a GTO. An N-MOS is connected in series with its cathode terminal and P-MOS is connected between the gate and the cathode terminal of SCR.

ETO Symbol

It has two gate terminals; a normal gate terminal for turn-on & another gate terminal for turn-off connected with series N-MOSFET. It turns on by applying a positive gate voltage to both gates making N-MOS turn-on & P-MOS turn-off. It turns off by applying a negative voltage to N-MOS gate providing the residual carrier to flow out through the P-MOS, which also provides fast switching.

11) Integrated Gate-Commutated Thyristor (IGCT)

IGCT integrates a **gate-commutated thyristor** (**GCT**) with a multi-layer **PCB** (printed circuit board) for gate drives circuitry.

The **GCT** is a hard-switched device that uses very fast-rising and large current pulse to drain all current from its cathode to ensure **fast turn-off**. It has an integrated diode for conduction of reactive load.

An IGCT is turned on by providing gate current. It is turned off by the multilayered PCB that provides a fast-rising, large current of approximately 4Kv/μs. It drains out all the current from its cathode & it turns-off immediately.

Applications

The main application of thyristors is to control high power circuits.

- They find applications in power supplies for digital circuits.
- AC & DC motor speed controllers consist of thyristors.
- A thyristor is also used in light dimmers.