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POWER SEMICONDUCTOR DEVICES VI CHARACTERISTICS LIMITATIONS

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Abstract:-
In semiconductor Power Devices it is observed that the VI characteristics shows linear operations for certain duration of time and that depend upon the majority of holes and Electron Concentrations present in the Device In electronic components, Power Semiconductor Devices are electronic devices that need an external power source to operate actively. Materials used to make semiconductor devices are neither excellent insulators nor conductors. They mainly manipulate, amplify, switch, or control the flow of electric current or voltage in a circuit. Power Semiconductor Devices, like diodes, transistors, thyristors, and sensors require power to do their job. A circuit is an interconnection of components. These components are capable of performing active functions like amplification, rectification, and switching they are called Power Semiconductor Devices.
In this article, we will be going through Semiconductor Devices Which are mainly divided into Diodes, Thyristors and Transistors. Semiconductor Devices are Classified into Two-Terminals, Three-Terminals and Four-Terminals Devices, We will go in-depth about these Devices. We will go through working of diodes, Thyristors, Transistors and Look at Its vi characteristics, At last we will conclude our Article with Advantages, Disadvantages, Applications, and Some FAQs.
What are Power Semiconductor Devices?
Power semiconductor devices are used as on/off switches in power control circuits. A power semiconductor device is a semiconductor device used as a switch or rectifier in power electronics for example in a switch-mode power supply. Such a device is also called a power device or, when used in an integrated circuit. Power devices operate at lower switching speeds whereas signal devices operate at higher switching speeds. The power semiconductor devices are used extensively in power electronic circuits.

These power semiconductor devices are divided into three types:
* Diodes
* Thyristors
* Transistors

Classification of Power Semiconductor Devices
Classification of Power Semiconductor Devices based on the terminals, basically these include two terminals, three terminals, and four terminal devices.
Two-Terminal Power Semiconductor Devices
* Diode
* Gunn diode
* IMPATT diode
* Laser diode
* Zener diode
* Schottky diode
* PIN diode
* Tunnel diode
* Light-emitting diode (LED)
* Photo transistor
* Photocell
Three-Terminal Power Semiconductor Devices
* Bipolar transistor
* Field-effect transistor
* Darlington transistor
* Insulated-gate bipolar transistor (IGBT)
* Unijunction transistor
* Silicon-controlled rectifier
* Thyristor
* TRIAC

Four-Terminal Power Semiconductor Devices
* Photo coupler
* Hall effect sensor

Power Diode
Diodes play a significant role in power electronics circuits. These are uncontrolled rectifying devices. It acts as a switch to perform various functions such as switches in rectifiers, change reversal of capacitor and energy transfer between components, voltage isolation, energy feedback from the load to power Source.

Diode
* Diodes consist of semiconductor materials, either silicon or germanium.
* It is a two terminal semiconductor device, these two terminals are called the anode and cathode.
* It lets the electricity to flow only in one direction.
* Most diodes have painted line on one end showing the direction or flow. The negative side is normally white
* Current flow through diode only when positive voltage is applied to anode and negative voltage is connected to cathode
* If these voltages are reversed, then the current will not flow.

Diode Circuit Symbol
Applications of Power Diodes
* They act as shields for solar panels.
* They are used to protect loads from voltage spikes.
* They are used in voltage and converting it from AC to DC.
* They are used to allow an unidirectional flow of current in circuit.
* They differ by its power, and how much current it can handle.
* They act as an electronic check valve and convert alternating current into direct current (DC).

The vi characteristics of pn junction diode can easily be understood under the following three headings.
* Forward-Biased Diode
* Reverse-Biased Diode
* Zero Biased Diode OR Unbiased Diode

Forward-Biased Diode
In forward biasing, a semiconductor is connected to an external source when the p-type semiconductor is connected to the positive terminal of the source or battery and the negative terminal to the n-type, then this type of junction is said to be forward-biased. In forward bias, the direction of the built-in electric field near the junction and the applied electric field are opposite in direction. This means that the resultant electric field has a magnitude lesser than the built-in electric field due to this there is less resistivity and therefore the depletion region is thinner. In silicon, at the voltage of 0.6 V, the resistance of the depletion region becomes completely negligible.

Reverse-Biased Diode
In reverse biasing, the n-type is connected to the positive terminal and the p-type is connected to the negative terminal of the battery. In this case, the applied electric field and the built-in electric field are in the same direction and the resultant electric field has a higher magnitude than the built-in electric field creating a more resistive, therefore depletion region is thicker. if the applied voltage becomes larger, then the depletion region becomes more resistive and thicker.

Zero Biased Diode OR Unbiased Diode
When there is no external source applied to semiconductors is known as an unbiased diode. the electric field is built up across the depletion layer between the p-type and the n-type material. this happens because of the unbalanced no. of electrons and holes due to doping. At room temperature, for a silicon diode, 0.7V is the barrier potential.

Thyristors
The thyristors are used extensively in power electronic circuits. They are operated as bistable switches, operating from of state to conducting state. The member of the Thyristors family are SCR, LASCR, RCT, GTO, SITH, and MCT.

Thyristor
Applications of Thyristors
* Thyristors are used in speed controls
* Thyristors are used in light dimmers
* Thyristors are used in Rectifiers
* Thyristors are used in power supplies
* Thyristors are used in Inverters

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* Thyristors are used in Battery charges
* Thyristors are used in camera flashes
* Thyristors are used in various types of circuits, such as logic and timer circuits.

V-I Characteristics of Thyristor

The V-I characteristics of thyristor is a graph between the anode current IA and the anode-cathode voltage VA for different values of gate current IG. This characteristics can be drawn by considering the basic operation of the SCR. The below figure shows the V-I characteristics which is also called as static-cathode characteristics. It basically consist of three regions, They are:

* Region 1
* Region 2
* Region 3

VI-characteristics-of-Thyristor

Region 1

When the positive terminal of the supply is connected to cathode and the negative terminal is connected to anode with gate circuit open then thyristor operates in region 1. In this region junction J1 and J3 becomes reverse biased, whereas the junction J2 becomes forward biased. The reverse biased junctions (J1 and J3) acts as open circuit and the forward biased junction(J2) acts as a short circuit, as shown in figure.

Region 2

When the positive terminal of the supply is connected to anode and the negative terminal is connected to cathode with gate circuit open then thyristor operates in region 2. In this region junction J1 and J3 becomes forward biased, whereas the junction J2 gets reverse biased. The forward biased junctions (J1 and J3) acts as short circuit and the reverse biased junction(J2) acts as a open circuit, as shown in figure. Even in this region, the thyristor does not conduct any current expect a very small value of the leakage current. This mode of thyristor is called as forward blocking mode. Just as the region 1, i. e., reverse blocking mode, the thyristor can be made to conduct in the forward blocking mode by increasing the anode-cathode voltage to a value called forward breakdown voltage(VBO). Even this method is not recommended as it may also damage the thyristor. Hence, the thyristor does not conduct even in this mode and is treated as open switch.

Region 3

When the positive terminal of the supply is connected to anode and the negative terminal to cathode with gate circuit closed the operates in region 3. In this region, all the three junctions (J1, J2 and J3) act as short circuits shown in figure and hence conduct current. In this region thyristor is said to be in a forward conduction mode and hence acts as a closed switch. This method of conducting the thyristor is the most efficient, as it requires a voltage which is very much less than VBO. The only extra thing we require is a gate signal for a small period of latching current. Once the anode current attains this value, the gate losses the control and hence can be removed. The removal of the gate signal will not have any effect on the thyristor conduction. However, if the anode current decreases to a value called ad holding current, the thyristor will once again go back to the forward blocking gate. Hence, care must be taken that, the anode current should not drop below the holding current after the gate signal is removed.

Turn off and Turn on Characteristics of Thyristor

The characteristics are as follows:

Turn ON Switching Characteristics of Thyristor

A forward biased thyristor is turned ON by applying a positive gate voltage between the gate and the cathode, as shown in figure(1).

Figure(2) , shows the waveforms of the gate current(IG), anode current(IA) and anode to cathode voltage(VAK). The total switching period being much smaller compared to the cycle time, IA and VAK before and after switching will appear flat. As shown in figure , there is a transition time "Toff" from forward OFF state to forward ON state. This transition time is called the thyristor turn ON time and can be divided into three separate intervals namely, They are

* Delay time (Td)
* Rise time (Tr)
* Spread time (Tp)

Turn-ON-Switching-Characteristics-of-Thyristors

Delay Time (Td)

It is the time between the instant at which the gate current reaches 90% of its final value and the instant at which the anode current reaches 10% of its final value. It is the time taken by the anode voltage to fall from VAK to 0.9 VAK

Rise Time (Tr)

For a resistive load, "rise time" is the time taken by the anode current to rise from 10% of its final value to 90% of its final value. At the same time, the voltage VAK falls from 90% of its initial value to 10% of its initial value. However, current rise and voltage fall characteristics are strongly influenced by the type of the load. For inductive load the voltage falls faster than the current. While, for a capacitive load, current rises rapidly.

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Spread Time (Tp)
It is the time taken by the anode current to rise from 90% of its final value to 100%. During this time conduction spreads over the entire cross-section of the cathode of the thyristor. The spreading interval depends on the area of the cathode and on the gate structure of the thyristor.

Turn OFF Switching Characteristics of Thyristor
* Once the thyristor is ON and its anode current is above the latching current level, the gate losses control. It can be turned OFF only by reducing the anode current below the holding current. The OFF time tq of a thyristor is defined as the time between the instant anode current becomes zero and the instant the thyristor regains forward blocking capability. If forward voltage is applied across the device, during this period the thyristor turns ON again.
* During turn OFF time, excess minority carriers from all the four layers of the thyristor must be removed. Accordingly, tq is divided into two intervals, the reverse recovery time(tRR) and the gate recovery time(tGR), figure shows the variation of the anode current and the anode to cathode voltage with time during turn OFF operation for an applied sinusoidal voltage(VI).

Turn OFF Switching Characteristics of Thyristor
The anode current becomes zero at time t1 and starts growing in the negative direction with the same DiA / Dt till time t2. This negative current removes excess carriers from the junctions J1 and J3. At time t2 excess carriers densities at these junctions are not sufficient to maintain the reverse current. The value of the anode current at time t2 is called as the reverse recovery current(IRR). The reverse anode current reduces to the level of reverse saturation current. The total charge removed from the junctions between t1 and t3 is called the reverse recovery charge(QRR). Fast decaying reverse current during the interval t2 – t3 coupled with the di / dt limiting inductor may cause a large reverse voltage spike to appear across the device. This voltage must be limited below the VRRM rating of the device. Up to time t2 the voltage across the device(VAK) does not change substantially from its state value. However, after the reverse recovery time, the thyristor regions the reverse blocking capacity and VAK starts following the supply voltage. At the end of the reverse recovery period(trr) trapped charges still exist at the junction J2 which prevents the device from blocking forward voltage just after trr. These trapped charges are removed only by the process of recombination. The time taken for this recombination process to complete between t3 and t4 is called the gate recovery time(tgr). The time interval tq = trr + tgr is called "device turn OFF time" of the thyristor.

Transistors
The power transistors have controlled turn-on and turn off characteristics. The switching speed of power transistors is much nigher than that of thyristors, and they are extensively used in dc-dc and dc-ac converters. The power transistors can classified as BJT, MOSFETs, SITs and IGBTs

BJT Symbol
* Transistors are able to amplify the power of a signal
* Bipolar Junction Transistors in which include NPN and PNP transistors are further classified based on their applications and characteristics:
* NPN Transistor: The NPN transistor is commonly used for the amplification and switching in electronic circuits. It is named after the arrangement of its layers: N-type collector, P-type base, and N-type emitter.
* PNP Transistor: The PNP transistor is also used for the amplification and switching but with the opposite current flow compared to NPN.

The terminals of the BJT bipolar transistor are:
* B: Base
* C: Collector
* E: Emitter

Transistor Circuit Symbol
Applications of Transistors
* They are used in amplifiers.
* They are used in digital logic circuits.
* They are used in voltage regulators.
* They are used in Logic Circuits
* They are used in Temperature Control Systems
* It is used in converters.
* They are used in automatic switches

MOSFET (Metal–Oxide–Semiconductor Field-Effect Transistor)
The MOSFET is a field-effect transistor and it is a four terminal device with source(S), gate (G), drain (D) and body (B) terminals. It's generally classified into two basic configurations: Depletion Mode MOSFET and Enhancement Mode MOSFET.

The logic gates are the basic building blocks of all digital circuits and computers. These logic gates are implemented using transistors called MOSFETs. A MOSFET transistor is a voltage-controlled switch. The MOSFET acts as a switch and turns on or off depending on whether the voltage on it is either high or low. There are two types of MOSFETs: NMOS and PMOS. The NMOS turns on when the voltage is high and off when the voltage is low.

MOSFET
Working of MOSFET Transistor
A MOSFET's operation is dependent on its MOS capacitor. The heart of the MOS-FET is the MOS capacitor. Between the source and drain terminals is where the semiconductor surface is situated at the bottom of the oxide layer. Positive or negative gate voltages can be applied to convert it from p-type to n-type.
Positive gate voltage exerts a repulsive force on the holes beneath the oxide layer, pushing the holes downward along with the substrate.
This depletion region is filled with bound negative charges connected to the acceptor atoms. Once the electrons arrive, a channel is created. Electrons from the drain and n+ source regions are also drawn into the channel by the positive voltage. The current now flows freely between the source and drain and the gate voltage regulates the electrons in the channel if a voltage is applied between the drain and source. A hole channel under the oxide layer will form if we apply a negative voltage.

Bipolar Junction Transistors (BJT)
A Bipolar Junction Transistor (BJT) is a three-terminal semiconductor device used for signal amplification and switching. Based on the arrangement of the semiconductor layers and the direction of current flow, BJTs are classified as NPN (Negative-Positive-Negative) or PNP (Positive-Negative-Positive).
Bipolar Junction Transistors in which include NPN and PNP transistors are further classified based on their applications and characteristics:
* NPN Transistor: The NPN transistor is commonly used for the amplification and switching in electronic circuits. It is named after the arrangement of its layers: N-type collector, P-type base, and N-type emitter.
* PNP Transistor: The PNP transistor is also used for the amplification and switching but with the opposite current flow compared to NPN.

BJT Symbol
Working of BJT Transistor
* The operation of a PNP transistor is based on the control of current flow between the emitter and collector by the current flowing into the base. Here's a brief overview:
* When a positive voltage is applied to the base-emitter junction. It allows the flow of electrons from the emitter to the base.
* The flow of electrons from the emitter to the base creates a path for majority charge carriers to flow from collector to the emitter.
* This controlled flow of holes from the collector to emitter constitutes the output current and it can be amplified based on current flowing into the base.

Insulated Gate Bipolar Transistor(IGBT)
IGBT stands for Insulated Gate Bipolar Transistor. It is a type of power transistor that integrates an input MOS (Metal-Oxide-Semiconductor) with an output bipolar transistor. It is commonly employed as a switching device in inverter circuits, facilitating the conversion of DC (Direct Current) to AC (Alternating Current) power.
* The IGBT combines the input characteristics of a MOSFET with the output characteristics of a BJT, resembling the structure of an N-channel MOSFET and a PNP BJT in Darlington configuration. Additionally, the resistance of the drift region can be integrated.

IGBT
Working of IGBT
IGBT has three terminals: collector (C), emitter (E) and gate (G). These terminals serve distinct roles in controlling current flow through the device. IGBT Operation. In the operation of an IGBT, the collector-emitter connection is established with the collector at a positive voltage compared to the emitter. These are forward biased junction J1 and reverse biases junction J2. Notably, there is no voltage applied to the gate at this stage. Due to the reverse bias at J2, the IGBT remains in the off state, preventing any current flow between the collector and emitter. When a positive gate voltage (VG) is

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applied relative to the emitter, negative charges accumulate beneath the SiO2 layer due to capacitance. As VG increases, more charges accumulate, forming a layer in the upper P-region when VG exceeds the threshold voltage.

Integrated Circuits

Integrated Circuit (IC) also called micro electronic chip, microchip, or chip. It is a group of electronic circuits placed on a metal plate designed with semiconductor materials

An IC is the fundamental building block of all modern electronic circuits. ICs are made up of several components such as R, C, L, diodes & transistors as active devices and capacitors & resistors as passive devices, and their interconnections are built up on a thin substrate of semiconductor material, typically silicon. An IC can function as an amplifier, oscillator, timer, counter, logic gate, microcontroller, or microprocessor.

Integrated circuits are a very special and important topic for digital electronics. Digital Electronics is related to 0 and 1. Using 0, 1 only every analog waveform is digitally represented.

An integrated circuit (IC) can consist of thousands or even millions of:

* Transistors
* Resistors
* Capacitors
* Diodes

The simple definition of the integrated circuit is a miniature low-cost electronic circuit that consists of both active and passive elements fabricated on single-crystal silicon. The integrated circuit is made of semiconductor material. Integrated circuits are divided based on many parameters. They are

* Based on application.
* Based on Technology.
* Based on the Integration level.

Applications of Power Semiconductor Devices

Power Semiconductor Devices are vital for various applications:

* They are used in consumer electronics
* They are used in military
* They are used in space technologies
* They are used in mobile devices
* They are used in smart cities
* They are used in automobiles

Advantages and Disadvantages of Power Semiconductor Devices

There are some list of Advantages and Disadvantages of Power Semiconductor Devices given below :

Advantages of Power Semiconductor Devices

* Power Semiconductor Devices actively control the flow of electric current in a circuit.
* Power Semiconductor Devices manipulate the flow of electric current in a circuit.
* Power Semiconductor Devices can communicate over longer distance.
* Power Semiconductor Devices can amplify the signal in the circuit
* Power Semiconductor Devices provide more functionality.
* We have more control on Power Semiconductor Devices.

Disadvantages of Power Semiconductor Devices

* They need extra power supply needed from outside.
* They are available at high cost.
* They are Large and Heavy
* They offer limited Lifetime
* These components are complex in design.
* Sometimes they have response issues.

Conclusion

In this article we have learnt about Power Semiconductor Devices, these can easily handle electric current in the electrical circuit. They can receive energy in the forms of thermal energy, chemical energy, hydraulic energy, and delivers in the circuit in the form of electrical energy. We have seen the properties of Power Semiconductor Devices and different types of Power Semiconductor Devices and we have the applications. In Electrical circuits, Power Semiconductor Devices play an important role in controlling and amplifying the power in the electrical circuits. Also it can be seen that every device has its linear region of operation which is not same and depends on concentration of electrons and Holes

What does the term “power semiconductor device protection” mean?

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Protection circuits, sometimes known as snubber circuits, are necessary for power semiconductor devices since their SOA is restricted during turn-on and turn-off transitions. The purpose of the snubber is to protect the power semiconductor device from potential failure by mitigating the voltage and current stresses that arise during switching transitions.
How can the classification of power semiconductor devices be done?
One way to categorize power semiconductors is into two groups: unipolar devices, which have a single conductor, and bipolar devices, which have two conductors. When it comes to unipolar devices, the primary current is conducted by only one kind of charge carrier: holes or electrons.

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