The Shirpur Education Society's
R. C. Patel College of Engineering and Polytechnic, Shirpur
Department of Electrical Engineering

NOTES

Programme Code: Electrical Engineering | **Year/Scheme:** EE3K | **Semester:** 3rd

Course Title: Fundamentals of Power Electronics | **Course Abbr.:** FPE | **Course Code:** 313335

Subject Teacher :- Ms. H.A.Badgujar

UNIT-01 – (12 MARKS)

POWER ELECTRONIC DEVICES

CO Coverage: - Test the functionality of a given power electronic device

Unit -01 Content (Syllabus)

1.1 Power electronic system: general block diagram, need, advantages and disadvantages

1.2 Switching in power electronic circuit: Need and its importance; Ideal switch and practical switch: concept, general characteristics, conduction losses, switching losses

1.3 SCR: Construction, working principle, Static V-I characteristics, switching characteristics, and applications

1.4 IGBT: Construction, working principle, Static V-I characteristics, switching characteristics, and applications

1.5 Power MOSFET: Construction, working principle, Static V-I characteristics, and applications

1.6 TRIAC: Construction, working principle, Static V-I characteristics, and applications

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1.1 Power Electronic System :- General block diagram, Need, Advantages, Disadvantages.

Power electronics is the branch of electrical engineering that deals with the processing of High voltages and currents to deliver power that supports a variety of needs.

It consist of following main Components :-

1) Power Source :- Provides input power that could be AC or DC.

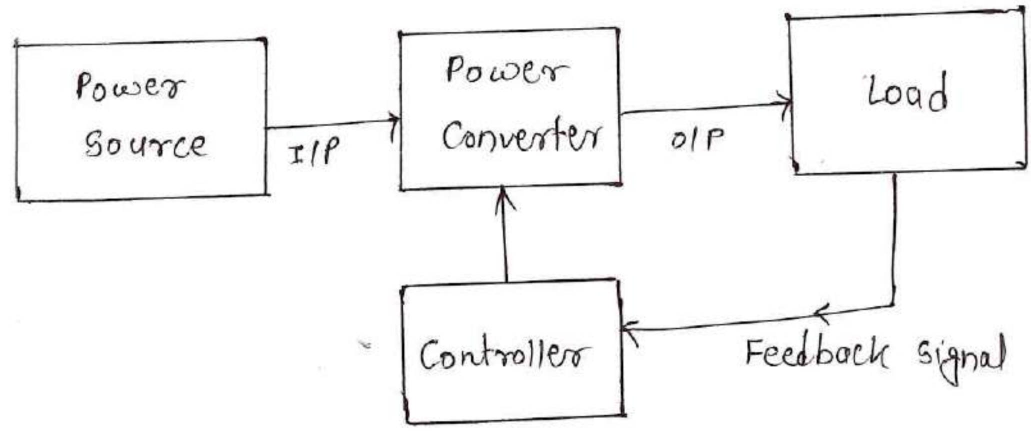


Fig. - Block diagram of Power Electronics.

2) Power Converter :→ Contains semiconductor switches that efficiently convert & process input power.
3) Load :- Load consumes converted power. The rating of the load largly determines the rating of the power electronic converter circuit.
4) Sensors :- Provide feedback signal on load conditions like current, voltage....etc.
5) Controllers :- Monitors feedback, compares it with reference and controls converter switches accordingly.

* Need of power Electronics :→

Power electronics is needed because we need to use it in various applications :-

1) Efficient energy conversion.
2) Voltage regulation and control
3) Renewable energy integration.
4) Power quality improvement.
5) Energy storage system
6) Industrial Applications.

* Advantages of Power Electronics :-

1) Compact size and light weight modular design.
2) Flexible and digitally controlled output.
3) Integration with digital control system.
4) Improved power quality with reduced harmonics.
5) Silent operation
6) Fast response time.

* Disadvantages :-

1) Power electronics converters have a low overload capacity.
2) Power electronics converter circuit have tendency to generate harmonics.
3) It has low power factor operation.
4) Regulation of power is difficult in a power electronics converter.

* Applications :-

1) Power supplies, battery chargers.
2) Electric vehicles.
3) Motor Control
4) washing machines.

1.2 Switching in Power Electronic Circuits

* Need of Power Electronic Circuits :-

1) Power delivered to the load can be regulated by turning semiconductor devices ON an OFF.
2) Used in AC-DC, DC-AC, DC-DC, and AC-AC converter.
3) Semiconductor devices disspate less power in fully ON or fully off states.
4) Essential in motor drives, inverters, SMPS, and Industrial automation.
5) Electronic switching is faster than mechanical switching.

* Importance of Switching :->

1) It improves efficiency.
2) Reduces size of transformers and filters.
3) Accurate control of power and output parameter is possible.
4) semiconductor switches have no moving parts and requires less maintenance.
5) Supports modern applications like UPS system, renewable energy systems, EV battery chargers... etc.

* Ideal Switch & Practical Switch :->

semiconductor devices are act as a switch in power electronic applications. Therefore in the equivalent circuit these devices are replaced by open circuit (o.c) and short circuit (s.c).

The switches can be of two types.

1) Ideal switch 2) Practical Switch.

* Ideal switch :-> A switch that operates with perfect efficiency and performance.

* characteristics of Ideal Switch :-

1) zero on state resistance :- when ideal switch is ON i.e. Closed, it offers zero resistance i.e. act as short circuit.
2) When device is in off state (open circuit), it should be capable of withstanding device voltage.
3) During Conducting state (ON-state) voltage drop should be zero.
4) zero ON state power loss (conduction loss) :- state voltage drop is 0 hence power loss in ideal switch is 0.
5) zero turn ON/OFF time :- Power is dissipated in switch at the time of switching it ON/off is called switching loss. For ideal switch switching loss is zero.
6) 100% switching frequency - multiple times switch can be turn ON/OFF.

** Practical switch :-> A practical switch is an actual physical device used to control the flow of electricity in a circuit.

* Characteristics of practical switch :-
1) Limited power handling capacity i.e. limited current carrying capacity when switch is in ON state & Limited blocking voltage when switch is in the OFF state.
2) Due to finite turn ON and turn OFF times, this limits maximum operating frequency of device.
3) Conduction losses during the ON state.
4) switching losses during switching transition.

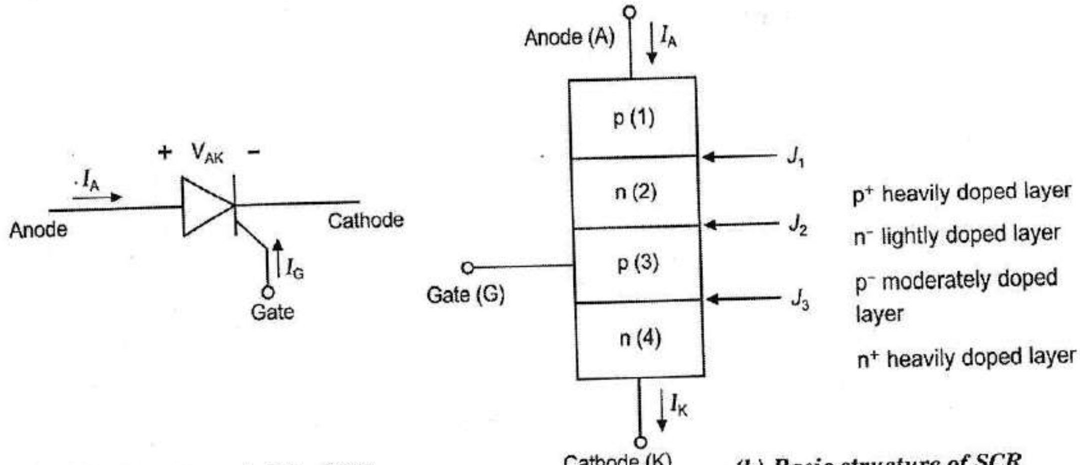
* Conduction loss :-> Energy loss occuring when the transistor is in ON state (conducting) state.

* switching losses :- switching loss is the power or energy loss that occurs in a semiconductor device during transition between on or off state.

1.3 - SCR - Construction, working principle, Static V-I Ch^s, switching characteristics and applications.

Question :- Draw & Explain V-I characteristics of SCR and define the following items :- i) Forward breakover voltage ii) Latching Current (iii) Holding Current & Any two applications of SCR.

* **Construction of SCR** :-> The basic structure of SCR is as shown in fig.



(a) Circuit symbol for SCR *(b) Basic structure of SCR*

→ It is a four layer PNPN device with three terminals namely anode, cathode and Gate.

→ The Gate terminal is the control terminal that can turn on the device whenever required.

→ The symbol of SCR is as shown in fig (a)

→ There are three junctions J_1, J_2 & J_3. In order to turn on SCR, the anode must be at a higher positive potential than Cathode. This means that SCR is forward biased.

→ The outer layers (1st P-type & last N-type) of SCR are heavily doped, where as middle P-type & N-type layers are lightly doped.

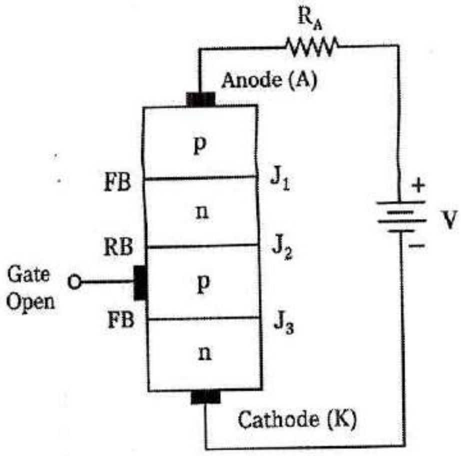
* **Working of SCR** :->

working operation of SCR can be explained under two different conditions :-

1) working operation without gate current :-
2) operation with gate current

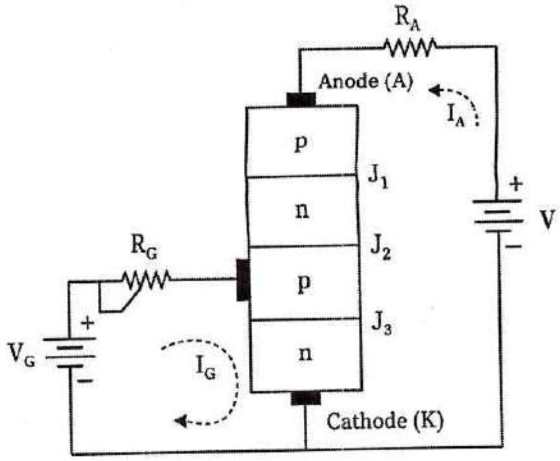
* **working operation without gate current** :-

→ consider fig (a) given below. The Gate terminal of SCR is left open so that $I_G = 0$.



FB : Forward biased
RB : Reverse biased

(a) Working operation of SCR without gate current



(b) Working operation of SCR with gate current

- → SCR is forward biased by applying a positive voltage to anode with respect to cathode.
- → out of 3 junctions J_1 & J_3 is forward biased and J_2 is reverse biased.
- → Therefore current does not flow through the SCR. As anode to cathode voltage increases, the voltage across junction J_2 increases.
- → At certain voltage, this junction with breakdown and SCR will start conducting.

*** operation with Gate Current :→**

- → fig -(b) shows that SCR is forward biased as before and gate cathode junction also is forward biased using an external power source.
- → The gate current I_G flowing which can be adjusted by the resistance R_G.
- → The value of Gate Current (I_G) decides breakover voltage of SCR. As I_G increases, breakover voltage will decrease i.e SCR will turn on at lower voltage.

*** V-I characteristics of SCR :→**

- → The V-I characteristics of SCR is a graph of anode current I_A on y-Axis and Anode to cathode voltage on x-axis, as shown in fig.
- → V-I Characteristics mainly consist of -

1) forward blocking state 2) Reverse blocking state.
3) forward Conduction state.

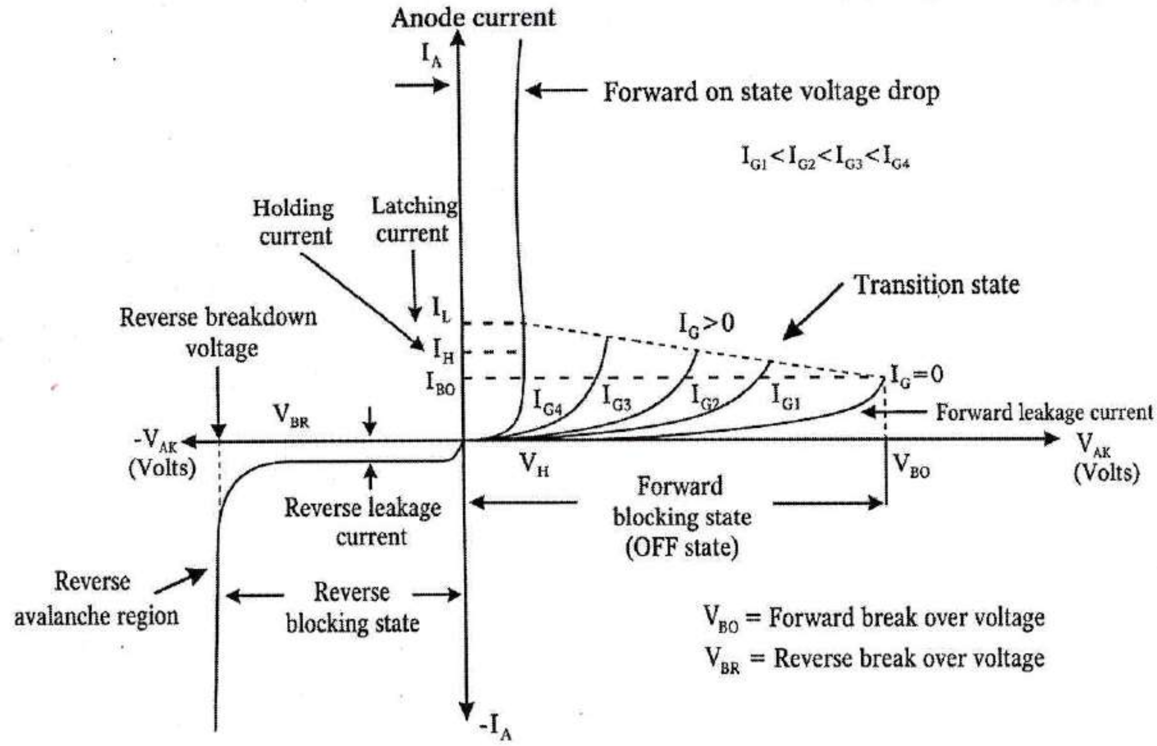


Fig. V-I Characteristics of SCR.

1) Forward blocking state :- This is the high voltage low current mode of operation in which SCR in off state.

→ The current flow through it is 'forward leakage current'

→ This current flows due to thermally generated minority carriers.

2) Reverse blocking state :-
The region from 0 volts upto VBR volts in which the SCR is reverse biased and non-conducting is called as 'reverse blocking state'. Reverse blocking means, the SCR is reverse biased and in non-conducting (blocking) state.

3) Forward Conduction State :-
In forward conduction state of SCR, the anode and cathode are connected to the positive and negative terminals with the gate circuit is closed. It will act as short circuit hence the SCR conducts.

* Important terms related to V-I characteristics of SCR :-

1) Forward breakover voltage :- It is the minimum value of the applied voltage at which the SCR is turned ON, provided the gate voltage is not applied.

2) Reverse breakover voltage :-
It is the maximum reverse voltage (K is +ve w.r.t. A) that can be applied to SCR without conducting in reverse direction.

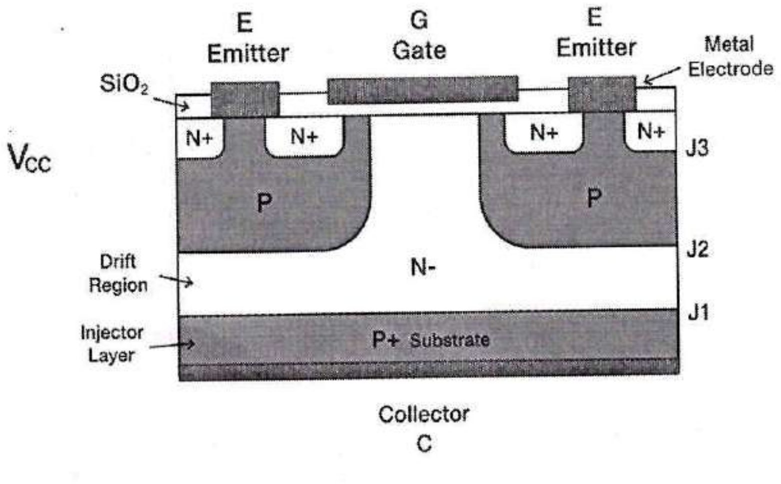
3) Holding Current :- It is the minimum anode current to maintain SCR in ON state.

4) Forward Latching Current :-
The minimum current required to maintain the SCR in the ON state on the removal of gate voltage is called latching current.

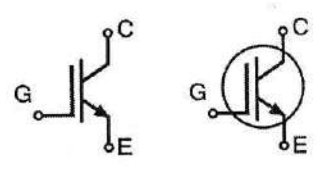
* Applications of SCR :-

1) Power Switching Circuit
2) Controlled rectifier
3) Speed control of DC motor.
4) Computer Logic Circuits.
5) Inverters
6) Battery charging regulators.
7) Temperature control system.

1.4 IGBT : Construction, working principle, static V-I characteristics, switching characteristics & applications :-



Structure of IGBT



symbol of IGBT

Fig. (a) structure of IGBT   fig. (b) Symbol of IGBT.

* Construction of IGBT :->

→ IGBT is made of four layers of semiconductor to form PNPN structure.
→ IGBT is a voltage controlled device. It has three junctions (J_1, J_2, J_3) and three terminals emitter (E), collector (C) and gate (G).

→ There is injection layer which injects high majority charge carriers (Holes)

→ Drift layer is to determine the voultage blocking capacity. of IGBT.

→ The main diffezence in the structure of IGBT as compared to that that of MOSFET is the existence of P+ layer that forms the collector of IGBT.

* Working :-

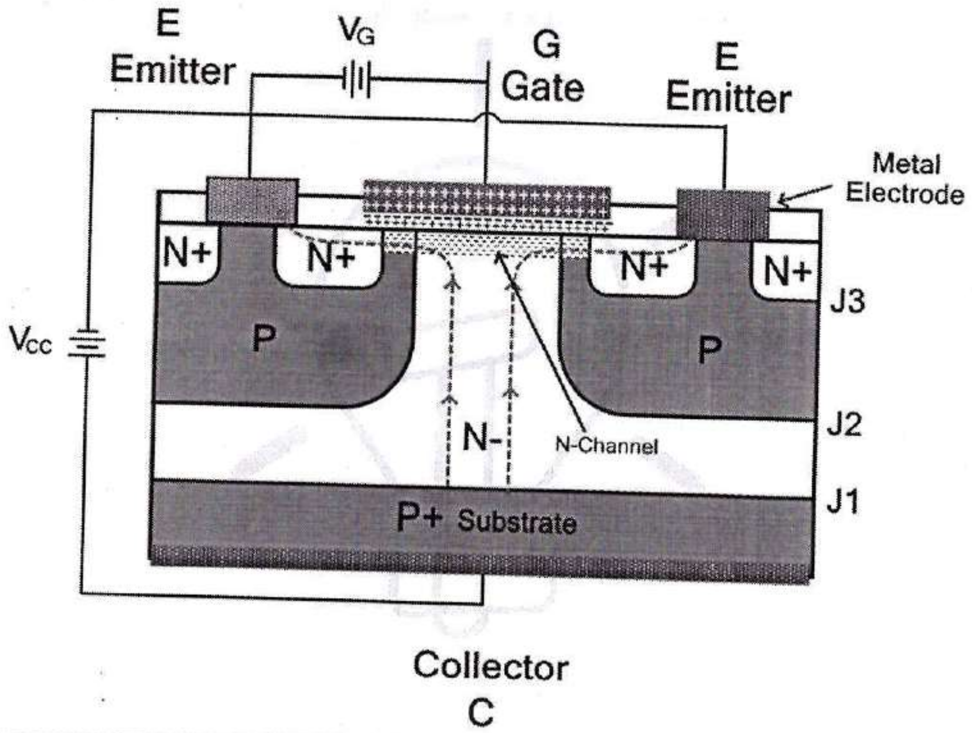


fig. working of IGBT

→ The two terminals of IGBT collector (C) and emitter (E) are used for the conduction of current while the gate (G) is used for controlling the IGBT.

→ When collector is +ve and gate (G) is open IGBT connected to the external supply source through terminals collector & emitter.

→ Diagram is as shown in fig.

→ Firstly collector and emitter are connected to supply, +ve & -ve ions are generated at P layer & N layer.

→ As J_2 is reverse biased, IGBT is off.

→ To turn on IGBT gate pulse will be applied and gate terminal is connected to supply V_{GE}.

→ when ~~the~~ a gate voltage is applied to the IGBT, charge carriers are generated near the terminals.

→ Electrons move from the emitter toward the collector, while current flows in the opposite direction.
→ This process turns the IGBT ON & increases conductivity, enabling the device to conduct current efficiently.

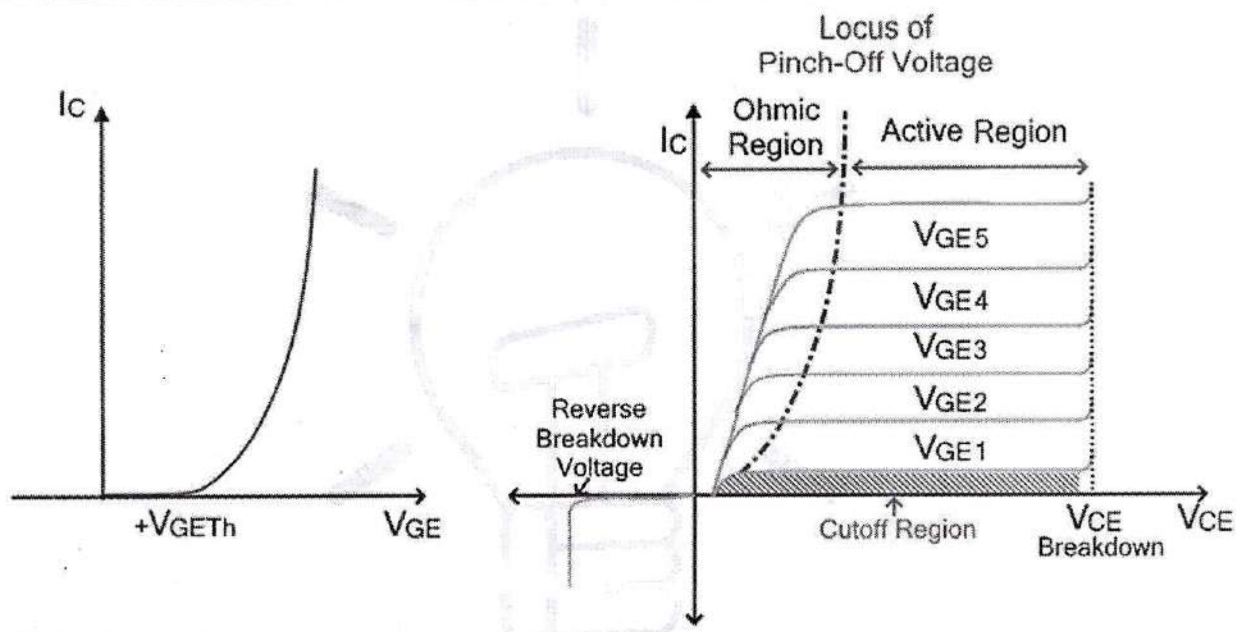


Fig. V-I characteristics of IGBT

→ IGBT is a voltage controlled device that requires small gate voltage to control collector current.
→ Above fig. shows the relationship between input voltage V_{GE} & V_{CE} w.r.t. collector current I_C.
→ when V_{GE} is 0V, the device remains switched off, while when V_{GE} is slightly increased but below threshold, it switches ON.
→ The graph shows the relationship between collector current I_C and collector-emitter voltage V_{CE} at different levels.

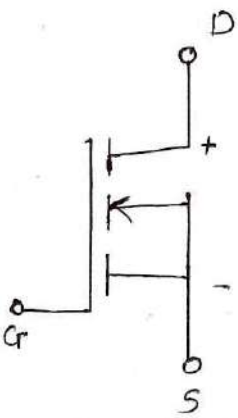
* Applications :

1) Used in SMPS (Switched mode Power Supply) to supply power to sensitive medical equipments and computers.
2) It is used in ups.
3) It is used in AC and DC motors drive offering speed control.
4) Used in choppers & Inverters.
5) Used in solar inverters.

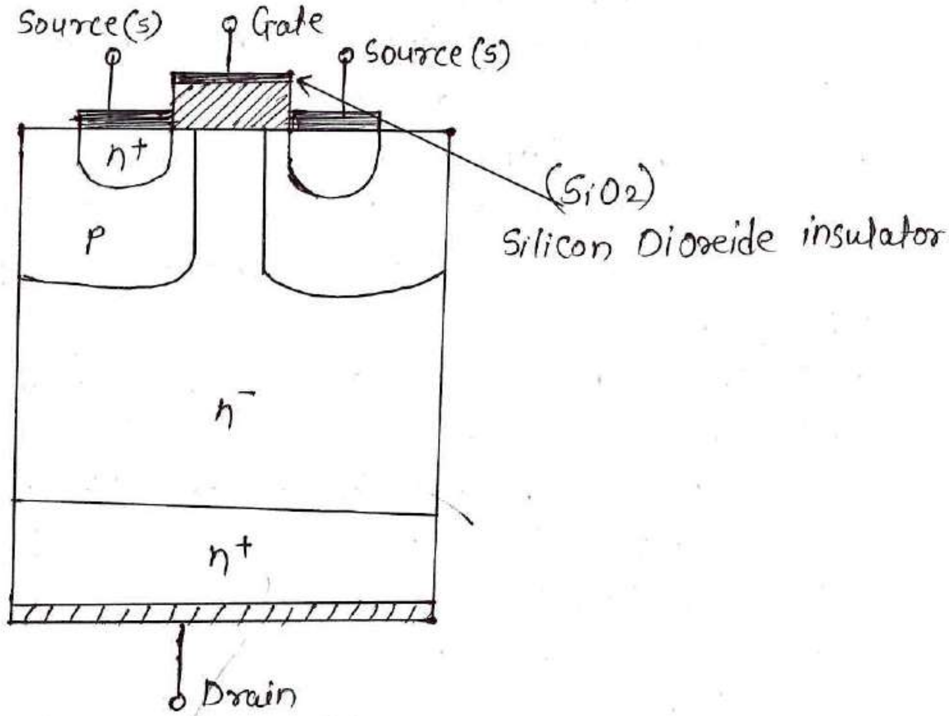
1.5 POWER MOSFET :-> Construction, working principle, static V-I characteristics and applications

* Construction :-> MOSFET (metal Oxide Semiconductor Field Effect trasistor)

→ It has high switching frequency 100 kHz and High power handling capacity.



a) Symbol - MOSFET



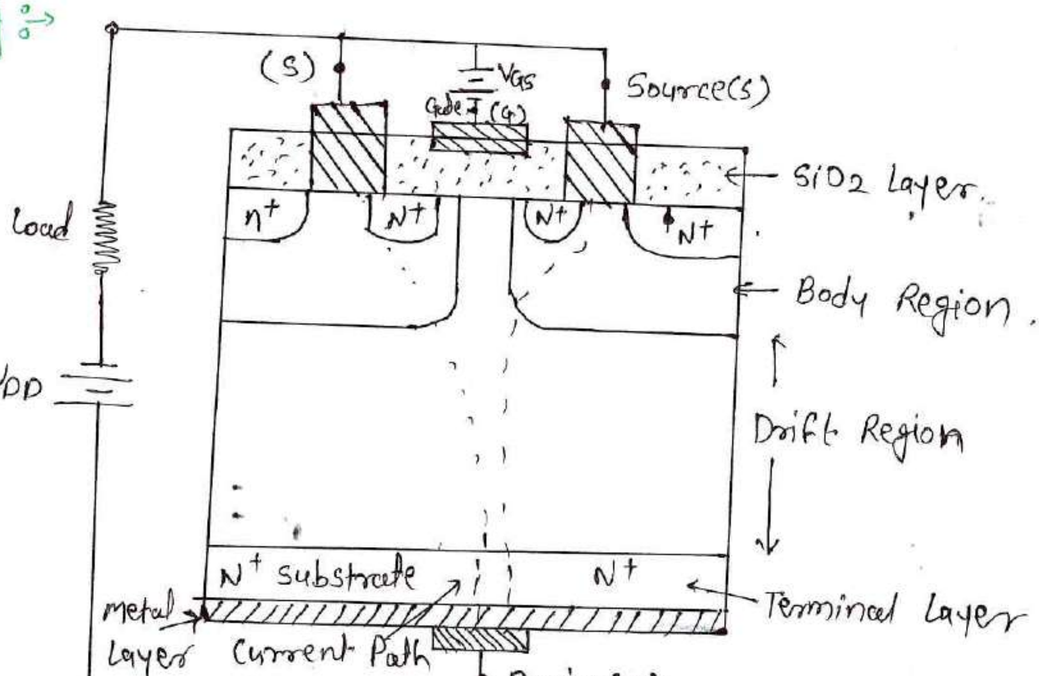
b) Construction of MOSFET

→ MOSFET is three terminal, three layer device. Power MOSFET consists of a parallel connection of thousand of basics MOSFET cell on a single silicon chip. MOSFETs are low voltage and High current devices.

→ Power MOSFETS are widely used in three modes as follows:-

i) N-channel enhancement mode.
ii) P-channel enhancement mode.
iii) n-channel depletion mode.

* Working :->



→ The structure shown in fig. is termed as enhancement mode n channel MOSFET (N^+, P, N^-, n^+).

→ Here, N^+ substrate layer is inserted, N^+ substrate means the layer which as high doping level & it also called as terminal level.

→ N-layer - doping level is less, also called as drift region

→ The basic mos cells are connected in parallel above the drift region.

→ The basic mos cells are connected in parallel above the drift region, which forms the junction J_1 & J_2.

→ Drift region decides the voltage blocking capacity of device.

→ metal layer is used for connection between semiconducting device & terminals.

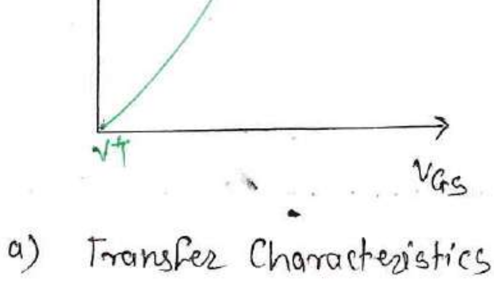
→ Now, D terminal is connected to +ve of supply & S is connected to -ve of supply, so J_1 is forward biased and J_2 is reverse biased.

→ Because of this depletion region will form in drift region. which does not allow to flow current from drain to source. i.e. $I_D = 0$

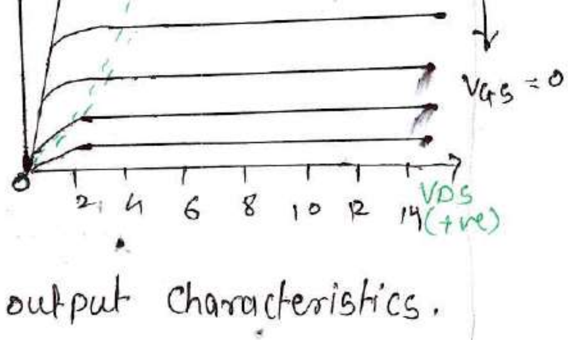
→ Now connect gate terminal to +ve terminal of battery and source to -ve terminal of battery i.e. V_{GS}.

→ If we continuosly increased V_{GS}, more lectrons will accumulate near gate. i.e. if V_{GS} is high then I_{DS} current is high. so, in this way, the power MOSFET will turn ON.

* V-I Characteristics of MOSFET :-



a) Transfer Characteristics



b) output Characteristics.

→ V.I Characteristics of MOSFET is as shown in fig. There are
1) Transfer Characteristics
2) Output characteristics.

→ Cut off region :- Cut off region is the region in which the MOSFET will be no current current flow through it. In this region MOSFET behaves like an open switch and is thus used when they are required to function as electronic switches.

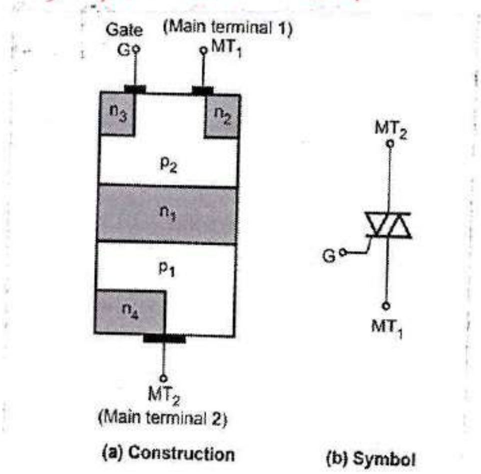
→ Ohmic Region :- It is the region where I_{DS} is increases with increase in value of VDS. When MOSFETs are made to operate in this region, they can be used as a amplifier.

→ Saturation Region :→ In this region, MOSFET have their I_{DS} constant inspite of increase in V_{DS}. Under this Condition, the device will act like a closed switch through which a saturated value of I_{DS} flows. As a result, this operating region is choosen whenever MOSFETS are required to perform switching operations.

* Applications of MOSFET :→

1) In ups.
2) Small Motor Control
3) Solar Inverters
4) Automotive applications.

1.6 - Triac :→ Construction, working principle, static V-I Characteristics & applications :-



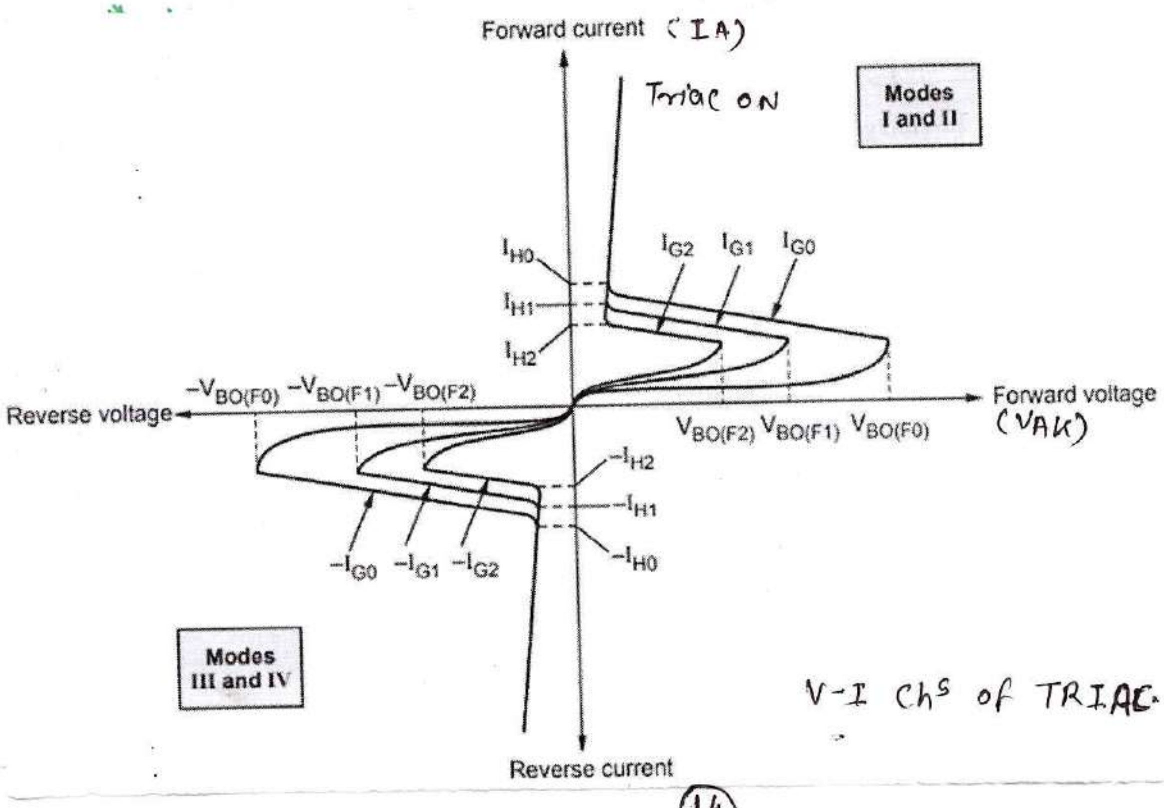
(a) Construction (b) Symbol

* Construction :-

- It is a bidirectional device and can conduct in both directions.
- The basic construction of a triac is as shown in fig. (a) & (b) shows symbol of triac.
- Triac conducts both ways Anode-Cathode terminology is not used. Two terminals are MT1 and MT2 while common terminal is called as Gate (G).
- The Triac can be turned ON by applying either a positive or negative voltage to the gate G with respect to the main terminal.

* Working :-

- when the gate terminal is open, the triac will block both the polarities of voltage across MT1 & MT2.
- If magnitude of voltage less than the breakover voltage, of device. That means triac will remains in OFF state.
- Mode - I
- MT2 is positive and Gate terminal is positive. Positive voltage at MT2 & gate terminal causes current flow from MT2 to MT1, so SCR1 is forward biased and SCR2 is reverse biased.
- As we increase gate current I_G triggering will get earlier.
- mode - 2 :- MT2 is -ve & MT1 is +ve.
- MT1 terminal has +ve voltage wrt. MT2., SO, SCR1 is reverse biased and has conduction properties.



V-I Ch^s of TRIAC.

* V-I Characteristics of Triac *

→ As seen from fig. characteristics of Triac same as that of two back to back connected SCR's.

→ With increase in gate current, the breakdown voltage decreases.

→ In triac the gate current can be positive or -ve. where as in SCR, the gate current can be only +ve.

→ The Triac characteristics can be ~~+ve~~ divided into 3 regions-

i) Blocking state (off state)

ii) Transition state (Unstable state)

iii) Conduction state (on state)

i) Forward blocking state :- (MT_2 +ve w.r.t. MT_1)
When forward voltage is less than the breakover voltage V_{BO} is applied with gate terminal open. The Triac can ~~be~~ successfully block the forward voltage without getting ON.

2) Reverse blocking state (MT_1 +ve w.r.t MT_2)
If reverse voltage < V_{BO} with gate open circuited, the triac will block the reverse voltage without getting turned ON.

3) Conduction or on state :-
Triac is bidirectional device that can conduct in positive as well as -ve half cycle of the supply voltage.

* Applications of Triac :-

1) In lamp dimmers.
2) Motor speed Control
3) Heating Control
4) AC Power Control.

Shirpur Education Soceity's

R. C. Patel College of Engineering and Polytechnic, Shirpur

Department of Electrical Engineering

QUESTION BANK/ASSIGNMENT -01

Course & Code: EE-3K

Name of Subject: Fundamentals of Power Electronics

Semester: Third

Subject Code: 313325

Que. No.	Unit 1 Power Electronics Devices (12 Marks)	Exam	Marks in Exam
1	Draw the symbol of IGBT and MOSFET.	S-22, W-24	2
2	Describe the constructional details of MOSFET with sketches.	S-22, W-24	4
3	Explain the modes of operation in TRIAC with quadrant diagram.	S-22	6
4	State the applications of power electronics.	S-23	2
5	Define forward break over voltage (VBO) of SCR.	S-23	2
6	Describe with sketch the construction of IGBT.	S-23	4
7	State any two applications of TRIAC	W-22	2
8	Draw symbol and characteristics of IGBT.	W-22	4
9	Compare SCR and TRIAC (any four points).	W-22, W-24, S-24	4
10	Draw V-I characteristics for: TRIAC.	W-24	2
11	Describe with neat sketch the constructional details of IGBT	W-24, S-24	4
12	State the applications of IGBT (any two).	S-24	2
13	Define: (i) Latching current (ii) Holding current	W-24	2
14	Draw and explain **V-I characteristics of SCR** and define the following terms: (i) Forward break over voltage (ii) Latching current (iii) Holding current & any two applications of SCR.	W-24, S-23, S-22, W-22, S-24	6
15	Draw the symbol and labelled V-I characteristics of following devices: (i) (ii) SCR TRIAC (iii) IGBT	W-24	6

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