Toppersnotes
Unleash the topper in you

JKSSB

Junior Engineer

Electrical

Jammu and Kashmir Services Selection Board (JKSSB)

Volume - 6

Power Electronics and Drives

SIERRA INNOVATIONS

Table of Content

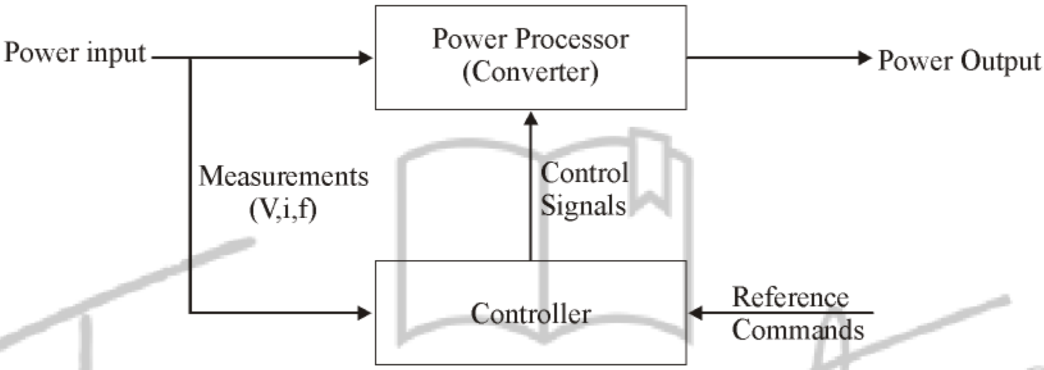
1 CHAPTER

Introduction to Power Electronics

THEORY

1.1 *INTRODUCTION TO POWER ELECTRONICS*

Power Electronics is used to change the characteristics (Voltage and current magnitude and frequency) of electrical power to suit a particular application. It is an interdisciplinary technology.



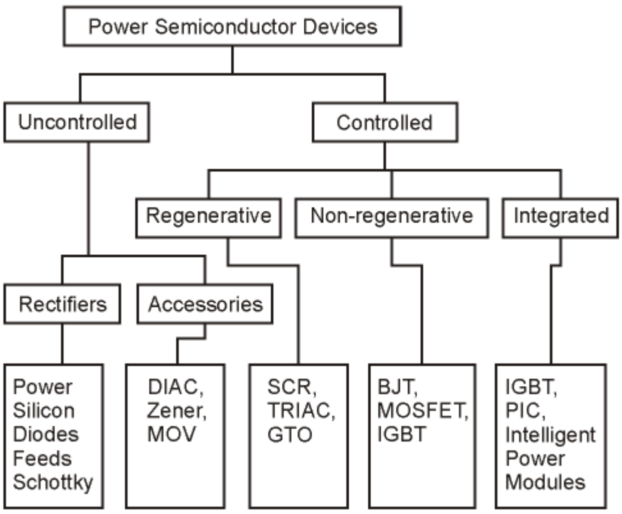
Power semiconductor devices can be categorized into three types based on their control input requirements:

(a) Current-driven devices: BJTs, GTOs.

(b) Voltage-driven devices: MOSFETs, IGBTs, MCTs.

(c) Pulse-driven devices: SCRs, TRIACs.

1.2 *POWER SECMICONDUCTOR DEVICE VARIETY*



1.3 *APPLICATIONS OF POWER ELECTRONICS*

1.3.1 Transportation

(i) Electric/Hybrid Electric Vehicles

(ii) Electric Locomotives

(ii) Electric Trucks, Buses, Construction Vehicles, Golf Carts.

1.3.2 Utilities

(i) Line transformers

(ii) Generating systems

(iii) Grid interface for alternative energy resources (Solar, wind, fuel cells, etc.) and energy storage.

(iv) FACTS

(v) HVDC

(vi) Solid state transformer

(vii)Solid state fault current limiter

(viii)Solid state circuit breaker

1.3.3 Industrial/Commercial

(i) Motor drive systems

(ii) Electric machinery and tools

(iii) Pumps/compressors

(iv) Process control

(v) Factory automation

1.3.4 Consumer Products

(i) Air conditioners/Heat pumps

(ii) Appliances

(iii) Computers

(iv) Lighting

(v) Telecommunications

(vi) Uninterruptible power supplies

(vii)Battery chargers

1.3.5 Utility Systems:

(i) High voltage DC transmission (HVDC)

(ii) Excitation Systems

(iii) VAR Compensation

(iv) Static circuit breakers

(v) Fans and boiler feed pumps

(vi) Supplementary energy systems (solar, wind)

1.3.6 Medical Equipment:

1.4 *DESIRABLE CHARACTERISTICS OF A POWER DEVICE*

(i) Small leakage current in off state.

(ii) Small on-state voltage drop to minimize conductive losses.

(iii) Short turn-on and turn-off times (high switching frequency.)

(iv) Large forward and reverse voltage blocking capability so, minimizes need to series several devices to enhance a blocking capability.

(v) High on-state current rating minimizes need to parallel devices.

1.5 *TYPES OF POWER CONVERSION*

(a) AC-DC converter (Rectifier) :

Converts input AC to variable magnitude DC, e.g. battery chargers, computer power supplies.

(b) AC-AC Converter (Cycloconverter and AC voltage Controller) :

Converts input AC to variable magnitude variable frequency AC, e.g. ship propulsion systems.

(c) DC-AC Converter (Inverter) :

Converts input DC to variable magnitude variable frequency AC, e.g. electric/hybrid electric traction drives.

(d) DC-DC converter (DC Chopper-Buck/Boost/Buck-Boost Converter)

Converts input DC to variable magnitude DC, e.g. voltage regulators.

(e) DC-DC converters (Switched Mode Power Supplies (SMPS))

Make up about 75% of power electronics industry.

(i) Power Supplies for Electronic Equipment

(ii) Robotics

(iii) Automotive/Transportation

(iv) Switching Power Amplifiers

(v) Photovoltaic Systems

(f) DC-AC-Inverter

(i) AC Machine Drive (permanent magnet, switched reluctance, or induction machine)

(ii) Uninterruptible Power Supply (UPS)

(iii) Machine Tools

(iv) Induction Heating-Steel Mills

(v) Locomotive Traction

(vi) Static Var Generation (Power Factor Correction)

(vii) Photovoltaic or Fuel Cell Interface with Utility

(g) AC-DC-rectifier

(i) DC Machine Drive

(ii) Input Stage to DC/DC or DC/AC Converter

(iii) Energy Storage Systems

(iv) Battery Chargers

(v) Aerospace Power Systems

(vi) Subways, Trolleys

(vii) High Voltage DC (HVDC) Transmission

(h) AC-AC Converters-Voltage Controller 1-ϕ to 3-ϕ Converters.

(i) Lighting/Heating Controls

(ii) Large Machine Drives

1.6 *POWER TRANSISTORS*

1. BJT
2. MOSFET
3. IGBT

1.6.1 *BJT*

- Bipolar device i.e. holes & electrons.
- Current controlled device.
- Low input impedance.
- Low ON-state voltage drop and lower conduction loss.
- Higher switching power losses.
- Secondary breakdown occur.
- Negative temperature coefficient because of negative temperature coefficient BJT are not advisable for parallel operation.
- Low conduction losses.
- Lower operating frequency (10 kHz).
- ON-state in saturation region.
- Controlled turn-on & turn-off device.
- Turn-on & Turn-off time depend on junction capacitances.
- Control signal requirement continuously.
- Ratings : 1400V, 400A, 10 kHz
- Switching period, $t_s = 50\mu$ sec-100μsec

1.6.2 *MOSFET*

- Unipolar device i.e. majority carrier device.
- Voltage controlled device.
- High input impedance.
- High-ON state voltage drop and higher conduction losses.
- Lower-switching power losses.
- Free from secondary breakdown.
- Positive temperature coefficient.
- Because of positive temperature coefficient, MOSFET are advisable for parallel operation.
- Higher conduction losses.
- Higher operating frequency (100 kHz).
- ON-operating in ohmic region.
- Control turn-on & turn-off device.
- Smaller turn-off time because it does not have minority carrier storage.
- Control signal requirement continuously.
- Ratings : 1000V; 50A, 100 kHz
- Switching period, $t_s = 1\mu$ sec

1.6.3 *IGBT*

- Bipolar device.
- Voltage controlled device.
- Three terminal device : Emitter, collector and gate.
- Low forward voltage drop.
- Low on-state power loss than MOSFET.
- Low conduction loss than MOSFET.
- Having characteristics of BJT & MOSFET.
- Controlled turned-on & turned-off devices.
- Control signal requirement continuously.
- High input impedances.
- Positive temperature coefficient.
- Secondary breakdown not occur.
- Used for parallel operation.
- Ratings : 1200V, 500A, 50 kHz.
- Switching period, t_s = 20μ sec.
- Two terminal, three layer device : power diode, DIAC.
- Majority carrier device : MOSFET, SIT.
- Bipolar device : Diode, BJT, IGBT, MCT.
- Unidirectional device : Diode, SCR, LASCR.
- Bidirectional device : TRIAC, DIAC, BJT.
- Negative pulse turn-on device : MCT.
- Negative pulse turn-off device : GTO.
- Controlled turn-on & off device : BJT, MOSFET, IGBT, SIT MCT.
- Continuous control signal : BJT, MOSFET, IGBT, SITH.
- Uncontrolled device : Diode, DIAC.
- Bistable switch : SCR.
- Bidirectional current device : TRIAC, RCT.
- Unidirectional current device : Diode, SCR, GTO, BJT, MOSFET, IGBT, SITH and MCT.

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PRACTICE SHEET

OBJECTIVE QUESTIONS

1. IGBT is used for applications in

(a) Low Power (b) Medium Power

(c) High Power (d) None of these

2. Which is the most suitable power device for high frequency (>100 kHz) switching application?

(a) Power MOSFET

(b) Bipolar junction transistor

(c) Schottky diode

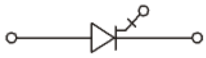
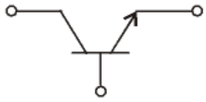
(d) Microwave transistor

3. Match List-I (Converters) with List-II (Type of Conversion) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Controlled Rectifier	**1.** Fixed DC to variable voltage and variable frequency AC
B. Chopper	**2.** Fixed DC to variable DC
C. Inverter	**3.** Fixed AC to variable DC
D. Cycloconverter	**4.** Fixed AC to variable frequency AC

Codes:	A	B	C	D
(a)	2	3	1	4
(b)	3	2	4	1
(c)	2	3	4	1
(d)	3	2	1	4

4. Match List-I (Power Electronic Devices) with List-II (Symbols) and select the correct answer using the codes given below the lists:

List-I	List-II
A. GTO thyristor	**1.** 
B. TRIAC	**2.** 
C. IGBT	**3.** 
D. BJT	**4.** 

Codes:	A	B	C	D
(a)	1	2	3	4
(b)	1	2	4	3
(c)	2	1	3	4
(d)	2	1	4	3

5. A gate-tum-off (GTO) thyristor

(a) requires a special turn-off circuit like a thyristor

(b) can be turned off by removing the gate pulse

(c) can be turned off by a negative current pulse at the gate

(d) can be turned off by a positive current pulse at the gate

6. The on-stage voltage of a GTO is

(a) 0.7 V (b) 1-2 V

(c) 2-3 V (d) >3

7. Match List-I (Power device) with List-II (Property) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Thyristor	**1.** Secondry breakdown
B. MOSFET	**2.** Large on-state drop
C. IGBT	**3.** Small on-state drop
D. BJT	**4.** Slow device

Codes:	**A**	**B**	**C**	**D**
(a)	4	3	2	1
(b)	1	2	3	4
(c)	4	2	3	1
(d)	3	1	2	4

8. Which one of the following statement is TRUE for an 'ideal' power diode?

(a) Forward voltage drop is zero and reverse saturation current is non zero

(b) Reverse recovery time is non-zero and reverse saturation current is zero

(c) Forward voltage drop is zero and reverse recovery time is zero

(d) Forward voltage drop is non-zero and reverse recovery time is zero

9. In a MOSFET, the pinch off voltage refers to

(a) drain to source voltage at which drain to source current is zero

(b) gate-to-source voltage at which gate-to-source current is zero

(c) drain-to-source voltage at which gate-to-source current is zero

(d) gate-to-source voltage at which drain-to-source current is zero

10. Which one of the following diodes contains a metal-semiconductor junction?

(a) Tunnel diode (b) Zener diode

(c) Schottky diode (d) Gunn diode

11 Resonant Converter's are basically used to

(a) Generate large peak voltage

(b) Reduce the switching losses

(c) Eliminate harmonics

(d) Convert a square wave into a sine wave

12. Which of them is a disadvantage of power converters over conventional switch.

(a) High efficiency

(b) small weight and good packaging

(c) high Reliability

(d) regeneration process is not easy .

13. Which of them is not characteristic of Ideal switch.

(a) Infinite current conduction capacity

(b) Zero on state voltage drop

(c) Infinite voltage blocking capacity

(d) Zero off state resistance

14. Which of them is not a fully controlled device

(a) Power MOSFET (b) IGBT.

(c) SCR. (d) GTO

15. Which one of them do not need continuous gate signal for triggering.

(a) MOSFET (b) IGBT

(c) SIT (d) GTO

16. Which of them needs +ve pulse for turn off process

(a) SCR (b) GTO

(c) IGCT (d) MCT.

17. Which of the device do not have control terminal.

(a) SCR (b) Power diode

(c) Power BJT (d) IGBT

18. Which of them is not disadvantage of power Electronic converters

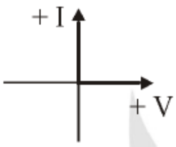
(a) they produce harmonics

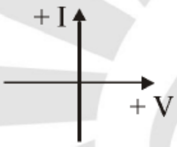
(b) they operate at low power factor

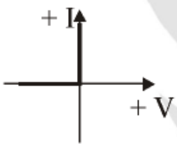
(c) they have high over load capacity

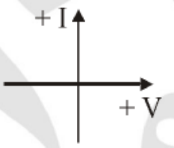
(d) Regeneration process is difficult

19. Which of them is correct VI characteristic of ideal switch

(a) 

(b) 

(c) 

(d) 

20. Low doping intensity is order of______in semi conductor layer.

(a) $10^{10} \sim 10^{11}$ doping/cm^3

(b) 10^{13-14} doping /cm^3

(c) 10^{16-17} doping/cm^3

(d) None of these

21. N^-layer is added in power diode so as to

(a) increase its conductivity

(b) increase its reverse blocking capacity

(c) Increase its switching speed

(d) None of these

22. On Increasing N^- layer in power diode

(a) switching speed decreases

(b) conduction loss decreases

(c) efficiency of device increases

(d) None of these.

23. P^-layer is not used generally in power electronic device because.

(a) Its switching time is better than N^-layer

(b) It offers more power loss than N^-layer

(c) hole mobility is less than e-mobility

(d) None of these.

24. One of the disadvantage of using N^-layer in PE devices

(a) Conduction losses are high

(b) Malfunctioning of control terminal increases

(c) Reliability of device decreases.

(d) None of these

25. The VI characteristic of power diode is linear because of

(a) N^-layer in diode

(b) N layer in diode

(c) e-mobility is higher than holes

(d) depletion layer is large

26. ON state voltage drop of power diode is

(a) 0.7 V (b) 0.3 V

(c) 1 V (d) 0.5 V

27. Which of these diodes have least turn on time:

(a) general purpose diode

(b) Fast recovery diode

(c) Schottky diode

(d) Diode used in rectifiers

28. Which is not an application of power diode

(a) Welding

(b) Traction

(c) Modulation circuit

(d) Battery charger

29. Which of the diode do not have a depletion layer in it

(a) Schottky diode

(b) general purpose diode

(c) fast recovery diode

(d) None of these

30. Which of them is not application of fast Recovery diode

(a) Induction heating

(b) Commutation circuits

(c) Electroplating

(d) SMPS.

31. Schottky diode has switching frequency of (Range)

(a) 10 kHz. (b) 200 kHZ

(c) 100 kHZ (d) 2000 kHZ.

32. During turn ON process of diode

(a) power factor is Low

(b) power factor is unity

(c) Power factor is leading

(d) None of these

33. For a Ideal diode

(a) reverse recovery time should be less

(b) reverse recovery time should be 0

(c) softness factor must be 0.

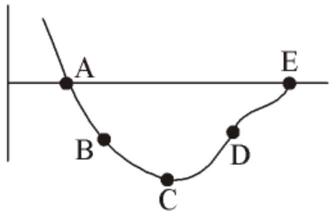
(d) softness factor must be 1.

34. Softness factor is defined as

(a) $\frac{t_b}{t_a}$ (b) $\frac{t_a}{t_b}$

(c) $\frac{t_a}{t_{rr}}$ (d) $\frac{t_b}{t_{rr}}$

35. For the given points in reverse Recovery characteristic of diode depletion layer is restored / replenished at point



(a) B (b) C

(c) D (d) E

36. In reverse recovery characteristic of diode, which is correct

(a) $t_a >> t_b$ (b) $t_{rr} \simeq t_b$

(c) $t_b >> t_a$ (d) None of these

37. Which of the relation is correct for reverse recovery of diode

(a) $I_{RM} = \left[\frac{Qrr}{di/dt}\right]^{\frac{1}{2}}$ (b) $I_{RM} = \left[\frac{2.Qrr}{di/dt}\right]^{\frac{1}{2}}$

(c) $I_{RM} = \left[\frac{Qrr}{2di/dt}\right]^{\frac{1}{2}}$ (d) None of these

38. If diode current is decaying at rate of 30 A/μsec and reverse recovery time is 3 μsec. Find I_{RM}

(a) 135 μA (b) 90 mA

(c) 90 A. (d) 135 mA.

39. Which of them is not a transistor

(a) IGBT (b) MOSFET

(c) SIT (d) MCT

40. Power transistor turns on when.

(a) $I_B > I_{BS.}$

(b) I_B =Leakage current (I_{CBO})

(c) $I_B < I_{BS}$

(d) None of these

41. Operating point on loadline characteristics of power BJT, operates on hard saturation line .when.

(a) $I_B = I_{BS}$ (b) $I_B < I_{BS}$

(c) $I_B = 2I_{BS}$ (d) $I_B = 4I_{BS}$

42. Primary Breakdown occur in power BJT. at

(a) $I_B = 0$; J_2 breaks

(b) $I_B = I_{BS}$; J_2 breaks

(c) $I_B = 0$; J_1 breaks

(d) $I_B = I_{BS}$; J_1 breaks

43. Secondary Breakdown occur in power BJT. Due to

(a) $I_B > I_{BS.}$

(b) $I_B < I_{BS}$

(c) heavy amount of electrons at J_2

(d) Thermal Runaway.

44. During storage time of BJT Switching characteristic

(a) Charge gets store in base

(b) Charge store in base are removed by recombination

(c) Charge store in all junctions gets removed by Removing load current

(d) Charge gets stored in all junctions.

45. For a power Electronic device, if N^- layer is increased then

(a) Switching frequency decrease

(b) More heat / conduction losses

(c) Gate drive circuit rating increases

(d) all of the above.

46. Which of them is not present during turn off process of BJT.

(a) Storage time (b) fall time

(c) decay time (d) None of the above

47. Why negative pulse is utilized in turn off process of BJT.

(a) If Negative pulse is not given, BJT do not gets turn off

(b) Negative pulse helps to turn off BJT early by clearing charges from base

(c) Negative pulse make the conduction current to flow in negative (opposite) direction.

(d) None of the above.

48. Which of the following is not an Application of MOSFET.

(a) Switch mode power supplies

(b) Buck - boost Regulator

(c) Inverter

(d) Electroplating in Industrial process.

49. Power MOSFET is a

(a) Three terminal device

(b) Three- four terminal device

(c) four terminal device

(d) None of the above.

50. Maximum operating frequency of a power MOSFET is

(a) 1 KHz (b) 10 KHz.

(c) 100 KHz. (d) 10000 KHz

51. Which of the terminology is related to MOSFET static characteristic.

(a) Saturation Region.

(b) Ohmic Region

(c) Quasi- Saturation

(d) Latch -up process.

52. Which of the following method is good to turn on process for power Electronic Device having Junction in it .

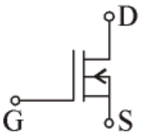
(a) Increasing operating voltage across power terminals.

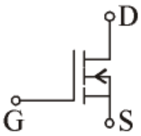
(b) Increasing no. of charges at depletion Region

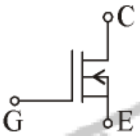
(c) Increasing temperature of depletion Region every time

(d) None of these

53. Which of the following is not a symbol of power MOSFET

(a) 

(b) 

(c) 

(d) None of these

54. Power MOSFET turns ON when gate to source voltage is about

(a) 0.7 V

(b) 1 Volt

(c) 2–3 V

(d) None of these.

55. As the p-type body terminal of N-channel MOSEFT is made more + ve Voltage:

(a) N- channel width increases

(b) N- channel width decreases

(c) N- channel width remains same.

(d) eliminates discharging effect of gate terminal

56. In power MOSFET, N - channel is completed at

(a) $V_{GS} = V_{GST}$

(b) $V_{GST} < V_{GS} < V_{GSP}$

(c) $V_{GS} = V_{GSP}$

(d) None of these

57. Choose the correct Statement about switching losses of device

(a) BJT > MOSFET > IGBT.

(b) BJT < MOSFET< IGBT.

(c) BJT > IGBT < MOSFET

(d) BJT > IGBT > MOSFET

58. Choose the correct statement about input resistance of device

(a) BJT > IGBT > MOSFET

(b) BJT > IGBT < MOSFET

(c) BJT < IGBT > MOSFET

(d) BJT < IGBT < MOSFET

59. Choose the correct statement about conduction losses of devices

(a) BJT > IGBT > MOSFET

(b) BJT > IGBT < MOSFET

(c) BJT < IGBT > MOSFET

(d) BJT < IGBT < MOSFET

60. Match the correct characteristic of devices.

(1) MOSFET	(A) Latch -Up Problem.
(2) BJT	(b) Electric Discharge problem
(3) IGBT	(c) Secondary Break down

(a) 1 – B, 2 – C, 3– A

(b) 1 – B, 2 – A, 3– C

(c) 1 – A, 2 – C, 3– B

(d) 1 – A, 2 – B, 3–C

61. IGBT has which of the Applications ?

(a) AC and DC Drives

(b) UPS systems and power supplies

(c) Drives for relay and contactors

(d) All of the Above

62. Which of the IGBT combination is correct :

(a) N – channel MOSFET + PNP BJT

(b) N – channel MOSFET + NPN BJT

(c) P– Channel MOSFET + PNP BJT

(d) None of these

63. IGBT looses its gate control when

(a) e – current flows through MOSFET and PNP BJT

(b) e – current flows through MOSFET and NPN BJT

(c) e- current flows through NPN BJT and PNP BJT

(d) e– current flows through PNP BJT and Body Region.

64. If collector Current in IGBT increases beyond its rated value then

(a) IGBT Gets damage instantly

(b) IGBT behaves as SCR

(c) IGBT behaves as BJT

(d) IGBT behaves as MOSFET

65. IGBT starts conducting when gate to emitter voltage is

(a) 0.7 V.

(b) 1 Volt

(c) 2–3 V

(d) None of these

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ANSWERS AND EXPLANATIONS

1. *Ans. (b)*

   IGBT is power semiconductor switch. It works at medium power leve.

2. *Ans. (a)*

3. *Ans. (d)*

   Controlled rectifier : fixed A.C. to pulsating (variable) D.C.

   Chopper : Fixed D.C. to variable D.C.

   Inverter : Fixed DC to variable voltage and variable frequency A.C.

   Cycloconuerter : Fixed AC to variable frequency A.C.

4. *Ans. (b)*
5. *Ans. (c)*
6. *Ans. (c)*
7. *Ans. (c)*
8. *Ans. (c)*
9. *Ans. (d)*
10. *Ans. (c)*
11. *Ans. (b)*
12. *Ans. (d)*
13. *Ans. (d)*
14. *Ans. (c)*
15. *Ans. (d)*
16. *Ans. (d)*
17. *Ans. (b)*
18. *Ans. (c)*
19. *Ans. (c)*
20. *Ans. (b)*
21. *Ans. (b)*
22. *Ans. (a)*
23. *Ans. (c)*
24. *Ans. (a)*
25. *Ans. (a)*
26. *Ans. (c)*
27. *Ans. (c)*
28. *Ans. (c)*
29. *Ans. (a)*
30. *Ans. (b)*
31. *Ans. (d)*
32. *Ans. (a)*
33. *Ans. (b)*
34. *Ans. (a)*
35. *Ans. (b)*
36. *Ans. (a)*
37. *Ans. (b)*
38. *Ans. (c)*
39. *Ans. (d)*
40. *Ans. (a)*
41. *Ans. (d)*
42. *Ans. (c)*
43. *Ans. (d)*
44. *Ans. (b)*
45. *Ans. (d)*
46. *Ans. (c)*
47. *Ans. (b)*
48. *Ans. (d)*
49. *Ans. (b)*
50. *Ans. (d)*
51. *Ans. (b)*
52. *Ans. (b)*
53. *Ans. (c)*
54. *Ans. (c)*
55. *Ans. (b)*
56. *Ans. (c)*
57. *Ans. (d)*
58. *Ans. (d)*
59. *Ans. (d)*
60. *Ans. (a)*
61. *Ans. (d)*
62. *Ans. (a)*
63. *Ans. (c)*
64. *Ans. (b)*
65. *Ans. (c)*

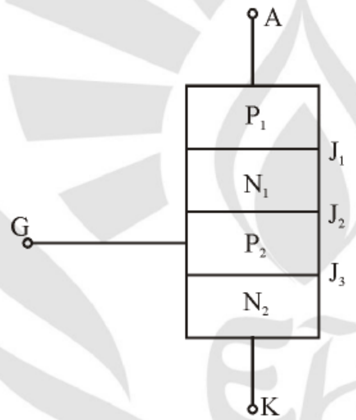
❑❑❑

2 CHAPTER
SCR

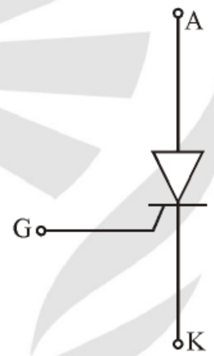
THEORY

2.1 *INTRODUCTION*

Thyristor (SCR) is 4 layer, 3 p-n junction, charge controlled semi conductor device. It has three terminals called Gate(G), Anode (A) and Cathode (K).Inner two layers of SCR are lightly doped so that the strength of junction J_2 is more than the strength of junctions of J_1 and J_3. SCRs are used up to 3000 A and Voltage up to 10 kV.



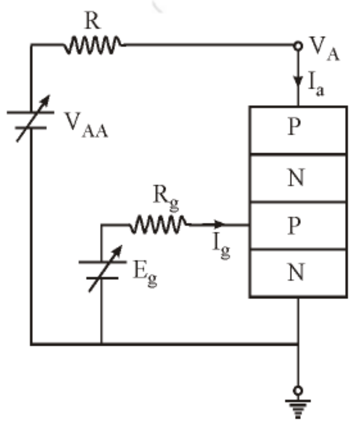
Layer Diagram

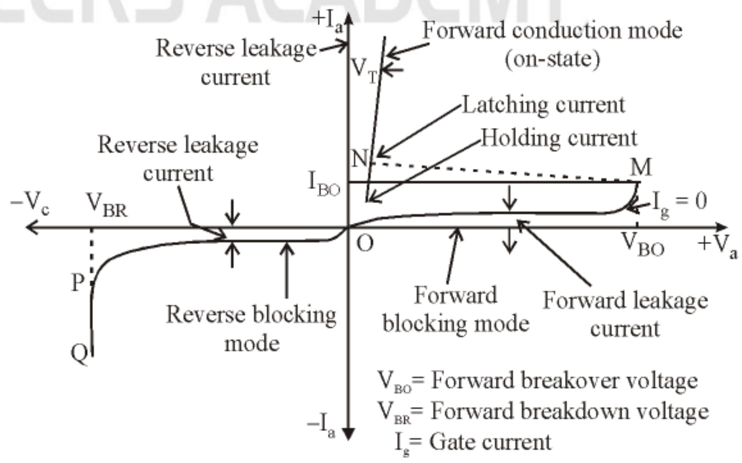


Symbol

Outer layers are heavily doped as Compared to inner layers.

2.2 *I-V CHARACTERISTICS*





2.2.1 Forward Blocking Mode :

In this mode of operation SCR is applied with positive anode voltage. The junctions J_1 and J_3 are in forward bias and J_2 is reverse bias and the device is in off state. The device remains in this mode until the anode voltage reaches a critical value called forward break over voltage (V_{FBO}).

2.2.2 Forward Conducting Mode :

When the anode voltage is greater than the forward break over voltage then avalanche break down occurs at Junction J_2 and the device starts conducting.In forward conduction mode SCR behaves like a closed switch. SCR start conducting only if the current through the device is greater than a minimum current called latching current during the turning ON process.

3.2.3 Reverse Blocking State :

When the anode voltage is negative, the junctions J_1 and J_3 are in reverse bias and junction J_2 is in forward bias, the device is in off state and this region of characteristic curve is called reverse blocking state. When the reverse voltage becomes more than V_{RBO} then avalanche break down occurs at reverse bias junctions J_1 and J_3 and the device start conducting in reverse direction.

2.2.4 Latching Current :

It is the minimum anode current required to turn on the SCR during turning on process. Latch current is related to turn on process where as the holding current is related to turn off process because when the junction J_2 breaks down then large number of carriers are generated. So, the large current starts flowing, this current is latch current.

2.2.5 Holding Current :

When the device is already in conducting state and if the anode current is reduced below a minimum level, the device gets turn off. This minimum current required to turn off device is called holding current. The holding current is therefore related to the turn off process. The holding current is always less than the latch current because current continues to flow even below latch current due to charges stored in layers.

Now to turn off the device the current has to be reduced till all the carriers are after re-combination anode current will be less than holding current.

Note: $V_{RBO} > V_{FBO}$, $I_L > I_H$ $\frac{I_L}{I_H} \approx 3$

2.2.6 Forward Break Over Voltage :

It is the critical voltage required for breakdown of junction J_2 under forward biased condition. It is minimum voltage to be applied across the device for turn ON the device cut out gate signal.

When anode voltage becomes equal to forward break over voltage the junction J_2 breaks down due to Avalanche multiplication and the device start conducting.The forward break over voltage can be reduced by applying a positive pulse at gate terminals. When the gate current increases, the forward break over voltage decreases.

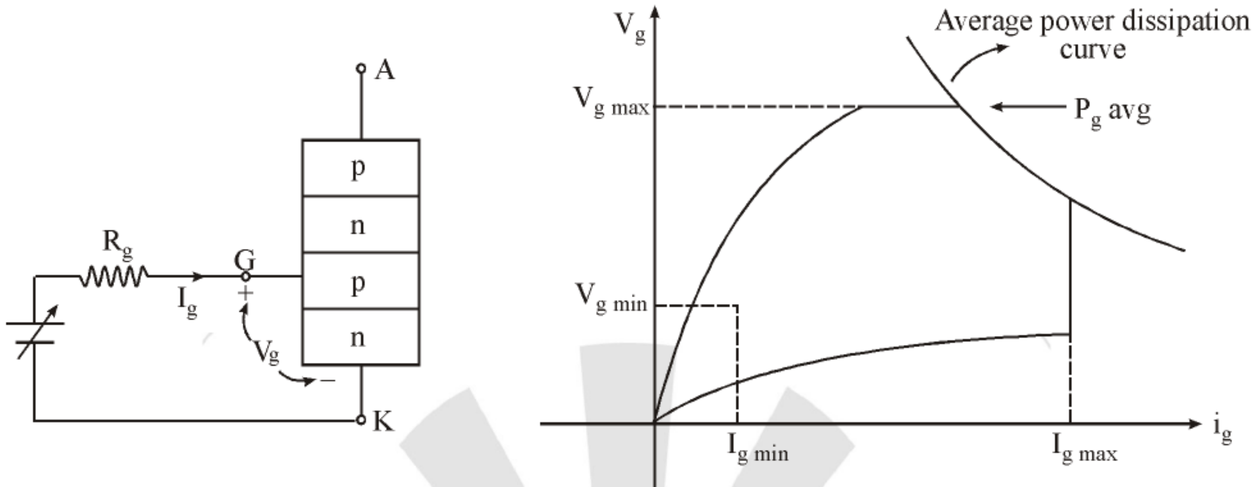
2.2.7 Zener Break Down :

Depends on voltage and dopping level. both layers must be highly dopped, small voltage is required for break down. It is electrostatic breakdown.

2.2.8 Avalanche Break Down :

It occurs due to thermal effect or temperature. It occurs in lightly doped semiconductor junctions.

2.2.9 Gate Characteristic :



Gate Characteristic

Where I_{gmax} = Maximum gate current allowed

V_{gmax} = Maximum gate voltage

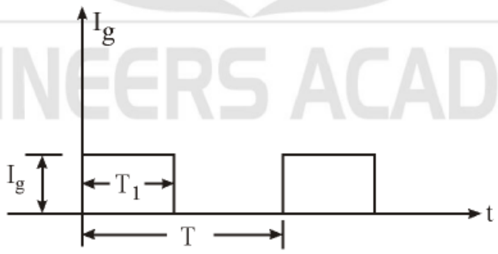
V_{gmin} = Minimum gate voltage

I_{gmin} = Minimum gate current

V_{gmin} and I_{gmin} are decided by satisfactory turning off of the device.

For the satisfactory turning on, the operating point of gate characteristic should always lie nearest to P_{avg} curve.

The turn on time of the thyristor can be reduced by increasing the amplitude of gate current and power dissipation can be reduced by reducing the period of gate pulse in pulse triggering the thyristor remains in on state even if gate current is reduced to zero once it turned ON by pulse triggering.

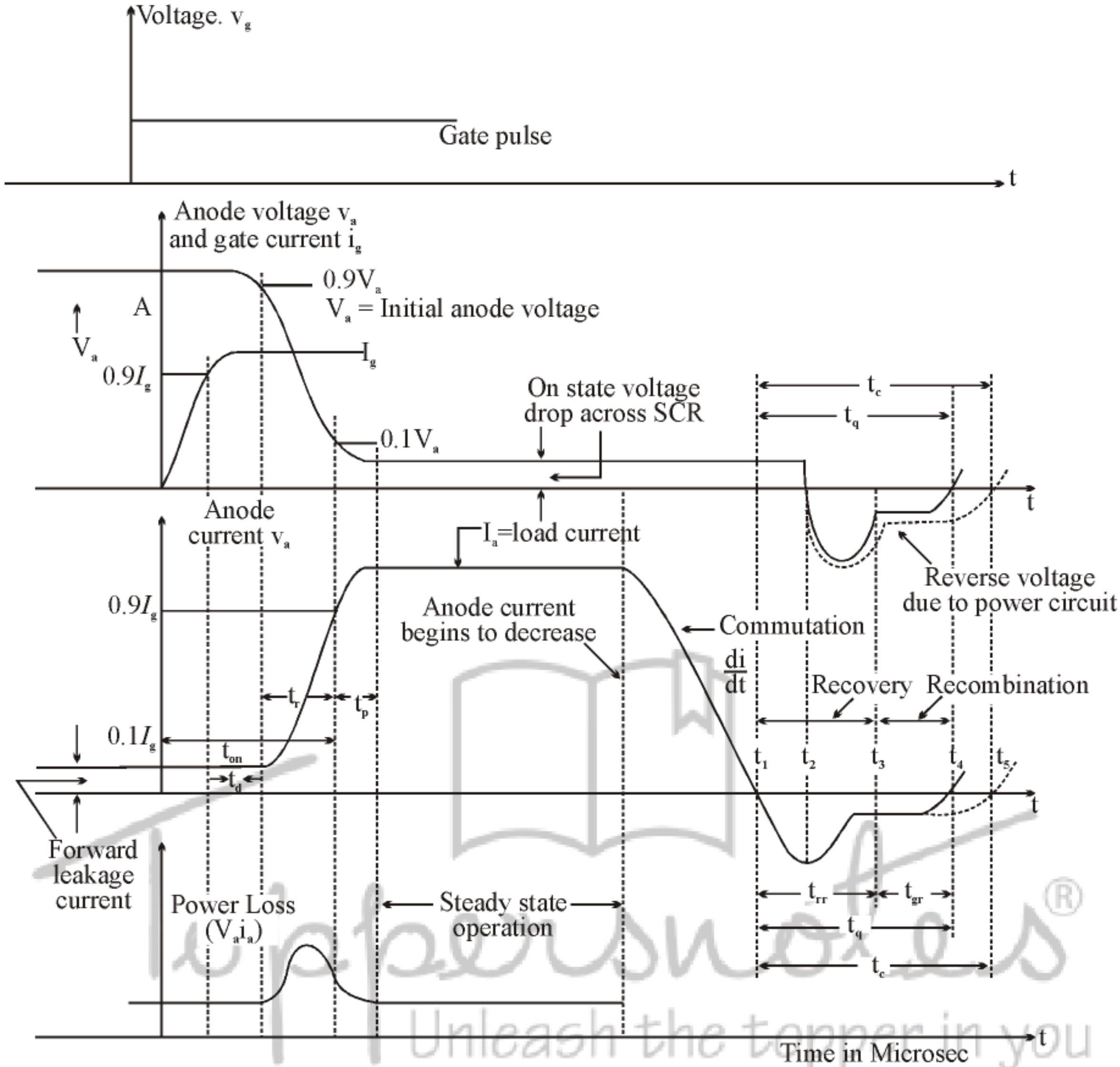


$$d = \text{duty cycle} = \frac{T_1}{T}$$

$$\frac{I_{g\,avg}}{\delta} \leq I_{gm} \qquad \text{(more power dissipation in gate)}$$

$\delta = f\ T_1$ There f is the frequency of firing or triggering pulse

2.3 *SWITCHING CHARACTERISTICS OF SCR*



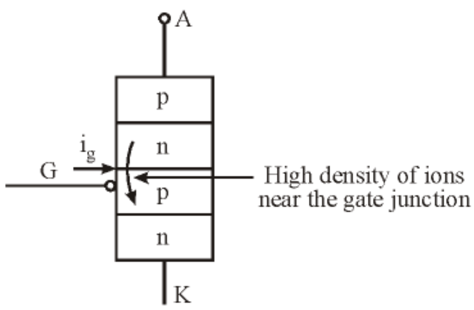
SCR Voltage and current waveforms during turn-on and turn-off processes.

2.3.1 *TURN ON TIME*

Delay time (t_d) : Time taken to rise the i_a from 0% to 10% of full load current, when the gate pulse is applied.

Rise time (t_r) : Time taken to rise the i_a from 10% to 90% of full load current.

Spread time (t_P) : Time taken to rise the i_a from 90% to full load current or it is time taken to spread the conducting channel (conduction) through out the junction.Once the device has turn on.



2.3.2 TURN OFF TIME

t_{rr} = reverse recovery time

t_{gr} = gate recovery time

t_q = turn off time

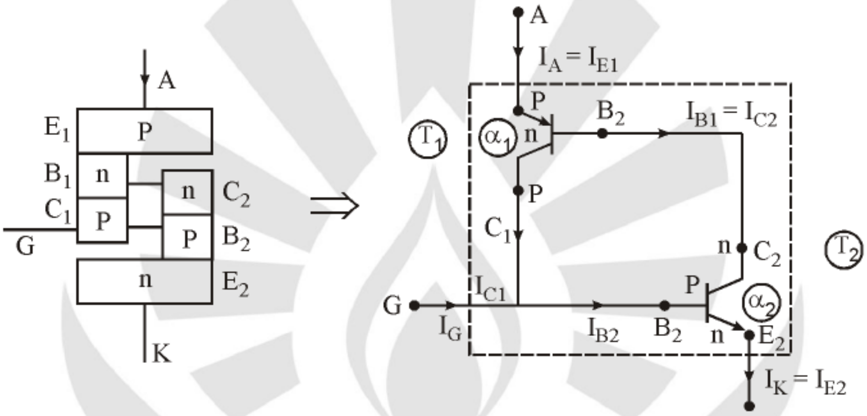
$t_q = t_{rr} + t_{gr}$

Turn off time is the time taken by the SCR to regain its forward blocking capability after the anode current is reduced to zero.

Losses in the SCR are maximum during turning on and turning off process.

Note : *for the proper operation of SCR the circuit turn off time must be greater than the thyristor turn off time.*

2.4 *TWO TRANSISTOR MODEL*



When Devices is conducting then :

$$I_{C1} = \alpha_1 I_{E1} + I_{CBO1}$$

$$\Rightarrow \quad I_{C1} = \alpha_1 I_A + I_{CBO1} \quad \ldots(i)$$

$$I_{C2} = \alpha_2 I_{E2} + I_{CBO2}$$

$$\Rightarrow \quad I_{C2} = \alpha_2 I_k + I_{CBO2} = I_{B1} \quad \ldots(ii)$$

$$I_{B1} + I_{C1} = I_{E1}$$

$$I_{B1} = I_{E1} - I_{C1} \quad \text{[From (ii)]}$$

$$I_{B1} = I_A - [\alpha_2 I_A + I_{CBO1}]$$

$$= I_{C2} = \alpha_2 I_k + I_{CBO2}$$

$$\Rightarrow \quad I_A - [\alpha_2 I_A + I_{CBO1}] = \alpha_2 I_k + I_{CBO2}$$

$$I_A - \alpha_2 I_A - \alpha_2 I_k = I_{CBO1} + I_{CBO2} \quad \ldots(iii)$$

also $\quad I_k = I_A + I_G$

Putting I_A in equation (iii),