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POWER ELECTRONICS

For

ELECTRICAL ENGINEERING

POWER ELECTRONICS

SYLLABUS

Semiconductor power diodes, transistors, thyristors, triacs, GTOs, MOSFETs and IGBTs – static characteristics and principles of operation; triggering circuits; phase control rectifiers; bridge converters – fully controlled and half controlled; principles of choppers and inverters; basis concepts of adjustable speed dc and ac drives.

ANALYSIS OF GATE PAPERS

Exam Year	1 Mark Ques.	2 Mark Ques.	Total
2003	3	4	11
2004	4	6	16
2005	3	5	13
2006	1	8	17
2007	4	7	18
2008	2	6	14
2009	1	4	9
2010	2	-	2
2011	2	3	8
2012	2	3	8
2013	-	7	14
2014 Set-1	2	3	8
2014 Set-2	1	3	7
2014 Set-3	-	3	6
2015 Set-1	2	3	8
2015 Set-2	2	3	8
2016 Set-1	2	4	10
2016 Set-2	3	4	11
2017 Set-1	2	2	6
2017 Set-2	4	3	10

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1 POWER SEMICONDUCTOR DEVICES

1.1 INTRODUCTION

Power electronics is a branch of engineering that combines the fields of electrical power, electronics, and control. It started with the introduction of the mercury are rectifier in 1900. The grid controlled vacuum tube rectifier, ignitron, and thyratron followed later. These found extensive application in industrial power control till 1950. In the meanwhile the invention of the transistor – a semiconductor device- in 1948 marked a revolution in the field of electronics. It also paved the way for the introduction of the silicon controlled rectifier (SCR), which was announced in 1957 by the General Electric Company. In due course it has come to be named as the 'thyristor'.

1.1.1 ADVANTAGES OF POWER ELECTRONICS

1. High efficiency because of low 'ON state' conduction losses when the power semiconductor is conducting and low 'OFF state' leakage when it is blocking the source voltage
2. Reduced maintenance
3. Long life
4. Compactness because of the facility of assembling the thyristors, diodes, and RLC elements in a common package
5. Faster dynamic response as compared to electromechanical equipment
6. Lower acoustic noise as compared to electromagnetic controllers.

1.1.2 DISADVANTAGES

1. They generate harmonics which adversely affect the loads connected to them and also get injected into the supply lines
2. Controlled rectifiers operate at low power factors and cause derating of the associated rectifier transformers
3. They do not have a short-time overload capacity. However, as their advantages outnumber their demerits, they are widely used in the various applications detailed above. They have also replaced conventional controllers.

1.1.3 APPLICATIONS OF POWER ELECTRONICS

1. **Aerospace:** Space shuttle power supplies, satellite power supplies, aircraft power systems.
2. **Commercial**: Advertising, heating, air conditioning, central refrigeration, computer and office equipment, uninterruptible power supplies, elevators, light dimmers and flashers.
3. **Industrial**: Arc and industrial furnaces, blowers & fans, pumps & compressors, industrial lasers, transformer-tap changers, rolling mills, textile mills, excavators, cement mills, welding.
4. **Residential:** Air conditioning, cooking, lighting, space heating, refrigerators, electric-door openers, dryers, fans, personal computers, other entertainment equipment, vacuum cleaners, washing and sewing machines, light dimmers, food mixers, electric blankets, food-warmer trays.
5. **Telecommunication:** Battery chargers, power supplies (dc and UPS)
6. **Transportation:** Battery chargers, traction control of electric vehicles, electric locomotives, street cars, trolley buses, subways and automotive electronics.
7. **Utility systems**: High voltage dc transmission (HVDC), excitation systems VAR compensation, static

circuit breakers, fans and boiler-feed pumps, supplementary energy systems (solar, wind)

1.1.4 CONTROLLED SWITCHES

Turn on and Turn off by the application of control signals. BJT, MOSFET, GTO, SITH, IGBT, SIT, MCT

- SCR, GTO, SITH & MCT require pulse gate signal for turning them on
- BJT, MOSFET, IGBT, SIT require continuous signal for keeping them in turn on state
- The devices which can with stand unipolar voltage are BJT, MOSFET, IGBT, MCT
- Thyristors and GTOs are capable for supporting bipolar voltages.
- Triac and RCT (Reverse Conducting Theory) possess bidirectional current capabilityDiode, SCR, GTO, BJT, MOSFET, IGBT, SIT, SITH, MCT are unidirectional current devices

1.2 DIODES & TRANSISTORS

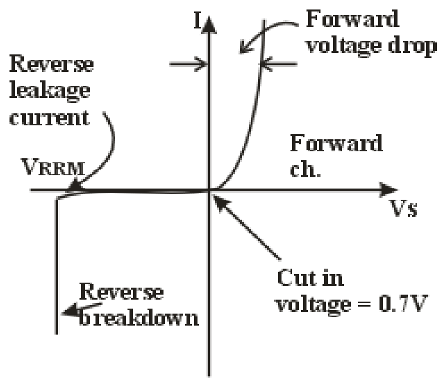
1.2.1 POWER DIODES

Power semiconductors devices are more complex in structure and in operation. Low power devices must be modified in order to make them suitable for high power applications. Power diodes are constructed with **n**$^-$ layer called drift region, because p^+ layer (anode) and n^+ layer (cathode). This is done to support large blocking voltages. Power devices operate at lower switching speeds whereas signal diodes and transistors operate at higher switching speeds.

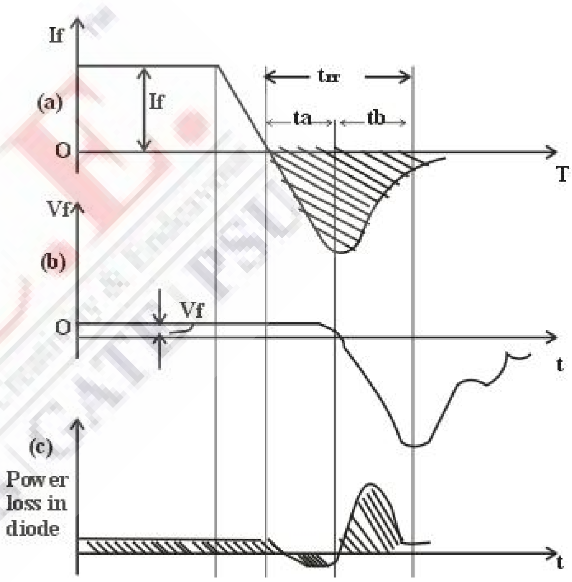
Applications:

1) As freewheeling diodes
2) For recovery of trapped energy

Static Characteristic of power diodes



1.2.2 DIODE REVERSE RECOVERY CHARACTERISTIC (Dynamic Characteristics)



Diode continuous to conduct in the reverse direction because of the presence of storage changes in the two layers (t_{rr}). The diode regains its blocking capability until reverse recovery current decays to zero.

The ratio of t_b/t_a is called the softness factor or s-factor show the voltage transient, that occur during the time diode recovers

s=1 low oscillatory reverse recovery process.

s small → diode has large oscillatory over volt

s=1 soft recovery diode

s<1 snappy recovery diode/ or fast recovery diode.

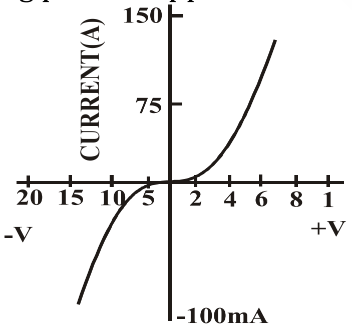
Peak inverse current $I_{RM} = t_a\, di/dt$

1.2.3 TYPES OF POWER DIODES

1. **General Purpose Diodes**
   Higher reverse recovery time t_{rr} (25 µs), Current rating1A to 1000A,Voltage rating 50V to 5KV
   Applications:
   Battery charging
   Electric traction
   Electro plating
   Welding
   UPS

2. **Fast recovery diodes**
   t_{rr} = 5µs or less, Voltage : 50V to 3KVolt, 1A to K amp.
   In order to shorten the reverse recovery time platinum or gold doping is carried outbut this doping is carried out → increase forward drop in diode
   Applications:
   Chopper
   Commutator circuits
   Switching mode power supply (SMPS)
   Induction heating

3. **Schottky diodes**
   This class of diodes use metal to semiconductor junction for rectification purposes instead of pn-junction. Fast recovery time. Low forward volt drop, 1A to 300A current.
   Application:
   High frequency instruments
   Switching power supplies



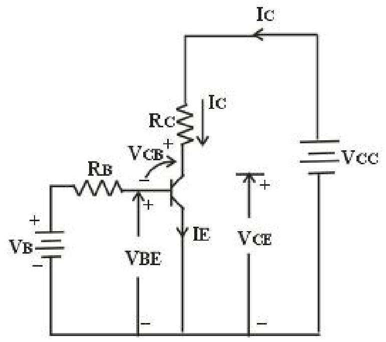
In a Schottky diode, only electrons participate in the conduction mechanism unlike in p-n junction diodes because there are no holes in the metal. As a result, there is no minority carrier storage decreasing the recovery time as in a junction diode. The reverse voltage of a Schottky diode is limited by its structure. It is designed to minimize the forward voltage drop necessitating extremely low contact resistance. The high resistivity epitaxial layer is sufficiently thin to reduce the series resistance.

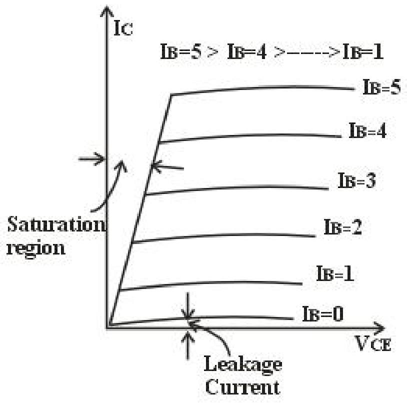
Device	Recovery Time
Schottky diode	150 µs
Alloyed p-n junction	5 µs
Diffused p-n junction	3 µs
Fast recovery p-n junction	1 µs

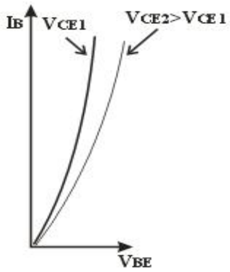
1.2.4 POWER TRANSISTORS TYPES

1. Bipolar junction Transistors (BJTs)
2. Metal-oxide semiconductor FET (MOSFET)
3. Insulated Gate Transistors (IGBTs)
4. static induction transistors (SIT)

1) **Bipolar junction Transistors (BJTs)**
   Three layers, two junctions pnp/ npn, current control device,
   bipolar→current flow in it is due to moment of both holes and electrons.
   Arrow indicate the direction of current.
   Steady state characteristics







Input characteristics: In between input current I_B and base –emitter voltage V_{BE}.

Output characteristics: The graph between I_C and collector meter voltage V_{CE}.

$I_c = \frac{V_{CC} - V_{CE}}{R_C}$ $\alpha = \frac{I_C}{I_E}$ value of α varies from 0.95 to 0.99

$\beta = \frac{I_C}{I_B}$ value of varies from 50 to 300

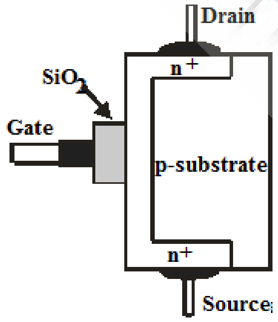
$\beta = h_{FE} = \frac{I_C}{I_B}$, $I_E = I_C + I_B$

$\beta = \frac{\alpha}{(1-\alpha)}$, $\alpha = \frac{\beta}{\beta + 1}$

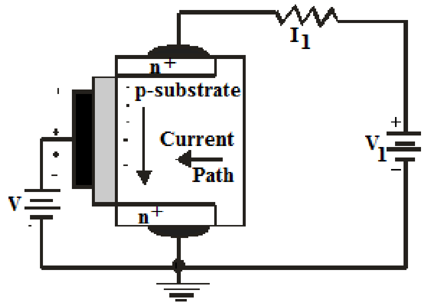
2) Metal- oxidesemiconductor FET (MOSFETs)

voltage control, Low control signal

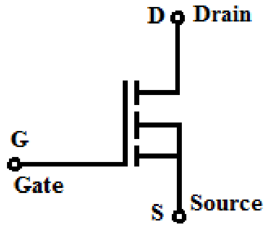
Gate circuit impedance of MOSFET is extremely high



(A) Basic Construction



(B) Induced Channel

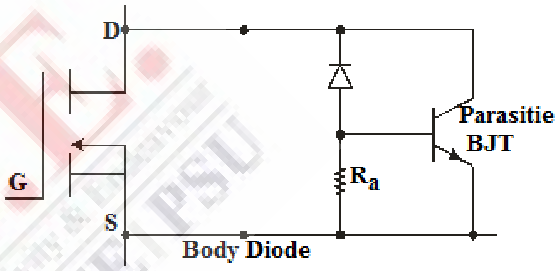


Two Types:

1. n-channel enhancement
2. p-channel enhancement

n-channel enhancement MOSFET is more common because of higher mobility of electrons (SiO_2) insulating layer.

Equivalent Circuit of Power MOSFET



Equivalent circuit of power MOSFET

The above discussed major performance advantages of power MOSFET over bipolar transistors can be summarized in tabular form as:

Power BJT	Power MOSFET
1. BJT is a minority as well as majority carrier device	1. MOSFET is a majority carrier device.
2. BJT is a current controlled device.	2. MOSFET is a voltage controlled device.
3. BJT has negative temperature coefficient.	3. MOSFET has positive temperature coefficient.
4. BJT cannot operate at very high frequency.	4. MOSFET can operate at higher frequencies.
5. BJT has different shapes for the FBSOA and RBSOA.	5. FBSOA and RBSOA are identical.
6. Second breakdown can take-place	6. No possibility of second breakdown.
7. Peak-current capability is less than that of MOSFET.	7. Peak current capability of MOSFET is higher than that of BJT.

8. BJTs are less sensitive to voltage spikes than MOSFETs.	8. MOSFETs are more sensitive to voltage spikes than BJT.
9. The on-state voltage is lower than that of power-MOSFET. Therefore, the on-state loss is lower.	9. The on-state voltage is higher than that of power BJT.
10. Conduction losses of a BJT are less than that of MOSFET.	10. Conduction losses of a MOSFET are greater than BJT.
11. Switching losses are more.	11. Switching losses are less.
12. More energy efficient at low frequency	12. More energy efficient at high frequency.

3) **Insulated Gate Transistors (IGBTs):** IGBT has been developed by combining into it the best qualities of both BJT and PMOSFET. Thus an IGBT possesses high input impedance like a PMOSFET and has low on-state power loss as in a BJT. Further, IGBT is free from second breakdown problem present in BJT. All these merits have made IGBT very popular amongst power-electronics engineers.

Comparison of IGBT and MOSFET

MOSFETs	IGBTs
1. In the power MOSFET, the decrease in the electron mobility with increasing temperature results in a rapid increase in the on-state resistance of the channel and hence the on-state drop.	1. In IGBTs, this increase in voltage drop is very small.
2. The on-state voltage drop increases by a factor of 3 between room temperature and 200^{o}C	2. Here with the identical condition, the increment in the on-state voltage drop is very small
3. All highest temperature, maximum current rating goes down to 1/3 value.	3. At high ambient temperature; IGBT is extraordinarily well suited.
4. Current sharing in multiple paralleled MOSFETs is comparatively poor than IGBTs.	4. Current sharing in multiple paralleled IGBTs is far better than power MOSFET.
5. The turn-on transients are identical to IGBTs.	5. Turn-on transients are identical to MOSFETs.
6. Power MOSFETs is suited for application that require low blocking voltage and high operating frequencies.	6. IGBT is the preferred device for applications that require high blocking voltages and lower operating frequencies.

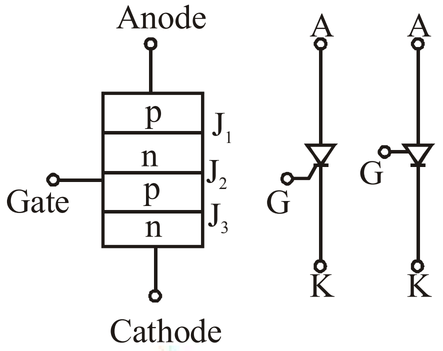
Application of IGBTs

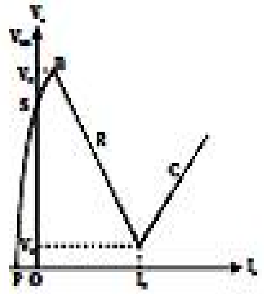
IGBTs are widely used in medium power application such as dc and ac motor drives, UPS systems, Power supplies and drives for solenoids, relays and contactors. Though IGBTs are somewhat more expensive than BJTs, yet they are becoming popular because of lower gate-drive requirements, lower switching losses and smaller snubber circuit requirements. IGBT converters are more efficient with less size as well as cost, as compared to converters based on BJTs. Recently, IGBT iverter induction-motor drives using 15-20 kHz switching frequency are finding favour where audio-noise is objectionable. In most application, IGBTs will eventually push out BJTs. At present, the state of the art IGBTs of 1200 V, 500 A ratings 0.25 to 20 μ s turn-off time with operating frequency upto 50 KHz available.

4) **PUT (Programmable Unifunction Transistor):** The characteristic of PUT and UJT are similar, the peak and valley currents of the PUT are typically lower than those of the UJT of a similar rating.

1.3 THYRISTORS

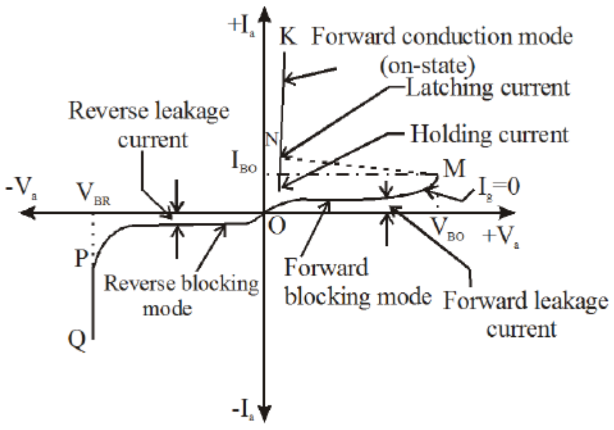
Bell Laboratories were the first to fabricate a silicon-based semiconductor device called thyristor. Semiconductor devices, with their characteristics identical with that of a thyristor, are triac, diac, silicon-controlled switch, programmable unijunction transistor (PUT), GTO, RCT etc. This whole family of semiconductor devices is given the name thyristor. Thus the term thyristor denotes a family of semiconductor devices used for power control in dc and ac systems.





A thyristor has characteristics similar to a thyratron tube. A thyristor (a pnpn device) belongs to transistor (pnp or npn device) family. The name 'thyristor', is derived by a combination of the capital letters from THYRatron and transISTOR.
An SCR is so called because silicon is used for its construction and its operation as a rectifier can be controlled. A thyristor also blocks the current flow from anode to cathode until it is triggered into conduction by a proper gate signal between gate and cathode terminals.

1.3.1 STATIC I-V CHARACTERISTICS OF A THYRISTOR



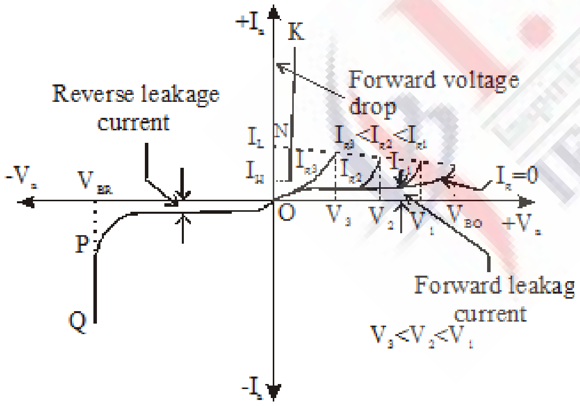
Forward blocking mode: Junctions J_1, J_3 are forward biased but junction J_2 is reverse biased. In this mode, a small current, called forward leakage current. SCR offers a high impedance. Therefore, a thyristor can be treated as an open switch.

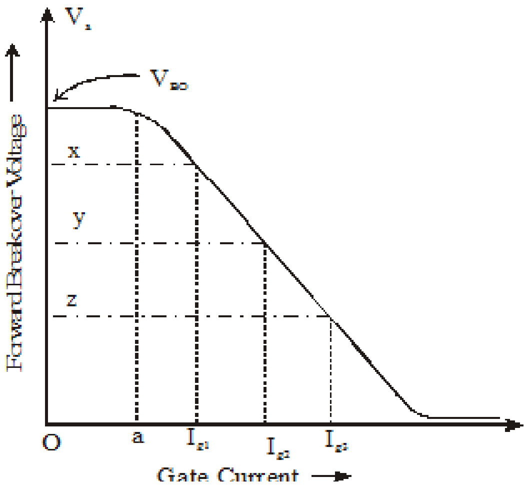
Forward conduction mode: Reverse biased junction J_2 will have an avalanche breakdown at a voltage called forward breakover voltage V_{BO}. A thyristor can be brought from forward blocking mode to forward conduction mode by turning it on by applying (i) a positive gate pulse between gate and cathode or (ii) a forward breakover voltage across anode and cathode.

1.3.2 THYRISTOR TURN-ON METHODS

1. **Forward voltage triggering:** Depletion layer is formed across junction J_2. The width of this layer decreases with an increase in anode-cathode voltage. Anode-cathode is gradually increased, depletion layer across J_2 vanishes. At this moment, reverse biased junction J_2 is said to have avalanche breakdown and the voltage at which it occurs is called forward breakover voltage V_{BO}. as a result, large forward anode-current flows. As stated before this forward current is limited by the load impedance.
The magnitudes of forward breakover and reverse breakdown voltages are nearly the same and both are temperature dependent. In practice, it is found that V_{BR} is slightly more than V_{BO}. Therefore, forward breakover voltage is taken as the final voltage rating of the device during the design of SCR applications.
After the avalanche breakdown, junction J_2 loses its reverse blocking capability. Therefore, if the anode voltage is reduced below V_{BO} SCR will continue conduction of the current. The SCR can now be turned off only by reducing the anode current below a certain value called holding current

2. **Gate Triggering:** Turning on of thyristors by gate triggering is simple, reliable and efficient; it is therefore the most usual method of firing the forward biased SCRs. A thyristor with forward breakover voltage (say 800 V) higher than the normal working voltage (say 400 V) is chosen.
When positive gate current is applied, gate p layer is flooded with electrons from the cathode. This is because cathode n layer is heavily doped as compared to gate p layer. As the thyristor is forward biased, some of these electrons reach junction J_2. As a result, width of depletion layer near junction J_2 is reduced. This causes the junction J_2 to breakdown at an applied voltage lower than the forward breakover voltage V_{BO}. If magnitude of gate current is increased, more electorns would reach junction J_2, as a consequence thyristor would get turned on at a much lower forward applied voltage.





3. **With forward voltage across the anode and cathode** of a thyristor, the two outer junctionJ_1, J_3 are forward biased, but inner junction J_2, has the characteristics of a capacitor due to charges existing across the junction. In other words, space-charges exist in the depletion region near junction J_2 and therefore junction J_2 behaves like a capacitance. If forward voltage is suddenly applied, a charging current through junction capacitance C_j may turn on the SCR.

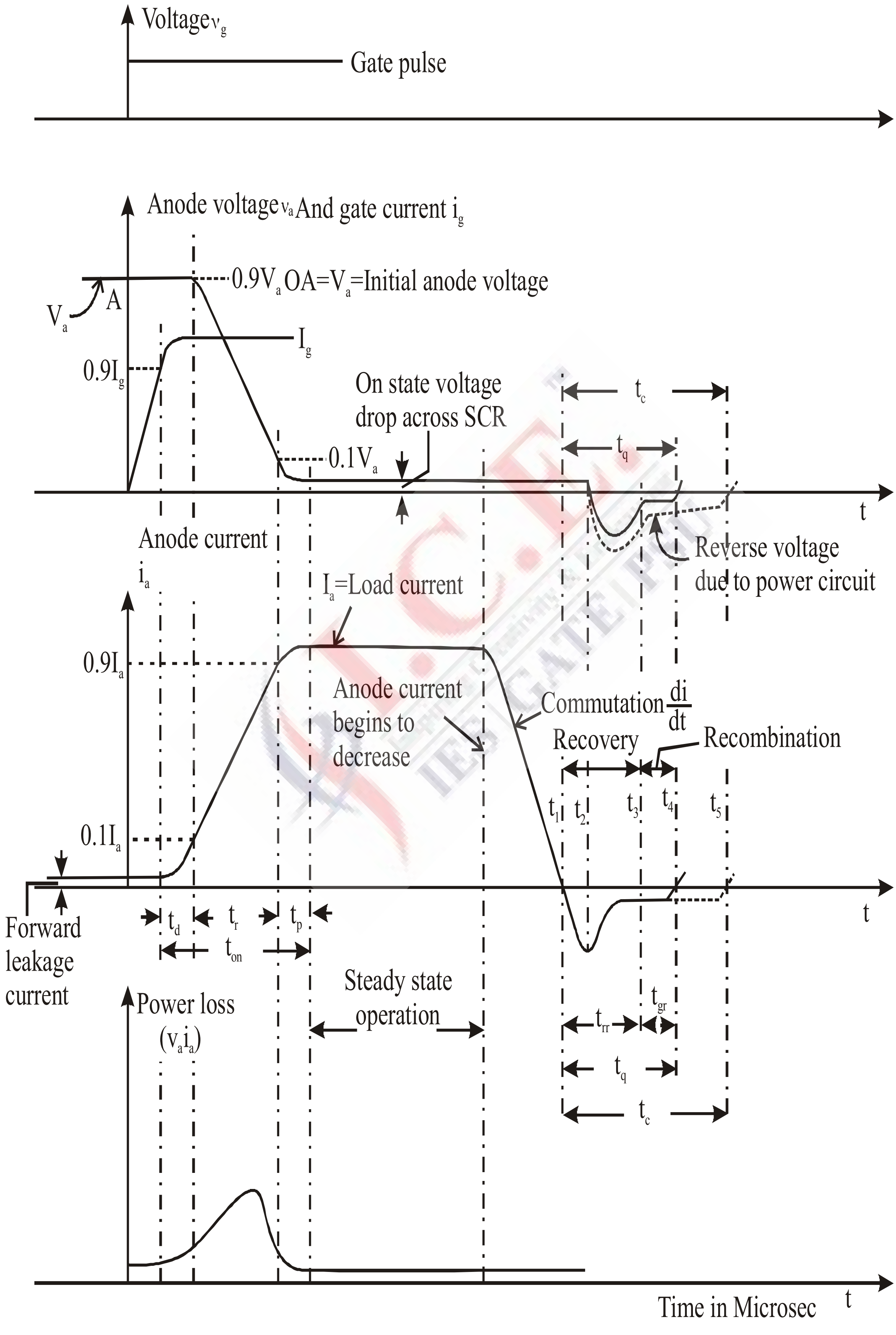
$$i_C = \frac{dQ}{dt} = \frac{d}{dt}(C_j.V_a) = C_j\frac{dV_a}{dt} + V_a.\frac{dC_j}{dt} \quad \text{……..(4.1a)}$$

As the junction capacitance is almost constant, $\frac{dC_j}{dt}$ is zero

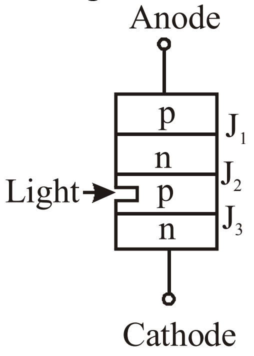
$$i_C = C_j\frac{dV_a}{dt}$$

Therefore, if rate of rise of forward voltage dV_a/dt is high, the charging current i_c would be more. This charging current plays the role of gate current and turns on the SCR even though gate signal is zero.

4. **Temperature Triggering (Thermal Triggering):** During forward blocking, most of the applied voltage appears across reverse biased junction J_2. This voltage across, J_2, associated with leakage current, would raise the temperature of this junction. With increase in temperature, width of depletion layer decreases. This further leads to more leakage current and therefore, more junction temperature. With the cumulative process, at some high temperature (within the safe limits), depletion layer of reverse biased junction vanishes and the device gets turned on.


Voltage v_g
Gate pulse
Anode voltage v_a And gate current i_g
0.9V_a OA=V_a=Initial anode voltage
V_a
A
I_g
0.9I_g
On state voltage
drop across SCR
0.1V_a
t_c
t_q
t
Anode current
i_a
I_a=Load current
Reverse voltage
due to power circuit
0.9I_a
Anode current
begins to
decrease
Commutation $\frac{di}{dt}$
Recovery
Recombination
t_1 t_2 t_3 t_4 t_5
0.1I_a
Forward
leakage
current
t_d t_r t_p
t_{on}
Steady state
operation
t_{gr}
t_{rr}
t_q
t_c
Power loss
($v_a i_a$)
Time in Microsec
t

5. **Light Triggering:** For light-triggered SCRs, a recess (or niche) is made in the inner p-layer as shown in Fig. When this recess is irradiated, free charge carriers (pairs of holes and electrons) are generated just like when gate signal is applied between gate and cathode.



1.3.3 SWITCHING CHARACTERISTICS DURING TURN-ON

A transition time from forward off-state to forward on state. This transition time, called thyristor turn-on time, is defined as the time during which it changes from forward blocking state to final on-state. Total turn-on time can be divided into three intervals; (i) delay time t_d, (ii) rise time t_r and (iii) spread time t_p,

i) **Delay time t_d:** which gate current reaches 0.9 I_g to at which anode current reaches $0.1I_a$.

ii) **Rise time t_r:** Thr rise time t_r is the time taken by the anode current to rise from $0.1I_a$ to $0.9I_a$. forward blocking off-state voltage to fall from 0.9 to 0.1 of its initial value OA. The rise time is inversely proportional to the magnitude of gate current and its build up rate. Thus t_r can be reduced if high and steep current pulses are applied to the gate. However, the main factor determining t_r is the nature of anode circuit. For example, for series RL circuit, the rate of rise of anode current is slow, therefore, t_r is more. For RC series circuit, di/dt is high, t_r is therefore, less.

iii) **Spread time t_p:** The spread time is the time taken by the anode current to rise from $0.9I_a$ to I_a. It is also defined at the time for the forward blocking voltage to fall form 0.1 of its initial value to the on-state voltage drop (1 to 1.5V). During this time, conduction spreads over the entire cross-section of the cathode of SCR.

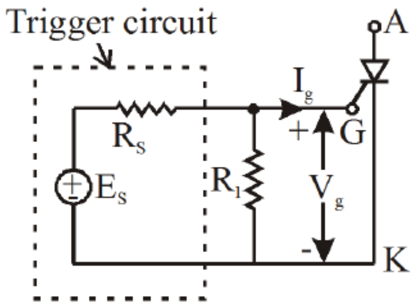
Thyristor manufacturers usually specify the rise time which is typically of the order of 1 to 4 μ sec.

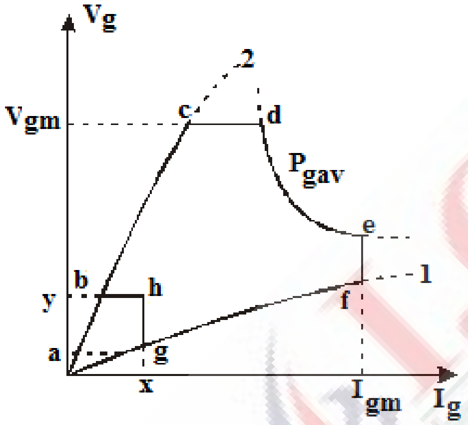
1.3.4 SWITCHING CHARACTERISTICS DURING TURN-OFF

Thyristor turn-off means that it has changed from on to off state and is capable of blocking the forward voltage. It is essential that the thyristor is reverse biased for a finite period after the anode current has reached zero. The turn-off time t_q The turn-off time is divided into two intervals; reverse recovery time t_{rr} and the gate recovery time t_{gr}; i.e. $t_q = t_{rr} + t_{gr}$. The reason for the reversal of anode current after t_1 is due to the presence of carriers stored in the four layers. The reverse recovery current removes excess carriers from the end junctions J_1 and J_3 between the instants t_1 and t_3. The fast decay of recovery current causes a reverse voltage across the device due to the circuit inductance. This reverse voltage surge appears across the thyristor terminals and may therefore damage it. In practive, this is avoided by using protective RC elements across SCR.

At the end of reverse recovery period (t_3-t_1), the middle junction J_2 still has trapped charges, therefore, the thyristor is not able to block the forward voltage at t_3. The trapped charges around J_2, i.e. in the inner two layers, cannot flow to the external circuit, therefore, these trapped charges must decay only by recombination. This recombination is possible if a reverse voltage is maintained across SCR, though the magnitude of this voltage is not important. The rate of recombination of charges is independent of the external circuit parameters. The time for the recombination of charges between t_3 and t_4 is called gate recovery time t_{gr}. The thyristor turn-off time t_q is in the range of 3 to 100 μ sec.

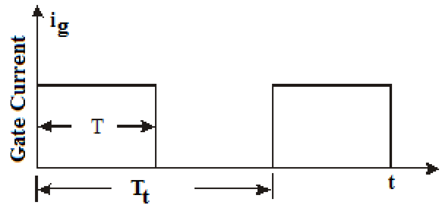
1.3.5 THYRISTOR GATE CHARACTERISTICS

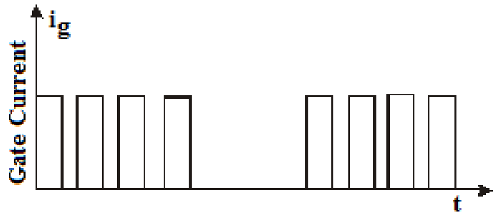




Trigger circuit feeding power to gate-cathode circuit. For this circuit, the internal resistance R_S of trigger source should be such that current (E_S/R_S) is not harmful to the source as well as to the gate circuit when SCR is turned on.

A resistance R_1 is also connected across gate-cathode terminals, so as to provide an easy path to the flow of leakage current between SCR terminals. With pulse triggering, greater amount of gate power dissipation can be allowed; this should, however, be less than the peak instantaneous gate power dissipation P_{gm} as specified. Frequency of firing (or pulse width) for trigger pulses can be obtained by taking pulse of (i) amplitude P_{gm} (ii) pulse width T and (iii) periodicity T_1. Therefore,





$$\frac{P_{gm}T}{T_1} \ge P_{gav} \text{ or } P_{gm}.T.f \ge P_{gav}$$

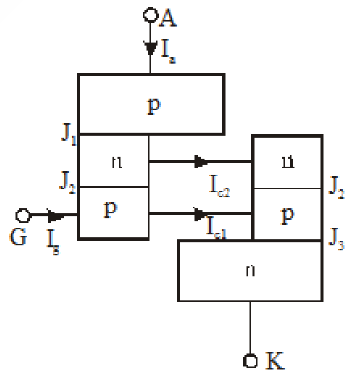
$$\frac{P_{gav}}{fT} \le P_{gm}$$

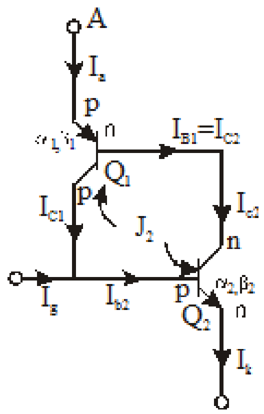
or $$f = \frac{P_{gav}}{T.P_{gm}}$$

$$\delta = \frac{T}{T_1} = fT$$

or $$\frac{P_{gav}}{\delta} = P_{gm}$$

1.3.6 TWO –TRANSISTOR MODEL OF A THYRISTOR





$I_a = \dfrac{\alpha_2 I_g + I_{CBO1} + I_{CBO2}}{1-(\alpha_1+\alpha_2)}$

SCR derating below dc value =

$I_{dc} - \dfrac{I_{dc}}{FF} = I_{dc}\left(1-\dfrac{1}{FF}\right)$

1.3.7 SURGE CURRENT RATING

A surge current rating indicates the maximum possible non-repetitive, or surge, current which the device can withstand. This rating is specified in terms of the number of surge cycles with corresponding surge current peak. Surge current rating in inversely proportional to the duration of the surge. It is usual to measure the surge duration in terms of the number of cycles of normal power frequency of 50 or 60 Hz. For example, a three-cycle surge current rating for a period of 60 msec (3×20 msec) for 50 Hz supply consists of three conducting half-cycles, each followed by an off-period.

One cycle surge current rating is the peak value of allowable non-recurrent half-sine wave of 10 msec duration for 50 Hz. For duration less than half-cycle i.e. 10 msec, a subcycle surge current rating is also specified.

$I_{sb}^2.t = I^2.T \qquad I_{sb} = I\sqrt{\dfrac{T}{t}}$

where T = time for one half-cycle of supply frequency, sec

I = one-cycle surge current rating, A

I_{sb}= subcycle surge current rating, A

t = duration of subcycle surge, sec

For 50 Hz supply, T = 10 msec

$\therefore\ I_{sb} = \dfrac{I}{10}.\dfrac{1}{\sqrt{t}}$

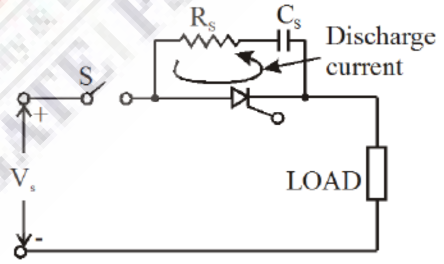
1.3.8 THYRISTOR PROTECTION

a) di/dt protection: If the rate of anode current, i.e.dt/dt, is large as compared to the spread velocity of carriers, local hot spots will be formed near the gate connection on account of high current density. This localized heating may destroy the thyristor. The value of di/dt can be maintained below acceptable limit by using a small inductor, called di/dt inductor. Typical di/dt limit values of SCRs are 20-500 A/μ sec.

b) dv/dt protection: If rate of rise of suddenly applied voltage across thyristor is high, the device may get turned on. dV_a/dt must be kept below the specified rated limit. Typical values of dv/dt are 20-500 V/μ sec.

1.3.9 DESIGN OF SNUBBER CIRCUITS

A capacitor C_S in parallel with the device is sufficient to prevent unwanted dv/dt triggering of the SCR. When switch S is closed, a sudden voltage appears across the circuit. Capacitor C_S behaves like a short circuit, therefore voltage across SCR is zero.



$i = I(1-e^{-t/\tau})$

where $I = \dfrac{V_s}{R_s+R_L}$

and $\tau = \dfrac{L}{R_s+R_L}$

$\dfrac{di}{dt} = I.e^{-t/\tau}.\dfrac{1}{\tau} = \dfrac{V_s}{R_s+R_L}.\dfrac{R_s+R_L}{L}e^{-t/\tau}$

The value of di/dt is maximum when t = 0.

$\left(\dfrac{di}{dt}\right)_{max} = \dfrac{V_s}{L}$

$L = \dfrac{V_s}{(di/dt)_{max}} = \dfrac{240\times10^{-6}}{50}$

$= 4.8\ \mu H$

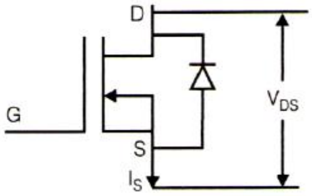
The voltage across SCR is given by, $v_a = R_S.i$

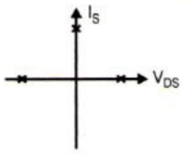
$\dfrac{dv_a}{dt} = R_S.\dfrac{di}{dt}$

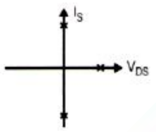
GATE QUESTIONS

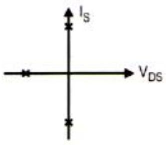
Topics **Page No**

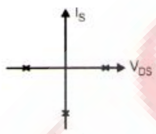
Q.1 Figure shows MOSFET with an integral body diode. It is employed as a power switching device in the ON and OFF states through appropriate control. The ON and OFF states of the switch are given on the $V_{DS} - I_s$ plane by



a) 

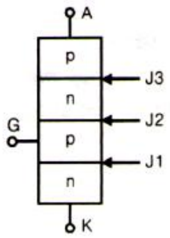
b) 

c) 

d) 

[GATE-2003]

Q.2 Figure shows a thyristor with the standard terminations of anode (A), cathode (K), gate (G) and the different junctions named J1, J2 and J3. When the thyristor is turned on and conducting



a) J1 and J2 are forward biased and J3 is reverse biased
b) J1 and J3 are forward biased and J2 is reverse biased
c) J1 is forward biased and J2 and J3 are reverse biased
d) J, J2 and J3 are all forward biased

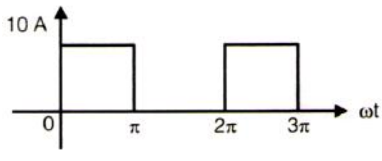
[GATE-2003]

Q.3 A bipolar junction transistor (BJT) is used as a power control switch by biasing it in the cut-off region (OFF state) or in the saturation region (ON state). In the ON state, for the BJT

a) both the base-emitter and base-collector junctions are reverse biased
b) the base-emitter junction is reverse biased, and the base-collector junction is forward biased
c) the base -emitter junction is forward biased, and the base-collector junction is reverse biased
d) both the base-emitter and base-collector junctions are forward biased

[GATE-2004]

Q.4 A MOSFFET rated for 10A carries a periodic current as shown in figure. The ON state resistance of the MOSFET is 0.15Ω. The average ON state loss in the MOSET is



a) 33.8 W
b) 15.0 W
c) 7.5 W
d) 3.8 W

[GATE-2004]

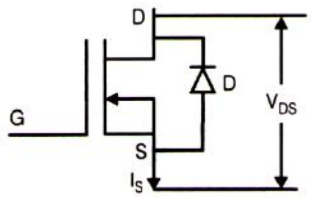
Q.5 The conduction loss versus device current characteristic of a power MOSFET is best approximated by

a) a parabola
b) a straight line
c) a rectangular hyperbola
d) an exponentially decaying function

[GATE-2005]

EXPLANATIONS

Q.1 (b)



When reverse current flows through diode D.

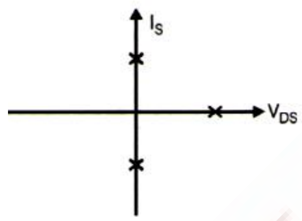
So, $I_s < 0$ and $V_{DS} = 0$

When MOSFET is in ON state

$I_s > 0$ and $V_{DS} = 0$

When MOSFET is in OFF state

$I_s = 0$ and $V_{DS} > 0$



Q.2 (b)

Reverse Blocking Mode: Cathode is more positive with respect to anode. Junctions J_1, J_3 are seen to be reverse biased whereas Junction J_2 is forward biased.

Forward Blocking Mode & Forward Conduction Mode: Anode is positive with respect to the cathode.

Junctions J_1, J_3 are forward biased but Junction J_2 is reverse biased.

Q.3 (d)

$V_{CB} = V_{CE} - V_{DE}$ ...(i)

Under saturated state, V_{BES} is greater than V_{CES} this means base-emitter junction (BEJ) is forward biased. Further eq. (i) shows that V_{CB} is negative under saturated conditions, therefore base-collector junction (CBJ) is also forward biased.

Q.4 (c)

Rated current during on state I = 10

ON state resistance

$R_{ON} = 0.15\Omega$ MOSFET is ON

$0 < \omega t < \pi$

$\Rightarrow 0 < t < \pi / \omega$

MOSFET is OFF

$\pi < \omega t < 2\pi$

$\Rightarrow \pi / \omega < t < 2\pi / \omega$

Average ON state Loss,

$$P_{avg} = \frac{1}{(2\pi / \omega)} \int_0^{\pi/\omega} I^2 R_{ON} dt$$

$$= \frac{\omega}{2\pi} \times I^2 R_{ON} \times \frac{\pi}{\omega}$$

$$= \frac{I^2 R_{ON}}{2} = \frac{10^2 \times 0.15}{2} = 7.5W$$

Q.5 (a)

Let I – device current

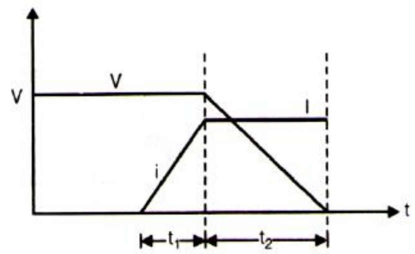
R_{ON} = ON state resistance of power MOSFET

Conduction loss $= P = I^2 R_{ON}$

Therefore, conditionless versus device current characteristic can be best approximated by a parabola.

Q.6 (a)

During interval t_2, voltage starts decreasing and becomes zero and current starts increasing and becomes constant (I), so transition is turn on.



During t_1 interval,

ASSIGNMENT QUESTIONS

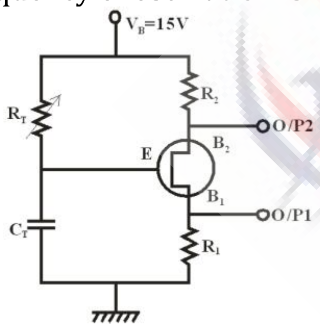
Q.1 For an UJT employed for the triggering of an SCR, stand-off ratio η=0.64 and dc source voltage V_{BB} is 20V. The UJT would trigger when the emitter voltage is

a) 12.8V b) 13.5V
c) 10V d) 5V

Q.2 A UJT used for triggering an SCR has supply voltage V_{BB}=25V. The intrinsic standoff ratio η=0.75. The UJT will conduct when the bias voltage V_E is

a) 25V b) ≥ 18.75V
c) ≥ 19.35V d) 33.3V

Q.3 A UJT relaxation oscillator circuit is shown in figure. If the value of timing resistor R_T=470 KΩ and C_T=0.01 μF and intrinsic standoff ratio is 0.7, the period and frequency of oscillation is



a) 4.7 ms, 213 Hz
b) 5.65 ms, 177 Hz
c) 3.29 ms, 304 Hz
d) 6.71 ms, 149 Hz

Q.4 An SCR has half cycle surge current rating of 3000 A for 50Hz supply. One cycle surge current rating will be

a) 1500 A b) 2121.32 A
c) 4242.64 A d) 6000 A

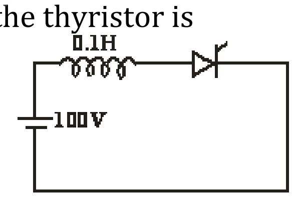
Q.5 Match List I (SMPS topology) with List II (output voltage) and select the correct answer using the codes given below the Lists:
(V-input voltage, V_0–output voltage, D-Duty cycle & a-Transformer ratio);

List-I	**List-II**
A. Boost	1. $V_0 = VD$
B. Buck	2. $V_0 = \frac{-VD}{1-D}$
C. Buck-Boost	3. $V_0 = \frac{V}{1-D}$
D. Isolated Buck-Boost	4. . $V_0 = \frac{VD}{a(1-D)}$

Codes:

	A	B	C	D
a)	2	1	3	4
b)	3	1	2	4
c)	2	4	3	1
c)	3	4	2	1

Q.6 The latching current in the circuit is 4mA. The minimum width of the gate pulse required to properly turn on the thyristor is



a) 6 μs b) 4 μs
c) 2 μs d) 1 μs

Q.7 When two identical SCRs are placed back to back in series with a load if each is fired at 90^0, a d.c. voltmeter across the load reads

a) $\frac{2}{\pi} \times$peak voltage b) zero
c) $\frac{1}{\pi} \times$peak voltage d) None of these

Q.8 A boost –regulation has an input voltage of 5 V and the average output voltage of 15 V.

EXPLANATIONS

Q.1 (b)

UJT triggering

$\eta = 0.64$

$V_{BB} = 20v$

$V_E = \eta V_{BB} + V_D$

$= 0.64 \times 20 + 0.7 = 13.5V$

Q.2 (c)

UJT triggering

$\eta = 0.75$

$V_{BB} = 25v$

$V_E = \eta V_{BB} + V_D$

$= 0.75 \times 25 + 0.7$

$= 19.35$

Q.3 (b)

UJT relaxation oscillator

$R_T = 470k\Omega$

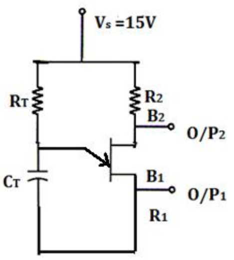
$C_T = 0.01\mu F, \eta = 0.7$

$$T = R_c \ln\left(\frac{1}{1-n}\right)$$

$$= 470 \times 10^3 \times 0.01 \times 10^{-6} \ln\left(\frac{1}{1-0.7}\right)$$

$= 5.65ms$

$$f = \frac{1}{T} = \frac{1}{5.65ms} = 176.7Hz$$



Q.4 (b)

Half cycle surge current = 3000A= i_{sb}

Equalizing the charge balance eqn

$I^2T = I_{sb}^2 t$

$t \rightarrow$ duration;

$T =$ half cycle duration

$$I^2 \times \frac{1}{100} = (3000)^2 \frac{1}{200}$$

$$I = 3000.\sqrt{\frac{1}{2}}$$

$= 2121.32A$

Q.5 (b)

Buck $\rightarrow V_o = VD$

Boost $\rightarrow \frac{V}{1-D}$

Buck-Boost $\rightarrow -\frac{VD}{1-D}$

Isolated buck-Boost $\rightarrow \frac{VD}{a(1-D)}$

Q.6 (b)

Latching current $= 4mA = I_{Lat}$

When Thyristor is conducting (or to start conduction)

Thyristor anode current

=Latching current

$$L\frac{di}{dt} = v$$

$$L\frac{I_{Lat}}{t_{on}} = 100$$

$$t_{on} = \frac{0.1 \times 4m}{100}$$

$= 4\mu s$

Q.7 (b)

Two identical SCRs are placed back to back $\propto = 90$

If DC voltammeter connected across load. The voltmeter connected load the voltmeter reads zero +ve half cycle =-ve half cycle