Model Answers

Winter – 2018 Examinations

Subject & Code: Fundamentals of Power Electronics (22326)

Important Instructions to examiners:

1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner may try to assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling errors should not be given more importance (Not applicable for subject English and Communication Skills).
4) While assessing figures, examiner may give credit for principal components indicated in the figure. The figures drawn by candidate and model answer may vary. The examiner may give credit for any equivalent figure drawn.
5) Credits may be given step wise for numerical problems. In some cases, the assumed constant values may vary and there may be some difference in the candidate's answers and model answer.
6) In case of some questions credit may be given by judgement on part of examiner of relevant answer based on candidate's understanding.
7) For programming language papers, credit may be given to any other program based on equivalent concept.

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1 Attempt any FIVE of the following: 10

1 a) State the applications of MOSFET (any two).

Ans:

Applications of MOSFET:

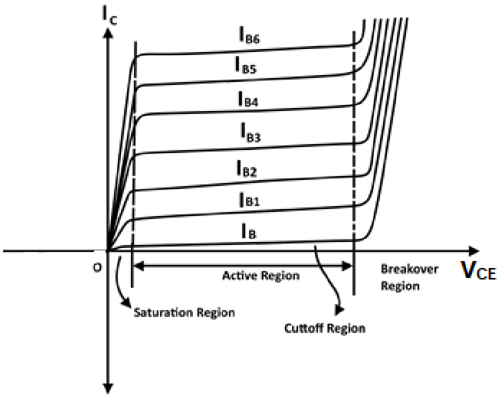
i) Switching-mode-power-supplies (SMPS) and linear power supplies.
ii) Brushless DC motor drives
iii) Solid state DC relay
iv) Automobile applications
v) Stepper motor controller
vi) Lighting controls
vii) Solenoid drivers
viii) Robotics
ix) Induction heating

1 mark for each of any two valid applications = 2 marks

1 b) Draw the V-I characteristics of power transistor.

Ans:

V-I characteristics of power transistor:



2 marks for labelled diagram

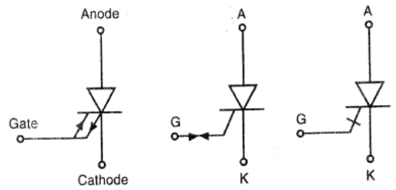
1 mark for partially labelled diagram

No marks for unlabeled diagram

1 c) Draw the symbol of GTO and TRIAC.

Ans:

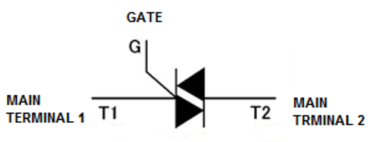
1) GTO:



GTO Symbols

1 mark for any one symbol

2) TRIAC:



1 mark

1 d) Define triggering. List the type of triggering.

Ans:

Triggering:

Triggering means turning-ON of a device from its OFF-state. — 1 mark for correct definition

Types of Triggering:

1) Forward voltage triggering
2) Thermal triggering (Temperature triggering)
3) Radiation triggering (Light triggering)
4) dv/dt triggering
5) Gate triggering
   (i) D.C. Gate triggering
   (ii) A.C. Gate triggering
   (iii) Pulse Gate triggering

1 mark for types

1 e) Define commutation. Give the types of commutation.

Ans:

Commutation:

The process of turning-off a conducting thyristor is called “commutation”. — 1 mark for definition

Types of Commutation:

i) Line commutation (Natural commutation)
ii) Load commutation
iii) Forced commutation
iv) External pulse commutation

OR

i) Class A: load commutation (Self-commutated by resonating the load)
ii) Class B: Resonant pulse commutation
iii) Class C: Complementary commutation
iv) Class D: Auxiliary commutation
v) Class E: External pulse commutation
vi) Class F: AC line commutation

1 mark for types

1 f) Define transfer time and back up time of UPS.

Ans:

Transfer time of UPS:

The transfer time, sometimes also called switchover time, is the amount of time the UPS will take to switch from utility to battery supply during a mains failure, or from battery to mains when normal utility power is restored. — 1 mark

Back up time of UPS:

The backup time is the amount of time for which the UPS will supply the power to load during mains failure. — 1 mark

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1 g) State the applications of power electronics.

Ans:

Applications of power electronics:

- Solid-state controllers for home appliances
- Light dimmers in home and theatres
- Switch-mode-power-supply (SMPS) and Uninterruptible-power-supply (UPS)
- Power supply for air-craft, space shuttle and satellites
- AC and DC drives in rolling mills, paper mills, textile mills, cement mills etc.
- Solid-state-controllers for mine winders, cranes, elevators, lifts, excavators etc.
- Solid-state-controllers for traction vehicles.
- Power control in chemical processes, metallurgical processes.
- HVDC transmission
- Active power filters and reactive power compensators in power system
- Static circuit breakers
- High voltage supplies for electrostatic precipitators, X-ray machines.

½ mark for each of any four applications = 2 marks

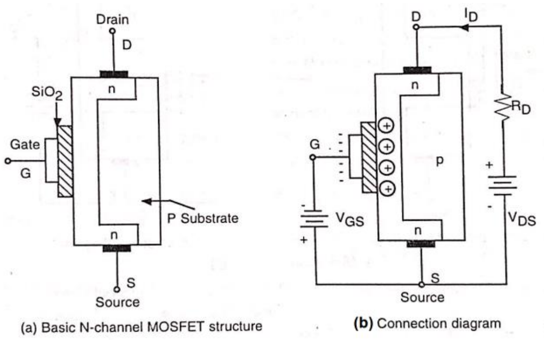
2 Attempt any THREE of the following: 12

2 a) Describe with neat sketch the construction and working principle of MOSFET.

Ans:

Construction and working principle of MOSFET:

A) Depletion type MOSFET:



A) Depletion type power MOSFET

1 mark for diagram

Construction:

The N-channel depletion type MOSFET is formed on P-type silicon substrate with two heavily doped n^+ silicon for low resistance connections of terminals Drain (D) and Source (S). The third terminal Gate (G) is isolated from the N-channel by a thin oxide layer. The substrate is normally connected to the source.

1 mark for construction

Operation:

The gate-to-source voltage V_{GS} can be either positive or negative. When V_{GS} is negative, gate becomes negative with respect to source and some of the electrons in the N-channel are repelled leaving behind positive ions. The depletion region is created below the oxide layer, effective channel width is reduced, resulting a high resistance from the drain to source, R_{DS}. At certain negative voltage V_{GS} the channel will be completely depleted, offering very high value of R_{DS} and no current will flow from drain to source i.e. $I_{DS} = 0$. The value of V_{GS} when this happens is called pinch-off voltage, V_P. When $V_{GS} = 0$, no charge will be induced in N-channel and the resistance

2 marks for operation

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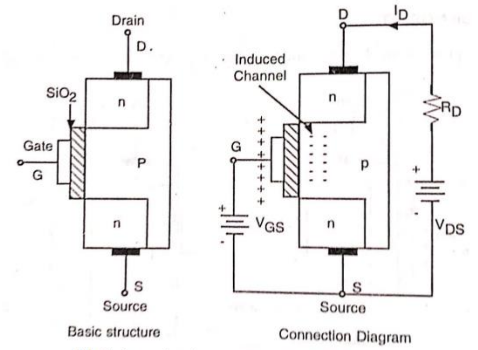
R_{DS} will be the normal resistance of the N-channel. When V_{GS} is positive, the gate is positive and hence attracts electrons into the N-channel. Thus channel becomes wider, more carriers are available for current, R_{DS} get reduced and the current I_{DS} increases.

OR

B) Enhancement type MOSFET:



1 mark for diagram

Construction:
The N-channel enhancement type MOSFET is formed on P-type silicon substrate with two heavily doped n^+ silicon for low resistance connections of terminals Drain (D) and Source (S). It has no physical N-channel. The third terminal Gate (G) is isolated from the substrate by a thin oxide layer. The substrate is normally connected to the source.

1 mark for construction

Operation:
When V_{GS} is positive, gate is positive and hence on opposite side of oxide layer, the electrons are attracted from the P-substrate and accumulated on the surface beneath the oxide layer. If V_{GS} is greater than or equal to a value known as threshold voltage, V_T, sufficient electrons are accumulated to form a virtual N-channel and the current flows from the drain to source. Further increase in V_{GS} will result in more accumulation of electrons and hence more current. Thus the MOSFET is a gate voltage controlled device.

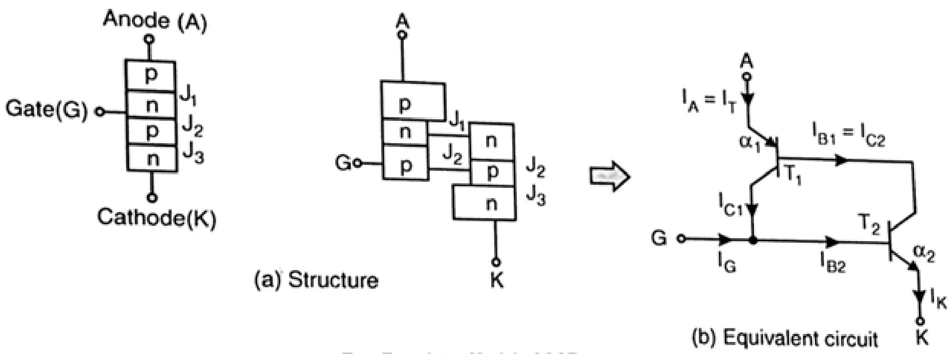
2 marks for operation

(Examiner is requested to award marks for P-channel MOSFET as well)

2 b) Draw construction of SCR using two transistor model. Explain its operation.

Ans:

Two-transistor Model of SCR:



Two Transistor Model of SCR

1 mark for (a)
1 mark for (b)
= 2 marks for diagram

A simple p-n-p-n structure of thyristor can be visualized as consisting of two complimentary transistors: one pnp transistor T_1 and other npn transistor T_2 as shown in the figures. The collector current of transistor is related to emitter current and leakage current as:

$$I_C = \alpha I_E + I_{CBO}$$

where, α = common-base current gain
I_{CBO}= leakage current from collector to base with emitter open
For transistors T_1 and T_2, we can write,
$I_{C1} = \alpha_1 I_A + I_{CBO1}$ and $I_{C2} = \alpha_2 I_K + I_{CBO2}$
From KCL applied to T_1, we can write

$$I_A = I_{C1} + I_{C2} = \alpha_1 I_A + I_{CBO1} + \alpha_2 I_K + I_{CBO2}$$

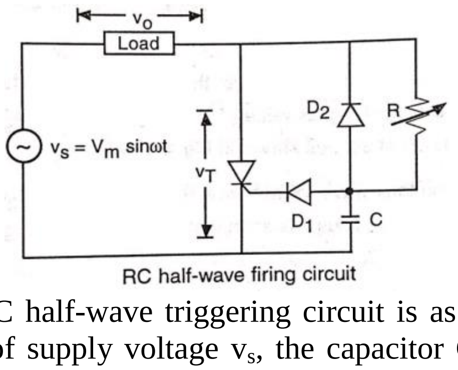
From KCL applied to entire equivalent circuit,
$I_K = I_A + I_G$ and substituting in above equation,
$I_A = \alpha_1 I_A + I_{CBO1} + \alpha_2(I_A + I_G) + I_{CBO2} = I_A(\alpha_1 + \alpha_2) + \alpha_2 I_G + I_{CBO1} + I_{CBO2}$
$I_A(1 - [\alpha_1 + \alpha_2]) = \alpha_2 I_G + I_{CBO1} + I_{CBO2}$

$$I_A = \frac{\alpha_2 I_G + I_{CBO1} + I_{CBO2}}{1 - [\alpha_1 + \alpha_2]}$$

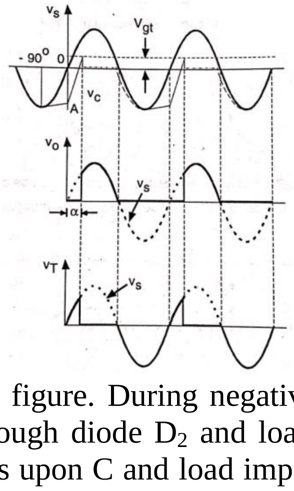
2 marks for mathematical treatment

From this equation it is clear that the anode current depends on the gate current, leakage currents and current gains.
If $(\alpha_1 + \alpha_2)$ tends to be unity, the denominator $1 - [\alpha_1 + \alpha_2]$ approaches zero, resulting in a large value of anode current and SCR will turn on. The current gains vary with their respective emitter currents.
When gate I_G current is applied, the anode current I_A is increased. The increased I_A, being emitter current of T_1, increases the current gain α_1. The gate current and anode current together form cathode current, which is emitter current of T_2. Thus increase in cathode current results in increase in current gain α_2. Increased current gains further increase the anode current and the anode current further increases the current gains. The cumulative action leads to the loop gain to approach unity and the anode current drastically rises which can be controlled by external circuit only. Thus the SCR is turned-ON.

2 c) Explain the operation of RC triggering circuit with neat diagram.
Ans:
RC triggering circuit:



RC half-wave firing circuit



1 mark for circuit diagram

2 marks for explanation

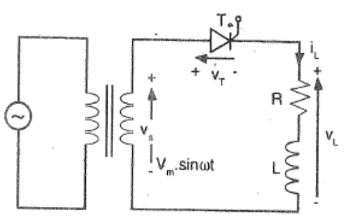
1 mark for waveform

The RC half-wave triggering circuit is as shown in the figure. During negative half-cycle of supply voltage v_s, the capacitor C charges through diode D_2 and load, with lower plate positive. The charging time constant depends upon C and load impedance. If this charging time constant is low, the capacitor gets quickly charged to supply voltage and may attain peak value V_m at -90° as shown in the waveform diagram. At this instant, as both capacitor voltage and supply voltage are equal and opposite, capacitor current is zero. During period after ωt = -90° to ωt = 0°, the supply voltage v_s drops from V_m as capacitor discharges. The discharging current passes through supply source, load and R. At ωt = 0°, the capacitor voltage reduces to a value less than V_m, represented by OA in the waveform diagram. After ωt = 0°, the supply voltage become positive, it now helps the discharging current and therefore, the capacitor gets discharged at faster rate. Its negative voltage (lower plate positive) get reduced to zero at a particular instant. The discharging current further continues in the same direction to charge capacitor with upper plate positive. When the capacitor voltage reaches to gate trigger voltage, the SCR is fired. After firing, voltage across SCR drops to low value and hence capacitor voltage also get reduced to low value as shown. The discharging of negatively charged (lower plate positive) capacitor and further charging with upper plate positive is through load and R. Therefore, R determines the discharging and positive charging time-constants. If R is increased, the time-constant get increased and firing is delayed. The SCR can never be triggered at 0° & 180° because the supply voltage is zero and less than finger voltage.

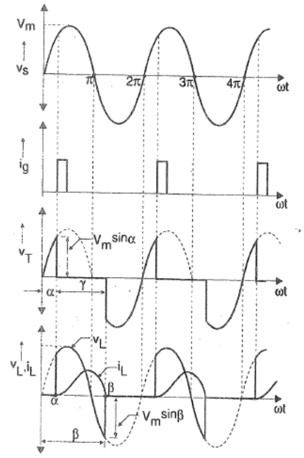
2 d) Draw a neat diagram of 1ϕ half wave controlled converter with RL load. Give its operation.

Ans:

Single phase fully controlled half wave converter:



(a) Circuit arrangement



(b) Waveforms

1 mark for circuit diagram

2 marks for explanation

1 mark for waveforms

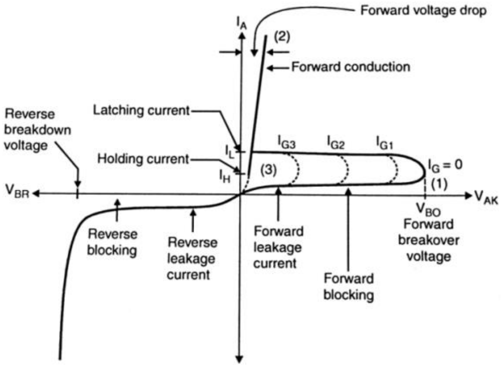
The circuit diagram of single-phase half-wave controlled rectifier with RL load and without freewheeling diode is shown in Fig. (a). The SCR T is forward biased only during positive half cycle whereas reverse biased during negative half cycle. Therefore, it is triggered in positive half cycles only. When the gate pulse is applied in positive half cycle with delay angle of α as shown in waveform diagram (b), the SCR conducts and starts to carry the load current. Since the load is inductive (RL), the current lags behind the voltage. The load inductance maintains the load current and keeps SCR on even if the supply voltage is reversed. Thus every positive half cycle of load voltage is followed by some negative voltage till the current drops to zero. The negative voltage appearing across load reduces the average load voltage. Thus the use of freewheeling diode helps to increase the average load voltage. For some sensitive loads, the negative voltage is undesirable. In such cases freewheeling diode is used to prevent the negative voltage across the load.

3 Attempt any THREE of the following: **12**

3 a) Draw a neat labelling V-I characteristics of SCR and explain the region.

Ans:

V-I characteristics of SCR:



V-I Characteristics of SCR

2 marks for labeled diagram

1 mark for partially labeled diagram

Operating regions:

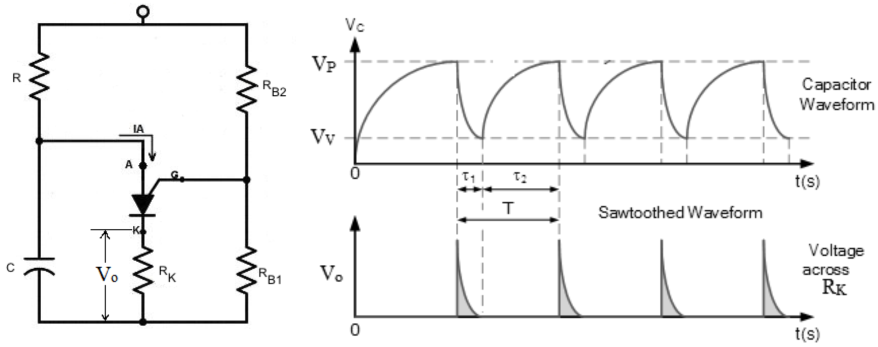
1) **Forward Blocking region**: In this region, the SCR is forward biased but not triggered. It carries only forward leakage current. The SCR in this region is treated as OFF switch.
2) **Forward conduction region**: In this region, the SCR conducts the forward current and latched into conduction after triggering. The SCR in this region is treated as ON switch.
3) **Reverse blocking region**: In this region, the SCR is reverse biased, hence carries only reverse leakage current. The SCR in this region is treated as OFF switch.
4) **Reverse conduction region:** In this region, the SCR conducts the reverse current after the breakdown of reverse biased junctions. The SCR get damaged if operated in this region.

2 marks for four regions and proportionally reduced if all are not covered.

3 b) Explain the operation of PUT relaxation oscillator with diagram.

Ans:

PUT as a Relaxation Oscillator:



1 mark for circuit diagram

1 mark for waveforms

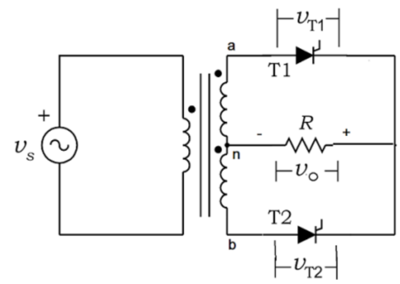
1. The circuit diagram of PUT as relaxation oscillator is as shown in the above figure.

2. The gate terminal is held at potential $V_G = \frac{R_{B1}}{R_{B1}+R_{B2}} V_{BB} = \eta V_{BB}$
   where, η is called intrinsic stand-off ratio & given by, $\eta = \frac{R_{B1}}{R_{B1}+R_{B2}}$
   Its value is thus decided by the external resistors R_{B1} & R_{B2}. It means by properly choosing these resistors (programming), we can fix its value, hence termed as Programmeable-UJT (PUT). 2 marks for explanation
3. The anode is held at capacitor voltage. Initially, the capacitor voltage is zero, hence the anode-gate junction is reverse biased and device remains off.
4. As soon as the supply voltage V_{BB} is connected to the circuit, the capacitor begins to charge towards V_{BB} volt. So far anode voltage is less than gate voltage, device remains off.
5. When the anode voltage reaches to peak-point voltage V_P, the anode voltage becomes higher that gate voltage. The anode-gate junction is forward biased, gate current flows, regeneration starts and device is turned on. The capacitor then discharges through the device to valley-point voltage V_V.
6. During discharging of capacitor, a pulse of current flows through the cathode resistor R_K and we get pulse voltage across it, as shown in the waveform.
7. At the end of discharging, the device is turned off due to very low current. The capacitor then starts charging and the cycle repeats.
8. The capacitor voltage waveform is saw-tooth in nature, whereas the voltage across R_K is in the form of pulses.

3 c) Explain with sketch the operation of single-phase fully controlled midpoint configuration with R load.

Ans:

Midpoint converter with resistive load:

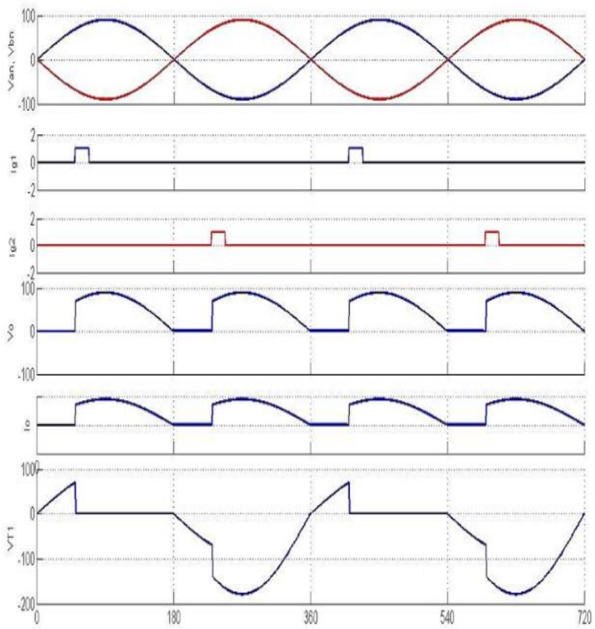


1 mark

Explanation:-

1) During positive half cycle of AC supply, A is positive with respect to B ,this makes T1 forward biased and T2 is reverse biased. But since no triggering pulse is applied, both are in off state. When SCR T1 is triggered at firing angle α, current flows through load from A, T1 and back to centre tap of the transformer. This current flow is continuous till angle π when the line voltage reverses the polarity and T1 is turned off. 2 marks
2) During negative half cycle of AC supply, B is positive with respect to A ,this makes T2 forward biased and T1 is reverse biased. But since no triggering pulse is applied, both are in off state. When SCR T2 is triggered at firing angle α+π, current flows

through load from B, T2 and back to centre tap of the transformer. This current flow is continuous till angle 2π, when the line voltage reverses the polarity and T2 is turned off. The operation is as shown in waveforms**.**

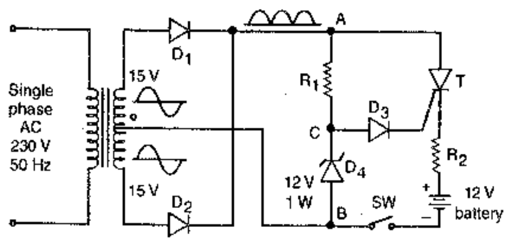


1 mark

3 d) Give the operation of battery charger using SCR with a neat diagram.

Ans:

Battery charger circuit using SCR:



Automatic battery charger using SCR

The figure shows the battery charger circuit using SCR. A 12V discharged battery is connected in the circuit and switch SW is closed. The single-phase 230V supply is stepped down to (15-0-15) V by a centre-tapped transformer. The diodes D_1 and D_2 forms full wave rectifier and pulsating DC supply appears across terminals A and B. When SCR is off, its cathode is held at the potential of discharged battery. During each positive half-cycle, when the potential of point C rises to sufficient level so as to forward bias diode D_3 and gate-cathode junction of SCR, the gate pulse is provided and SCR is turned on. When SCR is turned on, the charging current flows through battery. Thus during each positive half-cycle of pulsating DC supply, voltage across A-B, SCR is fired and charging current is passed till the end of that half-cycle. Due to Zener diode D_4, the maximum voltage at point C is held at 12V. Due to the charging process, the battery voltage rises and finally attains full value of 12V. When the battery is fully charged, the cathode of SCR is held at 12V. So the diode D_3 and gate-cathode junction of SCR cannot be forward biased, since the potential of point C can reach up to 12V. Therefore, no gate current is supplied and SCR is not fired. In this way, after full charging, further charging is automatically stopped.

2 marks for circuit diagram

2 marks for operation

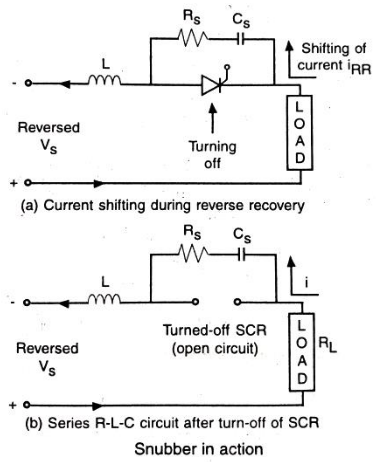
(Marks may please be awarded to any other valid battery charging scheme)

4 Attempt any THREE of the following. 12

4 a) Explain the operation of snubber protection circuit with diagram.

Ans:

Operation of Snubber protection circuit:



2 marks for circuit diagram

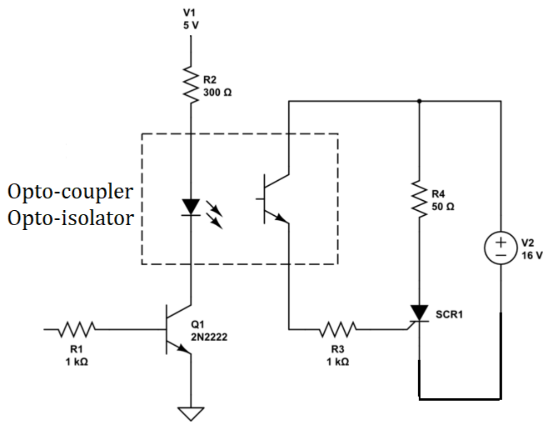
2 marks for explanation

The snubber circuit is used to provide protection against high dv/dt. During turn-on of thyristor, it is switched from high impedance state to low impedance state and current is suddenly increased. During turn-off, the forward current is first reduced to zero, then due to storage charges at the junctions, reverse current flows. This reverse recovery current reaches to peak value I_{RR} and then it is abruptly reduced to zero. When current is reduced abruptly (very high rate), the circuit inductance which includes load inductance, stray inductance and di/dt inductance cause high emf (Ldi/dt) that appears at high rate (dv/dt) across the thyristor. A snubber circuit having series RC combination is used to limit this high dv/dt as well as peak reverse voltage appearing across thyristor. As prior to turn-off, thyristor was conducting, voltage across it and also across snubber R-C circuit was negligibly small. The capacitor voltage at this instant therefore can be assumed to be zero. Thus when thyristor turns-off abruptly, the reverse recovery current I_{RR} is transferred through snubber R-C circuit. The uncharged capacitor initially acts as short-circuit and hence at this instant the voltage appearing across thyristor is only because of drop in resistance R_S i.e. R_S I_{RR}. Once the thyristor is turned-off, the snubber circuit R-C and circuit inductance with load impedance forms a series RLC circuit. After turn-off, the capacitor charges slowly and limits dv/dt across thyristor. The reverse voltage to which the capacitor be charged and the rate (dv/dt) at which it is charged, is determined by the circuit parameters R, L and C.

4 b) Explain the operation of opto-coupler based triggering circuit with diagram.

Ans:

Opto-coupler based triggering circuit:



2 marks for circuit diagram

2 marks for explanation

A simple opto-coupler based triggering circuit for SCR is shown in the figure. An opto-coupler or opto-isolator is a combination of light source and light-sensitive device enclosed in a compartment. The light source is LED or infra-red LED (IRLED) and light-sensitive device may be photo-diode or photo-transistor. Referring to the circuit diagram, when the SCR is to be turned-on, a voltage is applied to base of Q_1 through R_1. The base current flows and Q_1 is turned on. The collector current flow and voltage appears across the LED of opto-coupler. The light emitted by LED falls on the photo-transistor and it is turned-on. When photo-transistor is turned-on. It carries the current, which flows through R_3 and acts as gate current for the SCR. Thus gate current is provided to SCR and it is ultimately turned-on. The firing circuit is electrically isolated from SCR circuit but optically coupled.

OR

(Any other equivalent valid circuit and explanatiobn)

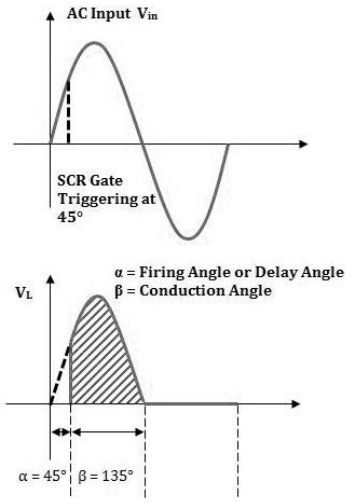
4 c) Give the concept of firing angle and conduction angle with a neat waveform.

Ans:

Firing Angle(α):

Firing angle is defined as the angle between the instant the SCR would conduct if it would be a diode and the instant it is triggered or fired.

Firing angle or delay angle can be defined as the angle measured from the angle that gives maximum average output voltage to the angle when the SCR is actually triggered or fired by gate pulse.



1 mark for each description and 1 mark for each waveform

= 4 marks

Conduction Angle (β):

Conduction angle is defined as the angle between the instant the SCR is triggered or turned on and the instant at which the SCR is turned off.

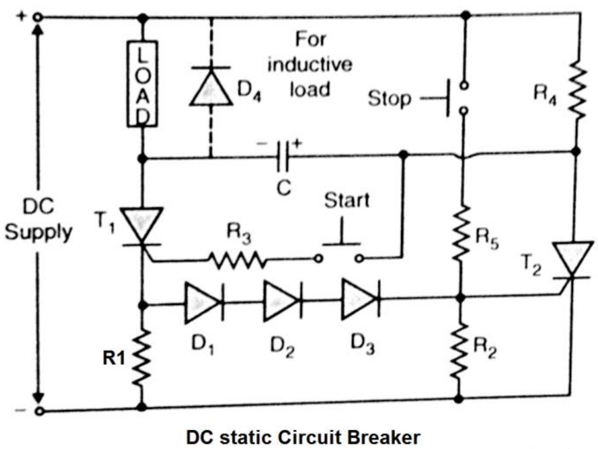
Assuming that the SCR is turned off naturally at the end of positive half cycle, the relation between the firing or delay angle (α) and conduction angle (β) can be expressed as:

$\alpha + \beta = \pi$ radian or 180°

4 d) Draw the circuit diagram of DC static circuit breaker and give its operation.

Ans:

DC Static Circuit Breaker:



DC static Circuit Breaker

The figure shows circuit configuration of DC static circuit breaker using SCR. When the 'Start' button is momentarily pressed, the SCR T_1 receives gate current through R_3 and starts to conduct. The turning on of T_1 causes major part of DC supply voltage to appear across the load and power is delivered to load. The capacitor C charges to load voltage with polarity as shown in the figure, through R_4.

2 marks for circuit diagram

2 marks for explanation

If we attempt to break the DC load current i.e switch off the load, using mechanical contact type switch, since current is DC, heavy arcing may damage the switch. Instead, if we use this circuit configuration, the load current can be interrupted by turning off the SCR T_1. When 'Stop' button is pressed momentarily, SCR T_2 receives gate current through R_5 and it is turned on. The turning on of T_2 causes the charged capacitor C to place across conducting SCR T_1. The capacitor provides reverse bias across T_1 and discharges quickly through T_2, resistance and T_1. The discharge current is reverse current for T_1 and it is turned off. The load current is then continued through C and T_2. The capacitor C first discharges and then charges with reverse polarity to supply DC voltage. At this instant, the load current falls to zero, and further since current falls below holding current level, T_2 is turned off naturally. Thus manual firing of T_2 by pressing 'Stop' button interrupts load current through T_1.

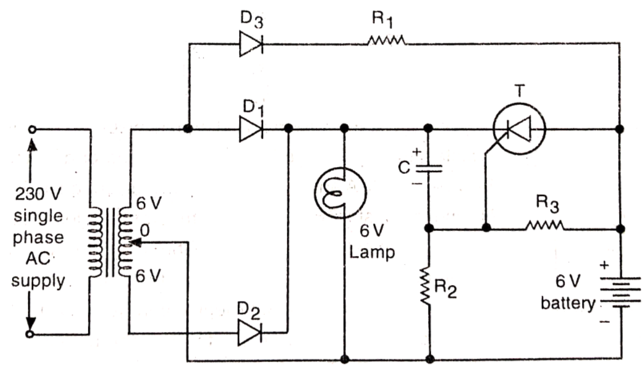
The load current can be automatically interrupted under overload condition. With T_1 on and carrying load current, if overload occurs, the voltage drop across R_1 exceeds the forward voltage drop of string of diodes D_1, D_2, D_3 and gate-cathode junction of T_2. Therefore, gate current is provided to T_2 and it is turned on. Turning on of T_2 immediately causes turning off of T_1 as mentioned above. The load current is interrupted and thus over-load protection is provided. Since no moving contact type mechanism is used for interruption of load current, this circuit configuration is called DC static circuit breaker. By proper selection of R_1 and number of diodes in string and replacing 'Stop' button by NO relay contact in fault sensing circuit, the circuit can be made to trip and interrupt the overload and fault current.

4 e) Describe emergency lighting system with neat diagram.

Ans:

Emergency lighting system:

In the residential, commercial and industrial areas, the illumination system work with available AC supply. In the event of AC supply failure, partial illumination can be obtained using emergency lighting system that works on DC supply. A very simple single source emergency lighting system which is most suitable for household application is shown in the figure. The input 230v AC supply is stepped down to 6-0-6V AC supply by centre-tapped transformer. The diodes D_1 and D_2 form full wave rectifier and comnvert 6-0-6V AC supply into 6V DC supply for 6V lamp. When AC supply is available, 6V DC supply appears across lamp & it glows. The pulsating current also flows through D_3, R_1 to trickle charge the battery. Thus battery charging is carried out when AC supply is availabl;e. The capacitor C get charged with upper plate positive to some voltage less than 6V. due to capacitor voltage, gate-cathode junction of thyristor T get reverse biased. The anode is at battery voltage and cathode is at rectifier output voltage, which is slightly higher, hence thyristor is reverse biased and can not conduct. The lamp glows due to rectifier output DC voltage.



Emergency lighting system

2 marks for circuit diagram

2 marks for explanation

When AC supply fails, rectifier output DC voltage is reduced to zero. The capacitor C then discharges through lamp and R_2. After discharging, due to battery, it charges through R_3 and lamp with lower plate positive. Due to capacitor voltage, gate-cathode junction get forward biased and gate current flows. Since the anode is now at higher potential than cathode, thyristor T is turned-on. The lamp get connected across battery through thyristor and therefore, it glows. In rthis way, on failure of AC supply, light is obtained from DC supply.

OR

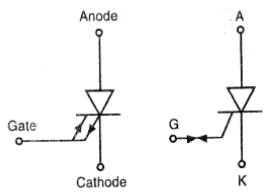
(Any other equivalent valid circuit and explanatiobn)

5 Attempt any TWO of the following: **12**

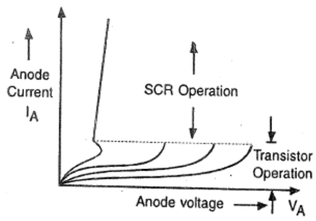
5 a) Draw a symbol and neat labeling V-I characteristics of GTO and explain its operation.

Ans:

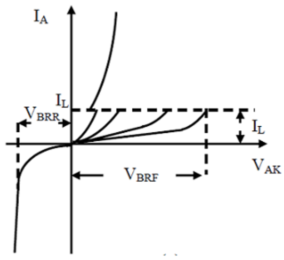
Symbol and V-I characteristics of GTO:



GTO Symbols



V-I characteristics of GTO



1 mark for any one symbol

Operation of GTO:

2 marks for v-i characteristic

3 marks for explanation

i) As the applied anode to cathode voltage is increased above zero, very small current (leakage current) flows through the device. Under this condition the GTO is said to be off. It will be continued till the applied voltage reaches the forward Breakover voltage (V_{BRF}).

ii) If the anode-cathode (applied) voltage exceeds the breakover voltage, the device conducts heavily and the GTO is turned ON. The anode to cathode voltage decreases quickly because, the GTO offers very low resistance when it is ON, hence it drops very low voltage across it.

iii) At this stage the GTO allows more current to flow through it. The amplitude of the current is depending upon the supply voltage and load resistance connected in the circuit.

iv) If the value of the gate current I_g is increased above zero, the GTO turns ON even at lower anode-cathode voltage (less than forward breakover voltage, V_{BRF}).

v) If the polarity of applied voltage is reversed, we get the reverse characteristics.

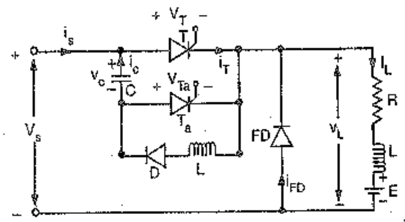
vi) In reverse direction GTO breaks down at very low voltage (V_{BRR}). The reverse breakdown voltage is of the order of 20 to 30 volt only.

5 b) Explain auxiliary commutation with a neat diagram. Also draw its waveform.

Ans:

Auxiliary Commutation

At start, the T_a is triggered and turned on to carry the load current. Due to the resonant circuit R-L-C, the current initially rises, attains peak and then falls to zero. This turns off the auxiliary SCR Ta. This current charges the capacitor C with upper plate positive. The capacitor thus forward biases the



Voltage-commutated chopper

2 marks for circuit diagram

main SCR T. When main SCR T is triggered, it is turned on and charged capacitor C is placed across T_a so as to apply reverse bias across it. The load current now flows through T. The capacitor continues to discharge through T, L and D. Since this LC is resonant combination, the capacitor discharges completely first and then charges with opposite polarity till the current falls to zero. The capacitor current cannot reverse because of diode D. Now the oppositely charged capacitor forward biases the auxiliary SCR T_a. Thus when T_a is triggered, T is turned off and the same cycle is repeated. In this configuration, the firing of auxiliary SCR commutates the main SCR, hence name is auxiliary commutation. 4 marks for stepwise operation

5 c) Explain in detail over-voltage protection.

Ans:

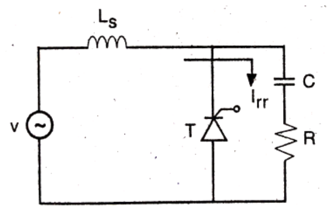
Over-voltage protection:

Over-voltage protection to the thyristor is provided using:

i) R-C Snubber circuit
ii) Non-linear resistor "Thyrector'

A) Snubber Circuit:

It is basically a series r-C circuit which is connected across the device to be protected. The snubber circuit helps to minimize the effects of internal or external overvoltages by following ways:



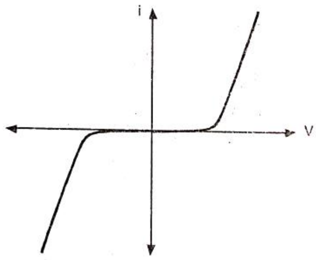
Equivalent circuit showing circuit condition for single SCR in converter

3 marks for snubber circuit

i) Internal over-voltages are generated by interruption of reverse recovery current I_{RR} during turn-off of device. With snubber circuit, the I_{RR} is diverted through R-C after SCR has blocked the reverse current. If L_S, R, and c are suitably chosen, the voltage across thyristor can be limited to suitable safe value.
ii) At the time of external over-voltages, the capacitor charges through R at slow rate, hence does not allow the voltage to change at high rate. Thus transient voltage spikes are damped and also rate of rise of forward voltage dv/dt across SCR is reduced.
iii) The resistance R of snubber circuit causes power loss at the time of energy transfer oscillations between snubber circuit capacitance C and stray circuit inductance, therefore the oscillations are damped and over-voltage transients are reduced.
iv) The snubber circuit can be connected directly across secondary winding of transformer to suppress the over-voltages caused by switching on or off the primary winding.

B) Non-linear resistor (Thyrector):

Thyrector is a non-linear resistor device having v-I characteristic as shown in the figure. Under normal working voltage it offers very high resistance and draws very small leakage current. However, under over-voltage conditions, its resistance is reduced, it draws heavy current and maintains safe voltage across it. Thus its resistance depends upon voltage



Thyrector characteristics

3 marks for thyrector

across it. This device is therefore used as surge diverter. At the time of over-voltage surge, it conducts heavy current, causing virtual short-circuit. The increased current produces more drop in source impedance and line impedance, by which the SCR volatge is maintained to safe low value. After the surge energy is dissipated in thyrector, the thyrectyior returns to its high resistance state. Thyrector is normally placed across the supply terminals.

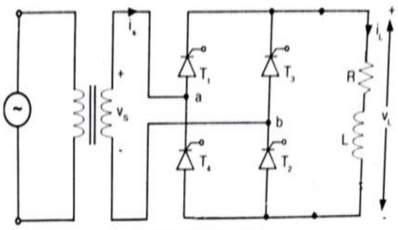
6 Attempt any TWO of the following: 12

6 a) Give the operation of single phase full wave bridge controlled converter with RL load with a neat diagram. Also draw its waveform.

Ans:

Single phase fully control bridge converter with RL load:

1. During positive half cycle of input voltage, T_1 and T_2 are forward biased and during negative half cycle, T_3 and T_4 are forward biased. Therefore, T_1-T_2 pair and T_3-T_4 pair are fired alternately in positive and negative half cycles of input voltage respectively, as shown in the waveform figure (b).

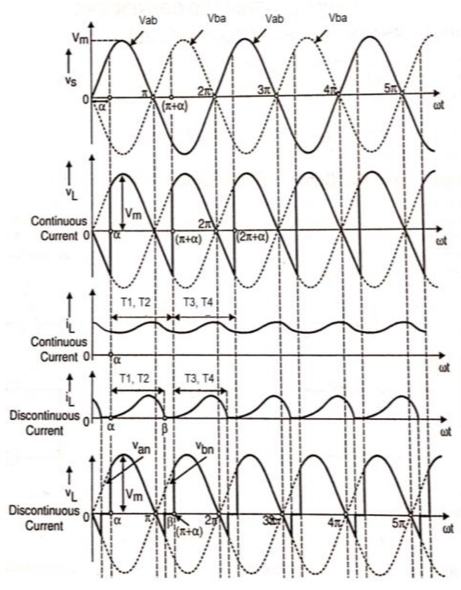


(a) Circuit arrangement

2 marks for description

2 marks for circuit diagram

2. In each half cycle, the respective SCRs are fired at firing or delay angle α, as shown. Once SCR pair conducts (at delay angle in each half cycle), the input source voltage appears across load, the current flows and if the load is inductive in nature, the conducting SCRs remain into conduction till the fall of current to zero or firing of next pair of SCRs as shown in the waveform diagram.
3. Due to load inductance, the current lags behind the output voltage and falls to zero after the end of that half cycle. Therefore, during the time interval between voltage zero instant and current zero instant, the reversed supply voltage appears across load for discontinuous conduction.



(b) Waveforms

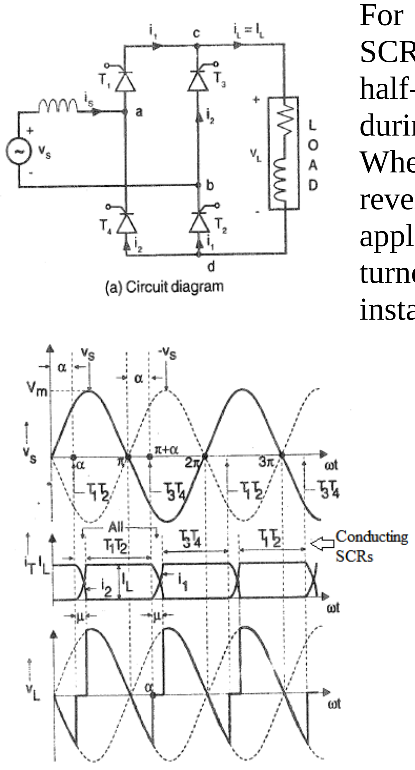
2 marks for waveforms

4. At current zero, the SCRs are turned off and load gets isolated from source, causing load voltage zero till the firing of next pair of SCRs.
5. If load inductance is large, the load current never falls to zero. The current attempts to fall, but before it could fall to zero, the next pair of SCR get fired and we get continuous conduction.
6. In this situation, the reversed voltage appears across load after the end of each half cycle till the firing of next pair of SCRs as shown in the waveform.

6 b) Give the effect of source impedance on converter operation.

Ans:

Effect of source impedance on converter operation:



(a) Circuit diagram

(b) Waveforms

Effect of Source Inductance on the performance of 1-ph full converter.

For single-phase fully controlled bridge converter, the SCRs are triggered in pairs alternately. During positive half-cycle of input, SCRs T_1 and T_2 are triggered whereas during negative half-cycle, SCRs T_3 and T_4 are triggered. When T_1 and T_2 are conducting, T_3 and T_4 are off. On the reversal of supply voltage, firing of T_3 and T_4 causes application of reverse bias across T_1 and T_2 and they are turned off. The current shifts from T_1 T_2 to T_3 T_4. The instantaneous current shift is possible only when the voltage source has no internal impedance. In practice, the source always possesses some internal impedance may be due to the transformer on supply side.

1 mark circuit diagram

2 marks for waveforms

1 mark for effect of source resistance

1) If the source impedance is purely resistive, then voltage drop across it causes reduction in input voltage and ultimately in the output voltage of converter.

2 marks for effect of source inductance

2) If the source impedance is largely inductive, then source current cannot change instantly. The current cannot get transferred immediately from outgoing SCRs to incoming SCRs. The commutation of SCRs is delayed. During current transfer, both pairs of SCRs conduct simultaneously and load voltage appears zero. As both pairs of SCRs conduct simultaneously, this commutation period is called "overlap period (μ)". The output dc voltage is given by,

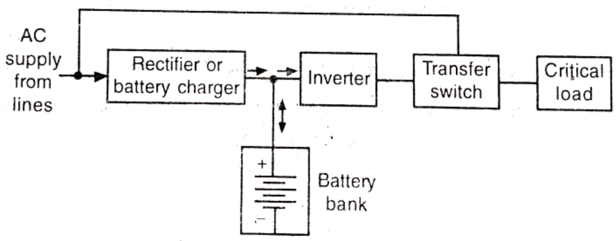
$$V_{dc} = \frac{2V_m}{\pi} cos\alpha - \frac{\omega L_s}{\pi} I_L$$

As source inductance (L_s) increases, the commutation period (overlap angle μ) increases and as a consequence, the output dc voltage decreases.

6 c) Explain the operation of UPS with a neat block diagram.

Ans:

Uninterruptible-Power-Supplies (UPS):



A UPS block diagram

2 mark for block diagram

A block diagram of UPS system is shown in figure. It essentially consists of four major components:

i)Rectifier (or battery charger) ii) Battery bank

iii) Inverter vi) Transfer switch

i) Rectifier (or battery charger):

Its function is to convert available AC supply at input line into DC supply and then to feed DC power to inverter and also to battery bank to keep it charged. It is designed to handle the total current supplied to inverter and battery bank. 1 mark for each block explanation = 4 marks

ii) Battery bank:

It consists of number of batteries in series. The rating and number of units in the bank depends upon the following factors: Input voltage required by inverter, Back-up time requirement of UPS, Efficiency of inverter and load power.

When the line voltage is present, the battery trickle charged to compensate for the slight self-discharge. The battery continuously draws a small amount of current to maintain itself in a fully charged state.

When AC input fails, battery supplies DC power to inveter, wherein it is converted into AC and then fed to load. During this period, the battery discharges. On recovery of AC mains supply, the battery charging starts.

iii) Inverter:

It is used to convert DC supply available at its input terminals into AC supply. The filter is normally used at the output of inverter to minimize the harmonic distortion. Most of the loads are highly non-linear and inject large harmonic currents into the UPS.

iv) Transfer switch:

It is a change over switch. When AC supply is available, the transfer switch connects load to AC supply directly. However, when AC supply from line is not available and load demands for AC supply, the transfer switch can be placed to connect inverter output AC supply to the load. Due to fast action requirement, transfer switch can be implemented by fast acting semiconductor devices.