Model Answers

Winter – 2018 Examinations

Subject & Code : Power Electronics (17638)

Important Instructions to examiners:

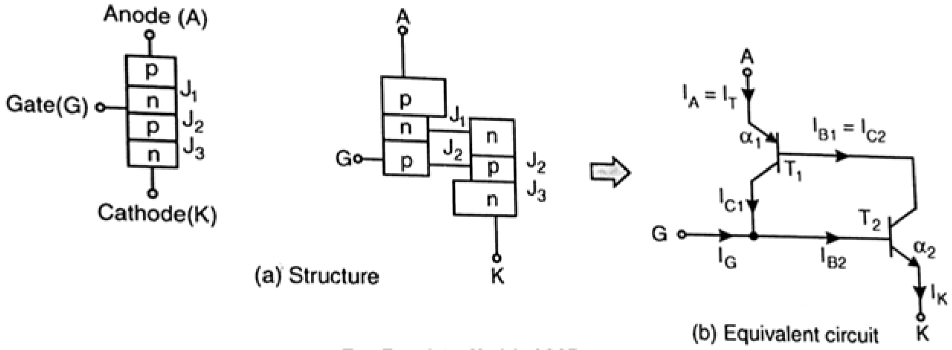
1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner may try to assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling 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.

1 Attempt any THREE of the following: 12

1 a) i) Describe two transistor analogy of SCR using neat sketch.

Ans:

Two-transistor Analogy 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.

1 a) ii) Compare single phase & 3 phase converter on basis of i)Efficiency ii)Ripple factor

iii)RMS value iv)Average value

Ans:

Particulars	**3ϕ Converter**	**1ϕ Converter**
Efficiency	For constant load current, the rectification efficiency is more and given by, $\eta = \dfrac{3cos\alpha}{\pi\left(\frac{1}{2}+\frac{3\sqrt{3}}{4\pi}cos2\alpha\right)^{\frac{1}{2}}}$	For constant load current, the rectification efficiency is less and given by, $\eta = \dfrac{2\sqrt{2}}{\pi}cos\alpha$
Ripple factor (RF)	RF = $\sqrt{\left[\frac{\pi^2}{9cos^2\alpha}\left(\frac{1}{2}+\frac{3\sqrt{3}}{4\pi}cos2\alpha\right)-1\right]}$ Less voltage ripple factor for same firing angle.	RF = $\sqrt{\left[\frac{\pi^2}{8cos^2\alpha}-1\right]}$ More voltage ripple factor for same firing angle.
RMS Values	With continuous conduction and without free-wheeling diode, the output rms voltage depends on the firing delay angle α. $V_{rms} = \sqrt{3}V_m\left[\frac{1}{2}+\frac{3\sqrt{3}}{4\pi}cos2\alpha\right]^{\frac{1}{2}}$	With continuous conduction and without free-wheeling diode, the output rms voltage is equal to the input rms voltage. $V_{rms} = \frac{V_m}{\sqrt{2}} = Vs$
Average Values	More average or DC voltage for same firing angle and phase voltage. $V_{dc} = \dfrac{3\sqrt{3}V_m}{\pi}cos\alpha$	Less average or DC voltage for same firing angle and phase voltage. $V_{dc} = \dfrac{2V_m}{\pi}cos\alpha$

1 mark for each correct difference

= 4 Marks

1 a) iii) Describe the harmonic reduction by single pulse width modulation method.

Ans:

Harmonic Reduction by Pulse Width Modulation (PWM):

The output voltage of single-phase bridge inverter is normally a square-wave as shown in fig.(a). From Fourier analysis, it is seen that the square wave output contains odd harmonics. The amplitude of n^{th} odd harmonic component in square wave is given by,

$$V_{Lnm\_sw} = \frac{4E_s}{n\pi}\ for\ n = 1,3,5, ...$$

In single-pulse modulation (SPM), the output pulse is delayed at start and advanced at the end by equal interval (π-δ)/2, as shown in fig.(b), where δ is the pulse width. Such a wave is called a quasi-square wave. In SPM control, the width of a pulse δ is varied to control the inverter output voltage.

From Fourier analysis, it is seen that the amplitude of the n^{th} harmonic component in quasi-square wave is given by,

2 marks for Diagram + 2 marks for Explanation =4 marks

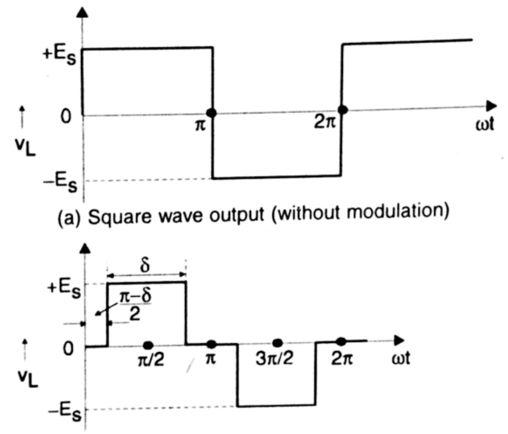
$$V_{Lnm\_Qsw} = \frac{4E_s}{n\pi}\ sin\left(\frac{n\delta}{2}\right)$$

The peak value of the fundamental component for pulse width δ = π is given by,

$V_{L1m\_Qsw} = \frac{4E_s}{\pi}$

It is seen that if δ = 2π/n, then $V_{Lnm\_Qsw} = 0$. Thus by adjusting the pulse width δ equal to 2π/n rad particular n^{th} harmonic can be eliminated. e.g if δ = 2π/3, then $V_{L3m\_Qsw} = 0$, the third harmonic component is eliminated.

Thus the harmonic reduction is possible using single-pulse-modulation.

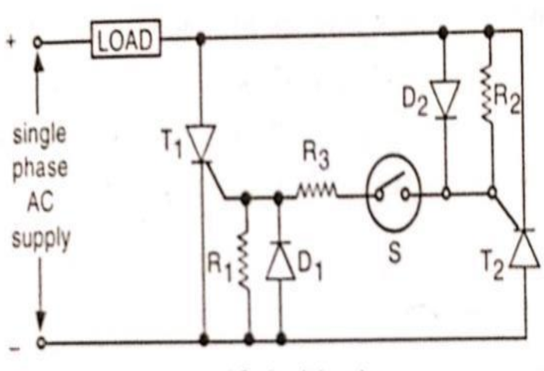


b) Quasi-square wave output (output with modulation)

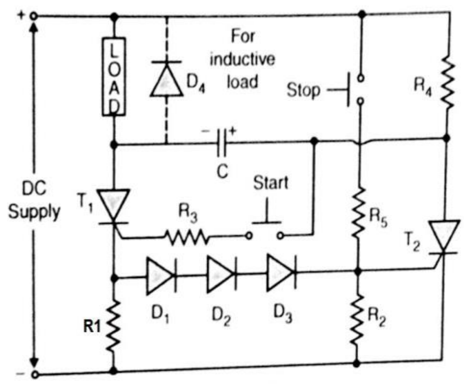
1 a) iv) (1) Draw static AC circuit breaker.

(2) Draw static DC circuit breaker.

Ans:



AC circuit breaker



DC static Circuit Breaker

2 marks for each diagram = 4 Marks

1 b) Attempt any ONE of the following: 6

i) Draw V-I characteristics of : 1)DIAC 2)TRIAC 3)GTO

Ans:

1) DIAC:

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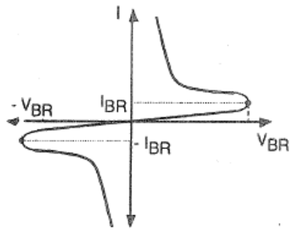
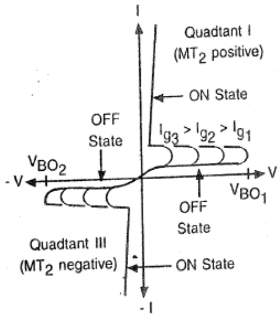


V-I Characteristics

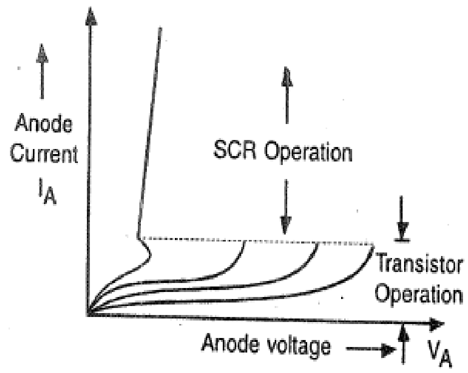
Correct V-I characteristic 2+2+2 = 6 marks

2) TRIAC:



V-I Characteristics

3) GTO:



V-I characteristics of GTO

1 b) ii) Descibe the operation of parallel inverter with sketch & waveform. List two advantages.

Ans:

Parallel Inverter:

The circuit diagram of basic parallel inverter is shown in fig.(a). The load is connected on the secondary side of centre-tapped transformer. The commutating capacitor C is connected across full primary winding, hence appears effectively in parallel with load. This is the reason why the inverter is termed as parallel inverter.

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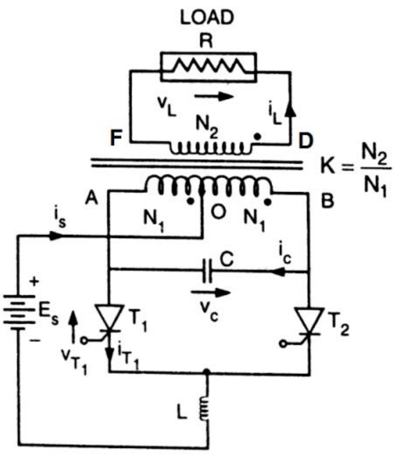
When T_1 is turned on, the DC source voltage E_s appears across half primary winding OA, neglecting small voltage drop in inductor L. Due to auto-transformer action, same voltage E_s is induced in other half primary winding OB. Thus total voltage across full primary becomes $2E_s$ with terminal B positive with respect to A. Since capacitor C is in parallel with full primary, it gets charged to $2E_s$ with right plate positive. The voltage is induced in secondary with terminal D positive with respect to terminal F. The charged capacitor C is placed across non-conducting SCR T_2 via conducting SCR T_1. Thus T_2 get forward biased is ready to conduct.



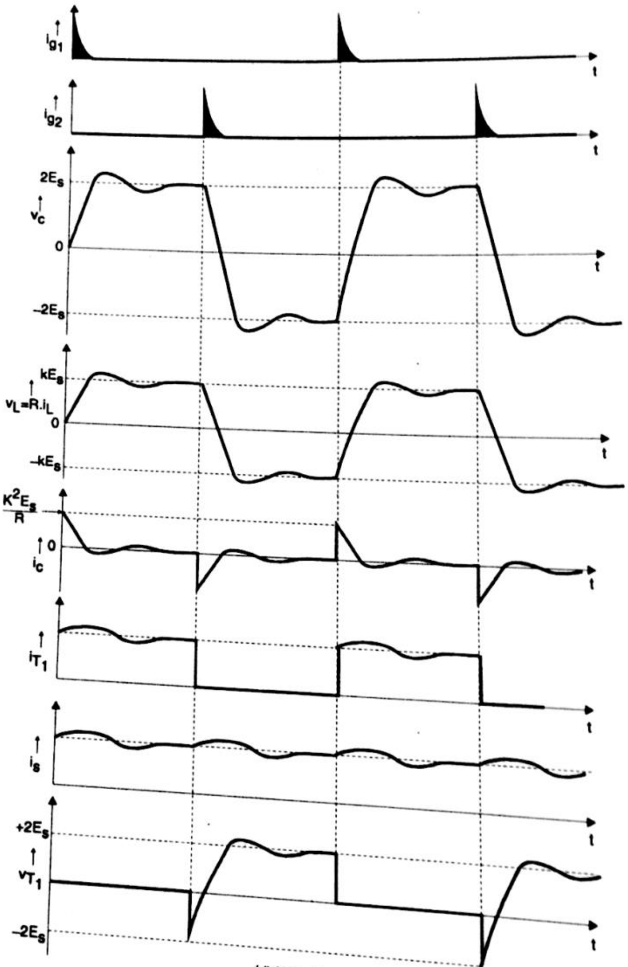
(a) Circuit arrangement

2 marks for circuit diagram

2 marks for explanation of circuit operation

When gate pulse is applied to T_2, it is turned on and charged capacitor C is placed across T_1 via T_2. It causes reverse bias across T_1 and it is turned off. The capacitor then discharges through T_2, L and DC source and recharges with opposite polarity to $-2E_s$. Thus primary voltage gets reversed, which also cause reversal of secondary (load) voltage. It is seen that the charged capacitor always provides forward bias to non-conducting SCR. If that SCR is gate triggered, it is turned on and already conducting SCR is turned off due to reverse bias provided by the capacitor placed across it through just triggered SCR.

Ideally the voltages across primary and secondary have rectangular waveforms but due to capacitor charging and non-linearities in magnetic circuit, the primary and secondary voltage waveforms appear close to trapezoidal. The waveforms of load voltage, SCR voltage, source current, SCR current and capacitor current are shown in Fig.(b).



(d) Waveforms

1 mark for waveforms

Advantages of Parallel Inverter:

1 mark for advantages

i) With the use of feedback diodes, the load reactive power is fed back to DC source and the efficiency is improved.

ii) Two SCRs are required, as compared to at least four required in bridge inverter.

iii) The frequency of output voltage is independent of load, it depends upon the triggering frequency of SCRs.

2 Attempt any FOUR of the following: **16**

2 a) List various triggering method. Describe any one.

Ans:

SCR Triggering Methods:

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 any four triggering methods

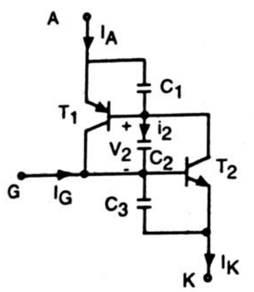
1) Forward Voltage Turn-on:

When the forward anode-to-cathode voltage V_{AK} is greater than forward break over voltage V_{BO} sufficient leakage current flows. The energy of leakage current carriers arriving at reverse biased junction is sufficient to dislodge additional carriers. These carriers in turn dislodge more carriers and this carrier multiplication due to regenerative action results in avalanche breakdown of junction. The anode current is sharply increased. This type of turn on may damage device by thermal runaway. Therefore this method is normally not adopted for turning on SCR, however it is employed to switch four layer diodes into conduction.

3 marks for explanation of any one triggering method

2) dv/dt turn-on or Triggering of Thyristor:

Any p-n junction has capacitance. Under transient conditions, these capacitances influence the characteristics of SCR. Fig. shows two-transistor transient model of SCR wherein the junction capacitances have been shown external to the transistors. If SCR is in forward blocking state and rapidly rising voltage is applied between anode and cathode, the high current will flow through the device to charge the capacitors. The current through capacitor C_2 (junction J_2) can be expressed as:



Two-traisistor transient model of thyristor

$$i_2 = \frac{d(q_2)}{dt} = \frac{d}{dt}(C_2V_2) = V_2\frac{dC_2}{dt} + C_2\frac{dV_2}{dt}$$

where, C_2 = capacitance of junction J_2

V_2 = voltage across junction J_2
q_2 = charge in the junction J_2

If the rate of rise of the voltage $\frac{dV_2}{dt}$ is large, then current i_2 would be large. As these capacitor currents are basically leakage currents, the transistor leakage currents i_{CBO1} and i_{CBO2} would be increased. The high values of leakage currents may cause $(\alpha_1 + \alpha_2)$ tending to unity and result in unwanted turn-on of the SCR by regenerative action. The rapidly rising anode voltage produces charging current through the junction capacitance, leading to gate terminal. This current then acts as gate current and SCR is triggered.

3) Temperature:
High temperature generates the additional carriers and hence leakage current is increased. At high temperatures, the leakage current in a reverse biased p-n junction is doubled approximately with 8°C rise in junction temperature. This increase in currents cause anode current I_A to increase, which further causes α_1 and α_2 to increase. Due to regenerative action, $(\alpha_1+\alpha_2)$ may tend to be unity and thyristor may be turned on. Such turn-on may cause thermal runaway and therefore it is avoided.

4) Gate Turn-on:
With anode voltage positive with respect to cathode, if positive voltage is applied to gate with respect to cathode, the gate current is injected into the structure. In two-transistor analogy, the gate current I_G increases the emitter current of T_2i.e cathode current I_K, which further leads to increase in current gain α_2. So collector current I_{C2} which is base current I_{B1} is increased. This causes I_{C1} and I_{E1}i.e anode current I_A to increase. Thus emitter currents and current gains tend to increase in regenerative action and finally thyristor is turned on. This is the method normally adopted for turning on the conventional thyristors.

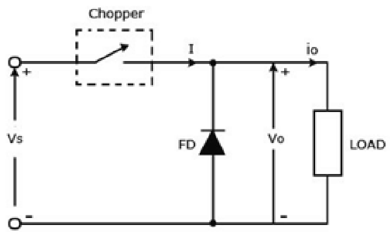
5) Radiant Energy (Light) Turn-on:
If light is allowed to strike the junctions of thyristor, due to incident radiant energy, considerable numbers of electron-hole pairs are released. This increase in current carriers, results in leakage currents to increase above a level when the regenerative action starts and the thyristor is turned on.

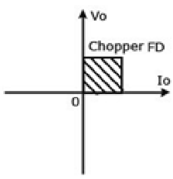
2 b) Draw & describe Class A chopper

Ans:

Class A chopper:

Chopper First Quadrant





2 marks for diagram + 2 marks explanation = 4 marks

This type of chopper is shown in the figure. It is known as first-quadrant chopper or type A chopper. When the chopper is on, $V_0 = V_S$ and as a result the current flows through the load as shown in the figure. But when the chopper is off V_0 is zero but I_O continues to flow in the same direction through the freewheeling diode FD, thus average value of voltage and current say V_0 and I_0 will be always positive as shown in the graph. In type A chopper the power flow will be always from source to the load. As a result, the average voltage V_0 is less than the dc input voltage Vs.

OR

Give full credit to any relevant diagram & Explanation

2 c) Define inverter give its classification?

Ans:

Inverter:

Inverter is a circuit which converts dc power into ac power at desired output voltage and frequency.

1 mark for definition + 3 marks for classification on any three basis

Classification:

Inverters are classified as:

i) According to nature of input source
- Voltage source inverter (VSI)
- Current source inverters (CSI)
- Current source inverter (CSI)

2) According to the wave shape of the output voltage.
- Sine wave inverter
- Square wave inverter
- Quasi square wave inverter
- Pulse width modulated inverter

3) According to the wave inverter
- line commutated inverter
- forced commutated inverter

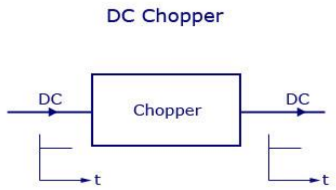
4) According to the connection of thyristor and commutation components
- Series inverter
- Parallel inverters
- Bridge inverters which are further classified as half bridge and full bridge.

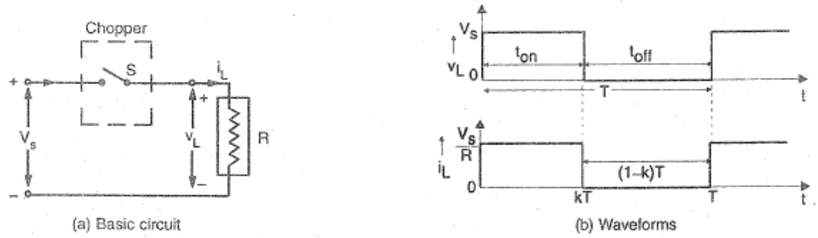
5) According to the semiconductor device used
- Thyristorised inverter
- Transistorized inverter
- MOSFET based inverter
- IGBT based inverter

2 d) State working principle of chopper with neat diagram.

Ans:

Working Principle of Chopper:





2 marks for diagram + 2 marks for explanation

A chopper is a device which converts fixed DC voltage into variable DC voltage.

A chopper is a high-speed On/Off semiconductor switch. During period t_{on}, the chopper is on and the load voltage is equal to the soure voltage. During period t_{off}, the chopper is off and the load voltage is zero. In this manner, chopped DC voltage is produced at the load terminals. The average load voltage is given by,

$$V_{Lav}=\frac{1}{T}\int_0^T V_L\,dt$$

$$V_{Lav}=\frac{1}{T}\left[\int_0^{t_{on}} V_L\,dt\right]$$

$$V_{Lav}=\frac{1}{T}\left[\int_0^{t_{on}} V_s dt\right]$$

$$V_{Lav}=\frac{V_s(t_{on}-0)}{T}$$

$$V_{Lav}=\frac{V_s t_{on}}{T}$$

$$V_{Lav}=kV_s$$

Where, k is the duty cycle.

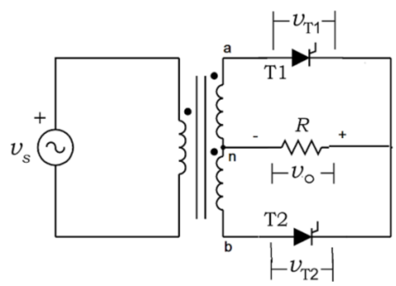
Duty cycle of chopper is defined as the ratio of the on time ton of chopper to the period T (= t_{on} + t_{off}) of the on-off cycle of chopper.

2 e) Draw & Describe mid-point converter with resistive load. Draw its load voltage waveform.

Ans:

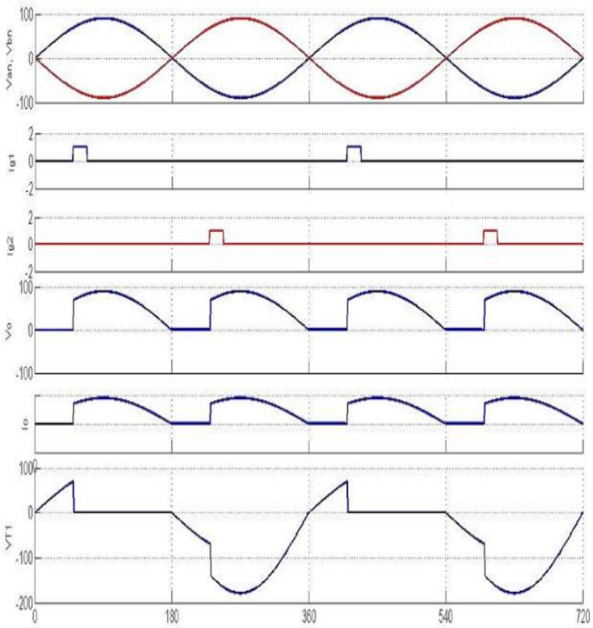
Midpoint converter with resistive load:

1 mark for diagram + 1 mark for waveform + 2 marks for explanation



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) 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.

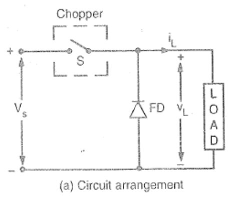
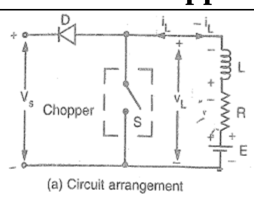


3 **Attempt any FOUR of the following:** **16**

3 a) Compare Class 'A' and Class 'B' chopper. (Any four points)

Ans:

Comparison of class A and class B chopper:

Particulars	**Class A Chopper**	**Class B Chopper**
Circuit Diagram		

1 mark each of any four points = 4 marks

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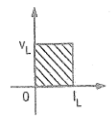
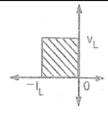
Quadrant of operation	 (b) Single-quadrant operation	 (b) Single-quadrant operation
Power Transfer	From source of higher voltage to the load of lower voltage	From load of lower voltage to the source of higher voltage
Load voltage current directions	Load voltage and current are always positive or zero.	Load voltage is always positive or zero but load current is always negative or zero.
Application	Step-down chopper Load voltage is less than input source voltage Motoring operation of DC motor	Step-up chopper Load side acts as input and source side acts as output. Regenerative breaking of DC motor

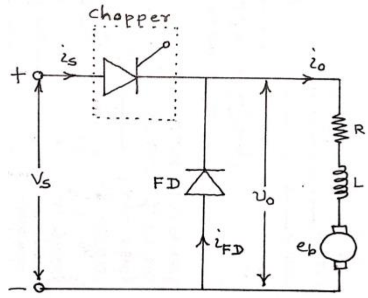
3 b) Describe speed control of DC series motor using step down chopper.

Ans:

Speed control of DC series motor with step down chopper:

Figure shows the basic arrangement for speed control of DC series motor using step down chopper. Armature current is assumed continuous and ripple free. The waveforms for the source voltage V_s, Motor terminal voltage v_0, motor current i_0, dc source current i_s and freewheeling diode current i_{FD} are also shown.

2 marks for explanation



Average motor voltage is given by,

$$V_0 = \frac{t_{on}}{T} V_s = \alpha V_s = f t_{on} V_s$$

where α = duty cycle = $\frac{t_{on}}{T}$

and f = Chopping frequency = $\frac{1}{T}$

Power delivered to motor is given by,

Power delivered to motor = Average motor voltage × Average motor current

$$= V_t I_a = \alpha V_s I_a$$

Motor voltage equation can be expressed as,

$$V_0 = \alpha V_s = E_b + I_a(R_a + R_{se})$$

The back emf is proportional to speed,

$$E_b \propto \omega_m \therefore E_b = K_m \omega_m$$

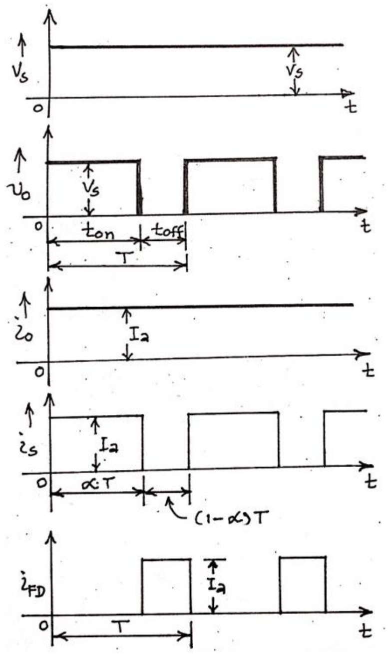
Thus voltage equation becomes,

$$V_0 = \alpha V_s = K_m \omega_m + I_a(R_a + R_{se})$$

The speed can be obtained as,

$$\omega_m = \frac{\alpha V_s - I_a(R_a + R_{se})}{K_m}$$

It is seen that by varying the duty cycle α of the chopper, armature terminal voltage can be controlled and thus speed of the dc series motor can be regulated.

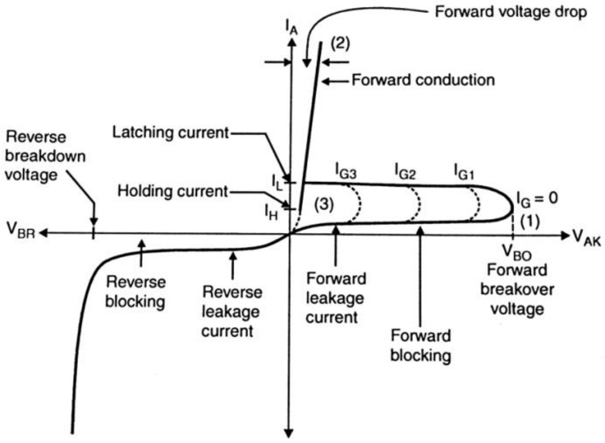


2 marks for diagram

3 c) Draw V-I characteristics of SCR. Define Latching current and Holding current.

Ans:

V-I characteristics of SCR:



V-I Characteristics of SCR

2 marks for characteristics

(i) Latching Current:

Latching current is defined as the minimum anode current required to maintain the SCR in the on-state immediately after the SCR has been turned on and the gate signal has been removed. 1 mark

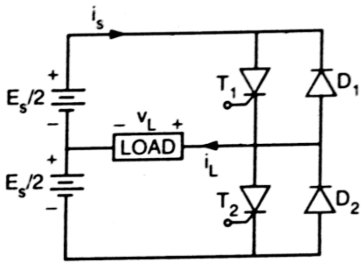
(ii) Holding Current:

Holding current is defined as the minimum anode current required to maintain the already conducting SCR in the on-state. 1 mark

3 d) Describe half bridge inverter with neat diagram.

Ans:

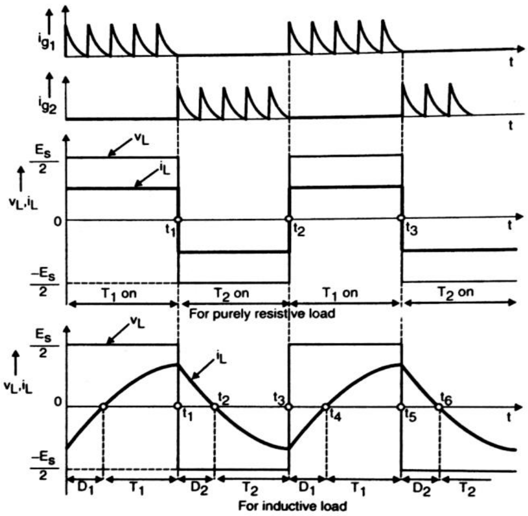
Half bridge inverter:



(a) Circuit arrangement

The circuit diagram of half-bridge inverter is shown in fig.(a). The circuit configuration requires three-wire DC supply, two SCRs and two diodes. The firing and commutation of SCRs is carried out by separate circuits, which are not shown here. The firing pulses and voltage-current waveforms are shown in fig.(b). The SCRs are turned off by commutation circuits when the gate pulses are removed. The SCRs are turned on alternately, thereby providing alternating voltage to the load.

2 marks for description



(b) Waveforms

2 marks for diagram (waveforms optional)

Purely Resistive Load:

Referring to waveforms in fig.(b), at t=0, the SCR T_1 is fired by gate pulse train. Once T_1 conducts, the upper source voltage ($E_s/2$) appears across the load. Thus constant voltage $+E_s/2$ appears across load when T_1 is on and T_2 is off. The load current is positive.

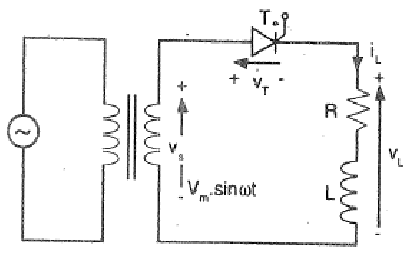
At instant t = t_1, the gate pulses of T_1 are removed and gate pulses are provided to T_2. Thus at t = t_1, T_1 is turned off and upper source voltage appears across T_1 whereas, T_2 is turned on and lower source voltage appears across load. Therefore load voltage is reversed and reversed current flows. During the period when T_2 is on, constant voltage $-E_s/2$ appears across load. Thus alternate switching of T_1 and T_2 causes alternating voltage across load and the load current follows the load voltage variations. The load voltage and load current both have rectangular waveforms as shown in fig.(b).

3 e) Draw and describe half wave converter with RL load.

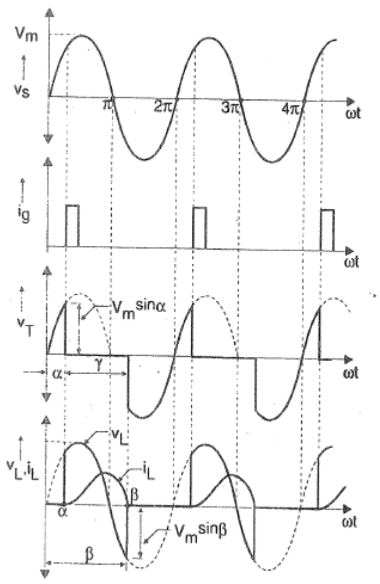
Ans:

Half-wave converter:

The circuit diagram of half wave converter with RL load 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 waveforms appearing across load reduces 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.



(a) Circuit arrangement



(b) Waveforms

1 marks for circuit diagram

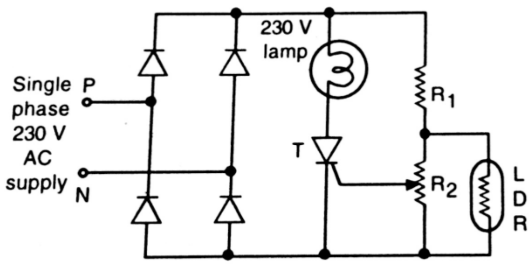
2 marks for explanation

1 marks for waveforms

3 f) Describe automatic street lighting circuit using SCR.

Ans:

Automatic Street Lighting Circuit Using SCR:



Automatic street lighting system

The circuit configuration of automatic street lighting system using SCR is shown in the fig. This circuit provides automatic glowing of street lamps in the evening. A light dependent resistor (LDR) is used as sensor for sensing the intensity of day light. When sufficient light falls on LDR, its resistance becomes very low as compared to R_2. The R_2 is then bypassed by LDR, and major part of current flowing through R_1, flows through LDR. Since negligibly small current flows through R_2, sufficient gate current is not received by SCR T and it is maintained off. Thus no current can flow through lamp and it remains off. 2 marks for circuit diagram 2 marks for description

In the evening hours, the intensity of day light is reduced. Hence resistance of LDR increases. Therefore current through R_2 also increases. At certain darkness, the resistance of LDR becomes so high that the sufficient current flows through R_2 to provide sufficient gate current to SCR and it is fired. Therefore, current flow through lamp and it glows. Since bridge rectifier provides pulsating DC, the SCR is triggered in every positive pulse and turn-off at the end of pulse at natural current zero value, assuming lamp is purely resistive. However, if the lamp is inductive, the lagging current prevents SCR from turning off at the end of positive pulse. Thus once SCR is turned on, it loses control and separate arrangement is necessary to turn-off the SCR.

4 Attempt any FOUR of the following: 16

4 a) i) Describe induction heating control circuit.

Ans:

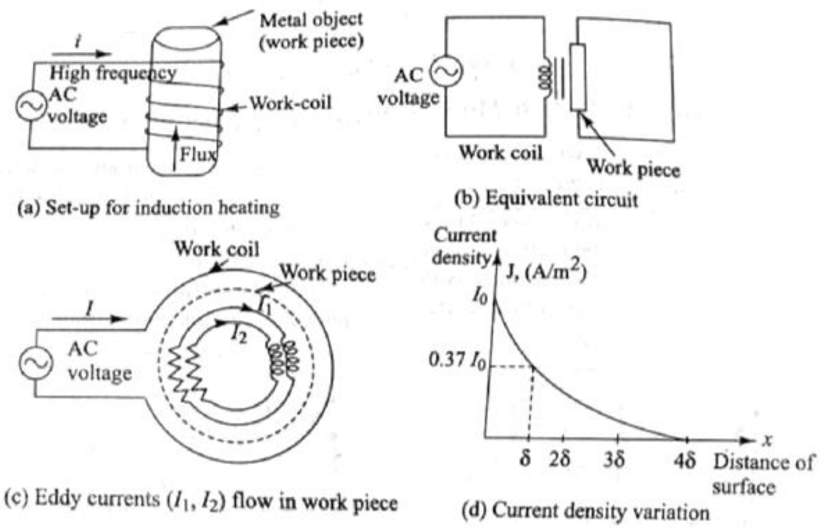
Induction heating control circuit:

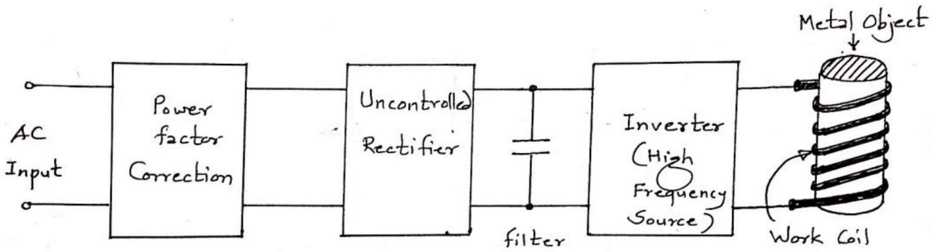
1. When a conducting object is subjected to a changing magnetic field, according to Faraday's laws of electromagnetic induction, emf is induced in the object.
2. The object, being conductor, offers many short-circuited paths. So the circulating current flows through these paths.
3. The currents are in the form of eddies (circular in nature), hence called "eddy currents". 2 marks for description
4. The eddy currents flowing through resistive paths in metal object cause power loss (i^2R loss) and heat is produced.
5. Since the heat is produced by eddy currents, which are induced by electromagnetic induction, this heating is called "Induction heating". The material to be heated is known as the work piece and the coil around it is known as work coil, as shown in the figure.
6. The coil acts as primary and work piece acts as short circuited secondary. When primary is excited by high frequency ac supply, eddy currents are set up in the work piece and electrical power loss heats up the object.
7. For induction heating, high frequency AC supply is obtained using thyristorised

converter circuits.

8. The block diagram of one of such arrangements is shown in the figure. The available AC supply is first converted to DC using uncontrolled rectifier and filter arrangement.
9. Then the DC is converted to AC with required high frequency using thyristorised inverter.
10. Since the load is highly inductive, the power factor of load is too low. So to improve it, power factor correction circuit is employed at the input stage.

Any one labeled figure 2 marks. (graphical figure optional)



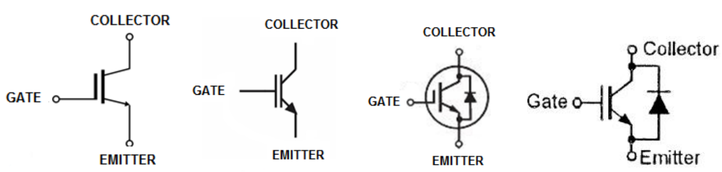


4 a) ii) Draw symbol of :

(1) IGBT
(2) SCR
(3) GTO
(4) SUS

Ans:

1) IGBT:



1 mark for each bit

2) SCR:

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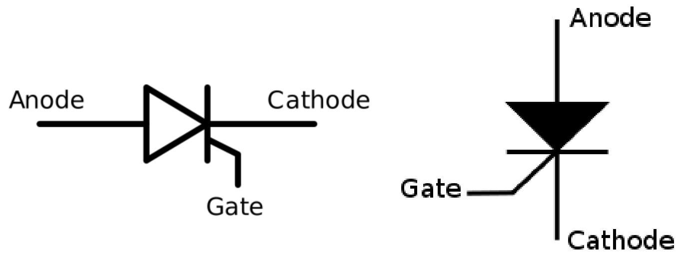
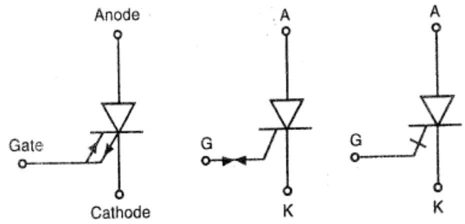
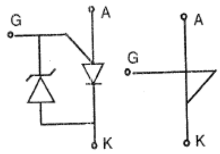


3) GTO:



GTO Symbols

4) SUS:

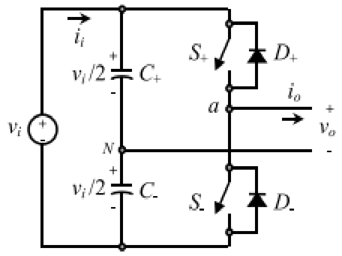
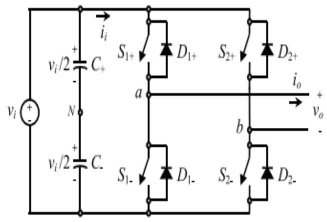
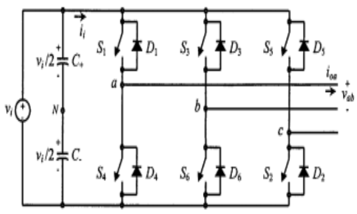


SUS Symbol

4 a) iii) Compare single phase inverter and 3 (three) phase inverter (any four).

Ans:

Comparison between Single-phase Inverter with Three-phase Inverter:

Sr. No.	Single phase inverter	Three phase inverter
1.	 1 phase half bridge inverter  1 phase full bridge inverter	 3 phase inverter

1 mark for each of any four points = 4 marks

2.	Single-phase inverter has only one pair of load terminals.	A three-phase inverter has three-phase load terminals.
3.	The pole voltages of the 1-phase inverter are phase apart by 180^0 each	The pole voltages of the 3-phase inverter are phase apart by 120^0 each
4.	Single-phase inverter is used for low-range power applications VSIs cover the medium- to high-power applications	Three-phase inverter is used for medium- to high-power applications
5.	Single phase inverters are basic inverters which produce a square shape single phase AC output with a DC input.	Three phase inverters are inverters which produce three phase stepped AC output with a DC input.
6.	There are two or four valid switches	There are the six valid switches

4 a) iv) Describe cyclo-converter with neat diagram and waveforms.

Ans:

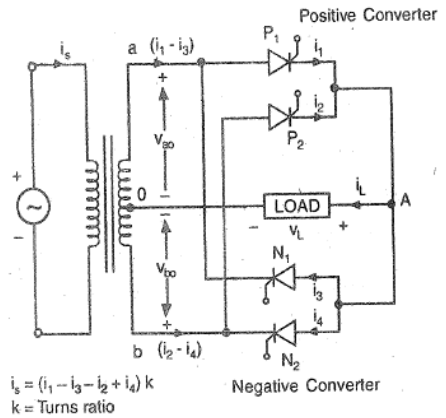
Cycloconverter:

Single-phase mid-point and bridge cycloconverter are as shown in fig. (a) and (b) respectively. Each cycloconverter has two converters: P-converter and N-converter. When SCRs in P-converters are fired in alternate positive and negative half cycles, we get positive voltage across load. Similarly, when SCRs in N-converter are fired in alternate positive and negative half cycles, we get negative voltage across load. Thus for fixed frequency input AC supply, we can obtain positive or negative voltage across load for longer duration (half-cycle) i.e output frequency is reduced.

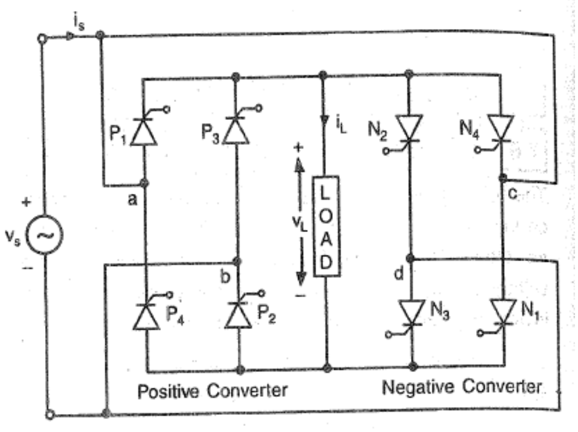
2 marks for description

1 mark for circuit diagram

1 mark for waveforms

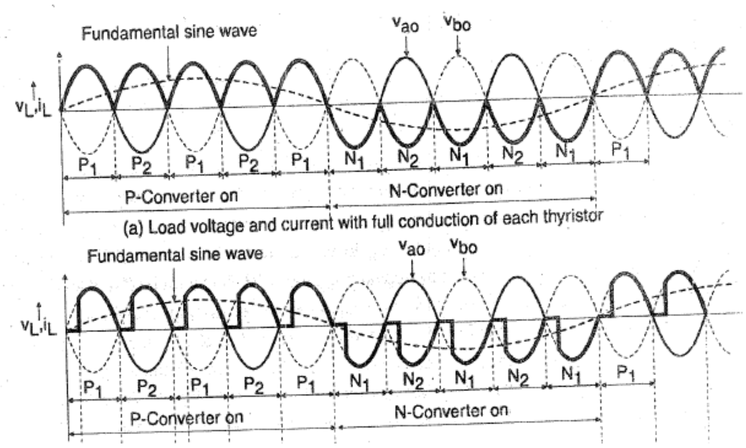


(a) Single-phase Mid-point cycloconverter



(b) Single-phase Bridge type cycloconverter

The basic operation is reflected in waveforms. In waveform diagram it is seen that the positive half cycle of output voltage is fabricated from five half cycles of input AC, so the output frequency is $1/5^{th}$ of input supply frequency.



4 b) **Attempt any <u>ONE</u> of the following:** **6**

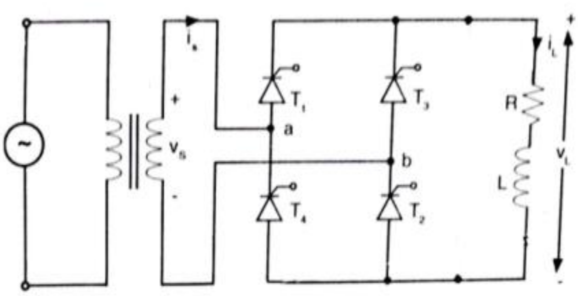
4 b) i) Draw and describe single phase fully control bridge converter with RL load also draw its neat waveform.

Ans:

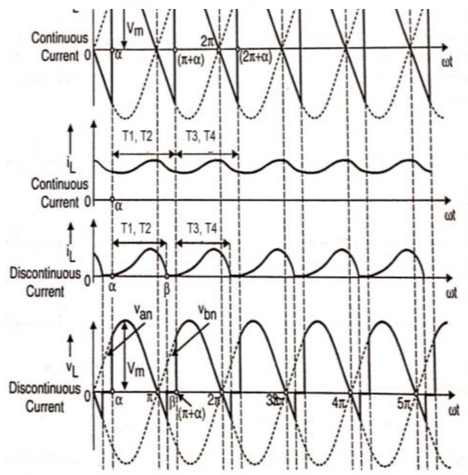
Single phase fully control bridge converter with RL load:

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). 2 marks for description
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. 2 marks for circuit diagram

2 marks for waveforms



(a) Circuit arrangement



(b) Waveforms

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.
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

4 b) ii) Describe speed control of three phase induction motor with neat diagram and waveform (any one method).

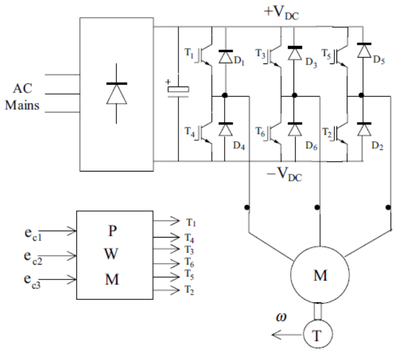
Ans:

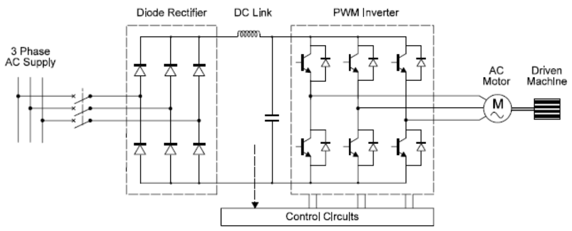
Methods of Speed Control of three-phase Induction Motor:

1) Stator voltage control
2) Rotor resistance control

3) Supply frequency control
4) Stator voltage and frequency (v/f) control
5) Stator current control
6) Voltage, current and frequency control

Variable frequency control of induction motor:





3 marks for diagram

The speed of an induction motor can be controlled by varying the supply frequency. When the supply frequency is changed, the synchronous speed N_s (=120f/P) is changed and accordingly the motor speed get changed.

3 marks for explanation

If the supply frequency f is changed to f* such that f* = β.f, the synchronous speed at new frequency f*becomes,

$N_s^* = \frac{120f^*}{P} = \frac{120\beta f}{P} = \beta N_s$ and the slip becomes $s^* = \frac{\beta N_s - N}{\beta N_s} = 1 - \frac{N}{\beta N_s}$

The maximum torque developed at any supply frequency is inversely proportional to the square of frequency. Therefore, maximum torque gets reduced in inverse proportion when frequency is increased.

When the frequency is changed, the values of the reactances in the equivalent circuit are changed and therefore circuit currents are also changed. If the frequency is increased above its rated value, the reactances are also increased, the currents fall, the flux and maximum torque get decreased but synchronous speed is increased and motor speed is also increased.

With a Sinusoidal Pulse Width Modulated (SPWM) inverter indicated in figure, the supply frequency to the motor can be easily adjusted for variable speed. However, if rated airgap flux is to be maintained at its rated value at all speeds, the supply voltage to the motor should be varied in proportion to the frequency. In the figure, the dc voltage obtained from diode rectifier remains constant and the PWM technique is applied to vary both the voltage and frequency within the inverter.

OR Any other method

5 Attempt any FOUR of the following: 16

5 a) Describe static VAR compensation system with a neat diagram.

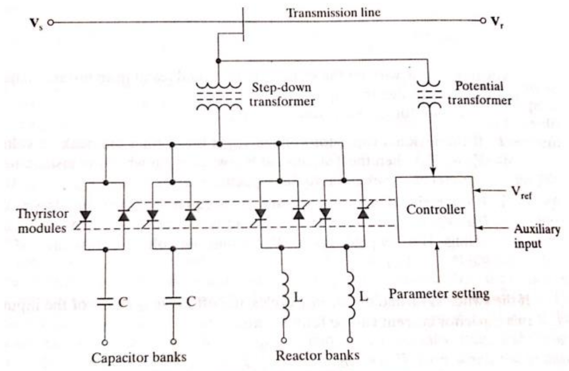
Ans:

Static VAR compensator:

- Static VAR compensation is a process of compensating the reactive power in the power system using static switches (semiconductor switches). In this process, the reactors and capacitors are switched to absorb or supply the reactive power

2 marks diagram

respectively.



General arrangement of static VAR compensator

2 marks Description =4 marks

- Static VAR compensators (SVC) consists of combinations of thyristor controlled reactor (TCR), thyristor switched capacitor (TSC) and fixed capacitor (FC).
- The electrical transmission and distribution networks are dominantly reactive in nature. During no or light load condition, the line capacitances play major role to produce the reactive power. If this reactive power is not absorbed by load then voltage rises and may cross the limit. In this situation, TCR is used to insert reactors in power system to absorb the reactive power.
- During peak load condition, most of the loads are inductive and they demand the reactive power. In this situation, TSC is used to insert capacitors in power system to generate the reactive power.
- In fact, SVC comprises combinations like (TCR+TSC), (TCR+FC) as per the need.
- In TCR, phase control is used to vary the effective inductance of the inductor.
- In TSC, the integral-cycle control is employed to vary the effective capacitance of the capacitor.

5 b) List any four specification of SCR

Ans:

1. **Voltage Rating:**
   - i) Peak working forward-blocking voltage V_{DWM}
   - ii) Peak repetitive forward-blocking voltage V_{DRM}
   - iii) Peak surge or non-repetitive forward blocking voltage V_{DSM}
   - iv) Peak working reverse voltage V_{RWM}
   - v) Pear repetitive reverse voltage V_{RRM}
   - vi) Peak surge or non-repetitive reverse voltage V_{RSM}
   - vii) On-state voltage drop V_T
   - viii) Finger voltage
   - ix) Forward dv/dt rating (Critical rate of rise voltage)

1 mark for each of any four = 4 marks

2. **Current Rating:**
   - i) Average on-state current I_{TAV}
   - ii) RMS current I_{Trms}
   - iii) Surge current rating I_{TSM}
   - iv) I^2t rating
   - v) di/dt rating
3. **Power Rating:**
   - i) Maximum gate power P_{gm}
   - ii) Average gate power P_{gav}
   - iii) Average Power dissipation (Forward on-state conduction loss)
   - iv) Loss due to leakage current during forward and reverse blocking
   - v) Switching losses during turn-on and turn-off
4. **Temperature Rating:**

i) Maximum junction temperature

5 c) Define duty cycle of chopper. Explain control techniques used in chopper.

Ans:

Duty cycle of chopper :

It is defined as the ratio of the on time T_{on} of chopper to the period T (= $T_{on} + T_{off}$) of the on-off cycle of chopper.

1 mark for definition

$$Duty\ Cycle\ \alpha = \frac{T_{on}}{T} = \frac{T_{on}}{T_{on} + T_{off}}$$

Chopper Control Techniques:

There are two ways of controlling the chopper operation:

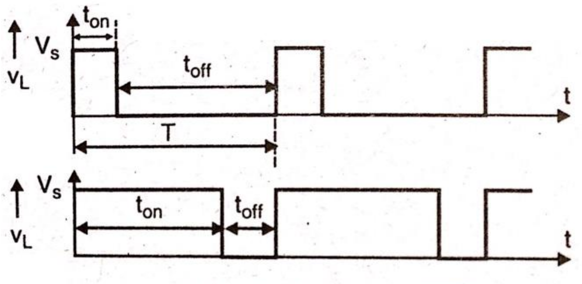
1) Time Ratio Control (TRC)
   (i) Constant frequency system
   (ii) Variable frequency system
2) Current Limit Control (CLC)

3 marks 3 techniques = 4 mark

Time Ratio Control:

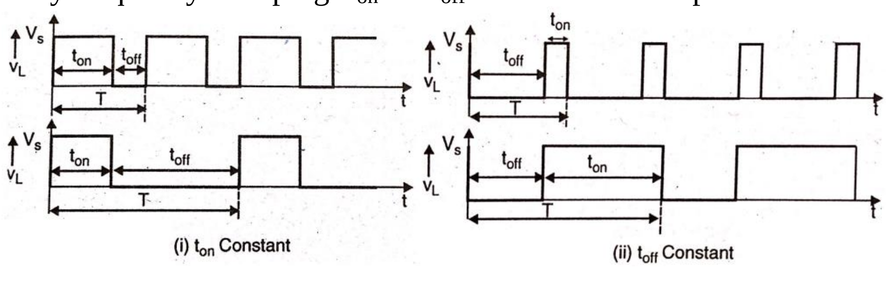
In this technique, the duty cycle 'k' is controlled to control the output voltage. It is carried out by two ways:

(i) Vary T_{on} keeping frequency constant i.e. time period T=1/f constant



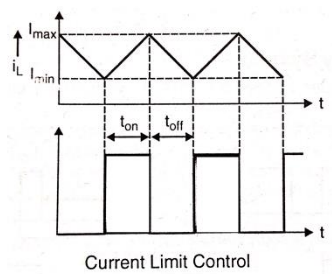
(a) Constant frequency TRC

(ii) Vary frequency f keeping T_{on} or T_{off} constant i.e time period T varies



Current Limit Control:

In this technique, the load current is allowed to vary only between a predetermined maximum and minimum limit. If the load current tends to increase beyond maximum limit, chopper switch is turned off and if the load current tends to fall below the minimum (lower) limit, the chopper switch is turned on. The load current is continuous.

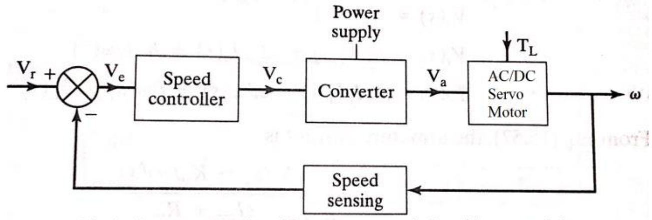


Current Limit Control

5 d) Describe closed loop speed control method for AC servomotor.

Ans:

Closed loop speed control method for AC servomotor:



Block diagram of a closed-loop converter-fed ac/dc motor drive.

A general scheme of closed loop speed control for servomotors is shown in fig. For both types of servomotors, voltage control based speed control scheme is used. DC servomotor is fed from ac-dc converter and AC servomotor is fed from ac controller or inverter. The speed of motor changes with the load torque. To maintain a constant speed, the motor voltage should be varied continuously by varying the delay angle converter. In practical drive systems it is required to operate the drive at a constant torque or constant power with controlled acceleration and deceleration. A closed-loop control system has the advantage of improved accuracy, fast dynamic response and reduced effects of load disturbances and system nonlinearities.

If the speed of servomotor does not match with the set speed, the speed error V_e increases. The speed controller responses with as increased control signal V_c. This control signal changes the operation of converter and voltage supplied to servomotor is changed so as to minimize the speed error.

2 marks diagram

2 marks Description

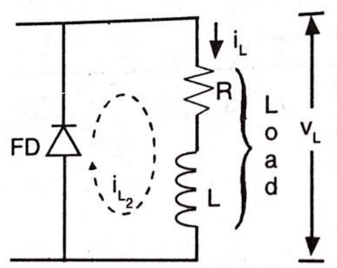
= 4 marks

5 e) State effect of freewheeling diode on converter.

Ans:

Effect of freewheeling diode in converters:

The freewheeling diode (FD) is connected across output or load with its cathode to positive terminal and anode to negative terminal. When the load is highly inductive, the load inductance voltage gets reversed during the fall of load current. The output or load voltage then attempts to reverse but as soon as the reversed voltage becomes more than threshold voltage, the freewheeling diode conducts and provides path for inductive load current. Since diode conducts, it maintains the load voltage nearly equal to zero and prevents from becoming negative. It improves the average load voltage and helps to dissipate the power stored in load inductance.



2 marks diagram

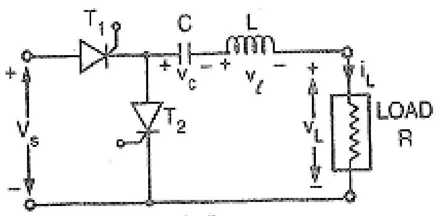
2 marks Description

= 4 marks

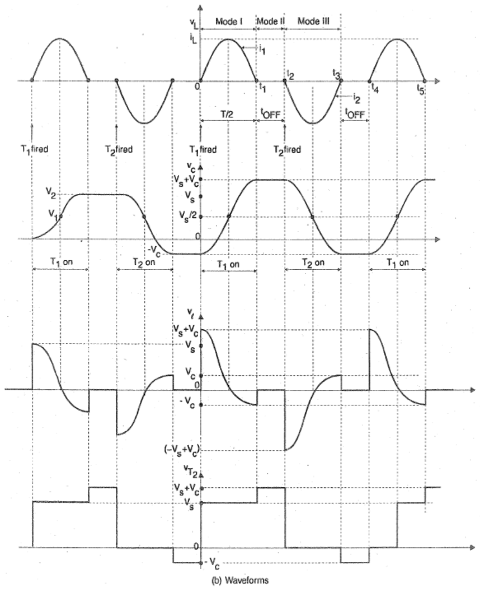
5 f) Draw circuit diagram of series inverter also draw its voltage and current waveform.

Ans:

Circuit diagram of series inverter:



2 marks circuit diagram



Voltage and Current waveforms

2 marks waveforms

= 4 marks

6 Attempt any FOUR of the following: 16

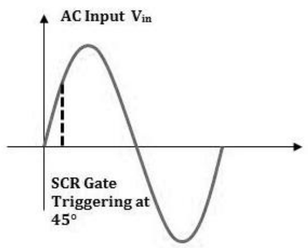
6 a) Define firing angle and conduction angle. Show it on waveform and give relationship between them.

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.

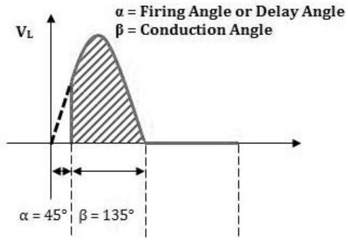
Firing angle or delay angle can be defined as the angle measured from the angle that gives maximum average output voltage to the angle when the SCR is actually triggered or fired by gate pulse.



Definition 1 mark waveform ½ mark

Conduction Angle (β):

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



Definition 1 mark waveform ½ mark

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°

Relation 1 mark = 4 marks

Model Answers
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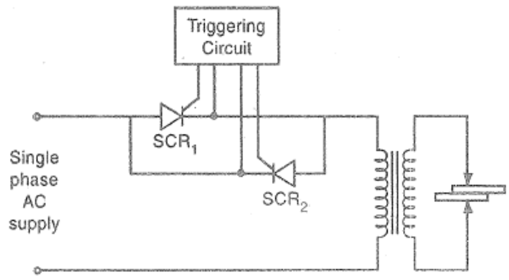
6 b) Describe electric welding control circuit.

Ans:

Electric Welding Control Circuit Using SCR:



Electric Welding Control Circuit using SCR

A simple SCR circuit employing a pair of antiparallel connected SCRs for controlling the primary current of welding transformer is shown in fig. The triggering circuit is not shown in the diagram. During positive half-cycle of input supply voltage, SCR_1 is fired at appropriate angle and during negative half-cycle, SCR_2 is fired. The triggering circuit provides gate pulses to these SCRs at appropriate instants in respective half-cycles. By this phase angle control, the voltage supplied to primary winding is controlled and ultimately the welding current is controlled.

2 marks diagram

2 marks description = 4 marks

6 c) List voltage control method of single phase inverter. Describe any one.

Ans:

Methods of Voltage Control in Inverters:

1) **External Control:**

a) Externally controlling the ac output voltage — 1 mark
   (i) AC voltage control: Using AC voltage controller between inverter & load
   (ii) Series inverter control: Connecting two or more inverters in series

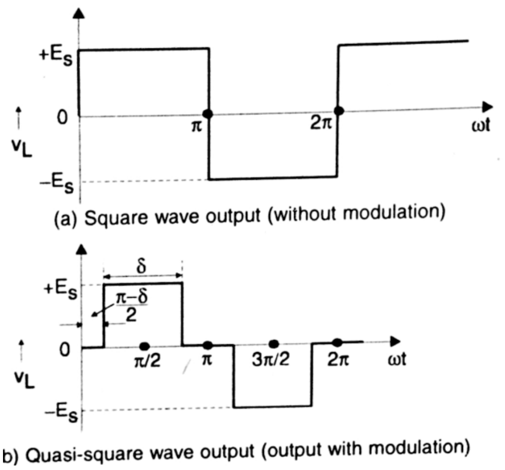
b) Externally controlling the dc input voltage — 1 mark
   (i) Obtaining controlled dc supply for inverter from fully controlled rectifier & filter arrangement.
   (ii) Obtaining controlled dc supply for inverter from uncontrolled rectifier, chopper & filter arrangement.
   (iii) Obtaining controlled dc supply for inverter from AC voltage controller, uncontrolled rectifier, filter arrangement.
   (iv) Obtaining controlled dc supply for inverter from chopper & filter arrangement.

2) **Internal Control:** By controlling the operation of inverter itself – PWM technique

Pulse-Width-Modulation (PWM) Control: — 2 marks description = 4 marks

The output voltage of single-phase bridge inverter is normally a square-wave as shown in fig.(a). The output voltage amplitude E_s depends on the input DC supply voltage. Therefore, to control the output voltage, external control of input DC voltage is required. From Fourier analysis, it is seen that the square wave output contains odd harmonics. The amplitude of n^{th} odd harmonic component in square wave is given by,

$$V_{Lnm\_sw} = \frac{4E_s}{n\pi} \; for \; n = 1,3,5, ...$$



(a) Square wave output (without modulation)
b) Quasi-square wave output (output with modulation)

The fundamental component of square wave output voltage is given by,

$$V_{L1m\_sw} = \frac{4E_s}{\pi}$$

In PWM control, the operation of inverter is controlled such that the width of the pulses in output is controlled. Varying the width of output pulses to control the output voltage is called Pulse Width Modulation (PWM). The most commonly used PWM techniques are:

1) Single-pulse modulation
2) Multiple-pulse modulation
3) Sinusoidal-pulse modulation

In single-pulse modulation (SPM), the output pulse is delayed at start and advanced at the end by equal interval (π-δ)/2, as shown in fig.(b), where δ is the pulse width. Such a wave is called a quasi-square wave. In SPM control, the width of a pulse δ is varied to control the inverter output voltage.

From Fourier analysis, it is seen that the amplitude of the n^{th} harmonic component in quasi-square wave is given by,

$$V_{Lnm\_Qsw} = \frac{4E_s}{n\pi}\, sin\left(\frac{n\delta}{2}\right)$$

The peak value of the fundamental component for pulse width δ is given by,

$$V_{L1m\_Qsw} = \frac{4E_s}{\pi}\, sin\left(\frac{\delta}{2}\right)$$

From above equation it is clear that peak value of the fundamental component is sinusoidal function of (δ/2). Thus by controlling the pulse width δ, the peak and rms output voltage can be controlled.

Other PWM techniques employ multiple switching on and off of thyristor switches in every positive and negative half cycles of output voltage for voltage control.

6 d) Define Chopper. Give its classification.

Ans:

Chopper:

Chopper is a circuit configuration which is a DC to DC converter, which converts Direct voltage into a controlled Direct voltage.

The controlled output DC voltage is obtained by chopping input DC voltage. — 1 mark Definition

Types of Choppers:

The choppers are classified according to following manner:

1) According to Input and Output voltage levels:
   - i) Step-down chopper: $V_{out} \le V_{in}$
   - ii) Step-up chopper: $V_{in} \ge V_{out}$
2) According to the direction of output voltage and current:
   - i) Class A (type A) chopper
   - ii) Class B (type B) chopper
   - iii) Class C (type C) chopper
   - iv) Class D (type D) chopper
   - v) Class E (type E) chopper
3) According to operation:
   - i) Single-quadrant chopper
   - ii) Two-quadrant chopper
   - iii) Four-quadrant chopper
4) According to commutation method:
   - i) Voltage commutated choppers
   - ii) Current commutated choppers
   - iii) Load commutated choppers
   - iv) Impulse commutated choppers

3 marks for any 3 basis = 4 marks

6 e) Describe Jone’s Chopper with neat diagram.

Ans:

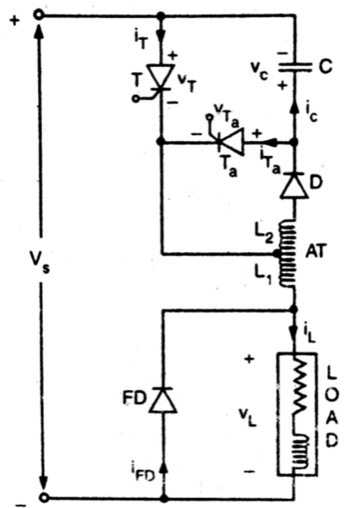
Jones Chopper:

The circuit diagram of Jones Chopper is shown in the fig. It employs class D commutation technique in which a charged capacitor is switched by an auxiliary SCR to commutate the main SCR. The circuit operation can be divided into various modes as follows:

Mode 1: In this mode, the main SCR T is triggered at start and then it conducts the load current. Since L_1 and L_2 are coupled inductors, the applied voltage across L_1 results in emf induced in L_2. This emf charges the capacitor C with shown polarity through diode D and conducting T. When capacitor is fully charged, the charging current falls to zero and cannot reverse due to diode.

2 marks diagram

2 marks Description = 4 marks



Jones chopper

Mode 2: In this mode, the auxiliary SCR T_a is triggered. Once T_a is turned on, the charged capacitor C is placed across main SCR T so as to apply reverse bias across it. Due to this reverse bias and alternate path provided by C and T_a to the load current, the main SCR is turned off. The load current now flowing through C and T_a causes capacitor to discharge fully.

Mode 3: The inductance L_1 and load inductance try to maintain the load current through C and T_a. The load current charges the capacitor with reverse polarity i.e upper plate positive. With rising capacitor voltage, the load current attempts to fall. To maintain the falling load current, the inductive voltages in L_1 and load changes their polarity. The reversal of load voltage V_L forward biases the free-wheeling diode and it conducts. The capacitor gets overcharged due to the energy supplied by V_s and L_1. The load current falls below holding current level of T_a , hence T_a is turned off.

Mode 4: The overcharged capacitor C, with upper plate positive, then starts discharging through V_s, FD, L_1, L_2 and D. The discharging current is in the form of a pulse. At the end of this mode, the capacitor voltage falls to a level less that V_s and therefore current falls to zero and attempts to reverse but diode stops conducting.

Mode 5: The capacitor voltage with upper plate positive is maintained till the next firing of T. The load current is continued through free-wheeling diode till the next conduction of main SCR T.

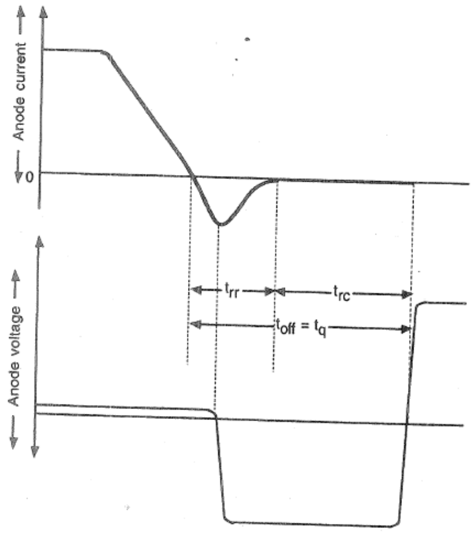
Jones chopper offers flexible control and effective use of trapped energy in coupled inductors. There is no starting problem and any SCR can be triggered at start.

Model Answers
Winter – 2018 Examinations
Subject & Code : Power Electronics (17638)

6 f) Describe turn off process of SCR with neat voltage and current waveform.

Ans:

Forward conducting SCR is turned off means the forward current I_A has been reduced to zero and also SCR has regained its forward voltage blocking capability. During conduction, the two base regions (two-transistor model) are heavily saturated with holes and electrons. When reverse voltage is applied to turn off the SCR, the holes and electrons in the vicinity of two end junctions J_1 and J_3 diffuse and result in reverse current in the external circuit as shown in the figure. So far this reverse current is appreciable in magnitude, the voltage across the SCR remains at about 0.7 volt. The stored charge in SCR structure depends upon the peak forward current, di/dt at the time of commutation and junction temperature.



Dynamic turn-off characteristics

2 marks diagram

2 marks Description = 4 marks

On applying revcerse bias, the forward current is reduced to zero and then reverse current flows. When about 60% of stored charge gets recovered, the reverse current reaches a peak value. Beyond this point, the SCR develops reverse blocking capability and reverse current starts reducing with faster rate. The reverse current must flow until most of the extra stored carriers of junctions J_1 and J_3 have been removed. After this the junction reverts to blocking state and the reverse current reduces to zero (actually to leakage value).

Reverse Recovery Time (t_{rr}): It is the time required to recover (remove) the stored charge (extra carriers) from the vicinity of junctions J_1 and J_3.

At the end of reverse recovery time, the junction J_1 and J_3 are recovered, but junction J_2 still has trapped charges. The SCR can block forward voltage only when this excess carriers at junction J_2 recombine.

Recombination Time (t_{rc}): It is the time require to recombine the excess carriers trapped at junction J_2.

Turn-off Time (t_q): It is the minimum value of time interval between the instant when the on-state current has reduced to zero to the instant when the SCR is capable of withstanding forward voltage.i.e $t_q = t_{rr} + t_{rc}$