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 should assess the understanding level of the candidate.

3) The language errors such as grammatical, spelling errors should not be given 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 should give credit for any equivalent figure/figures drawn.

5) Credits to 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 (as long as the assumptions are not incorrect).

6) In case of some questions credit may be given by judgment on part of examiner of relevant answer based on candidate's understanding.

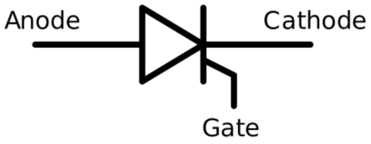
7) For programming language papers, credit may be given to any other program based on equivalent concept

1 a) Attempt any THREE of the following 12

1 a) i) Draw the symbols of – 1) SCR, 2) GTO, 3) IGBT, 4) TRIAC

Ans:

1) SCR



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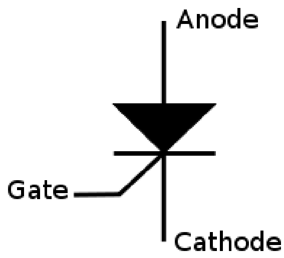
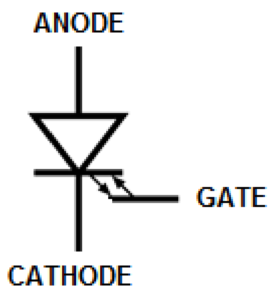


1 mark for any one symbol

2) GTO



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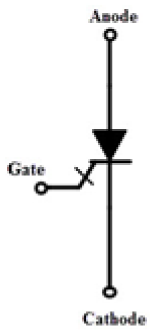
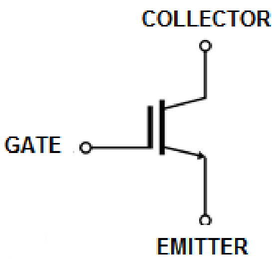


1 mark for any one symbol

3) IGBT



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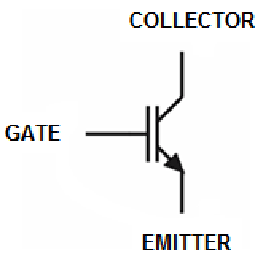

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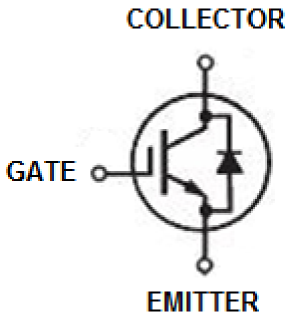

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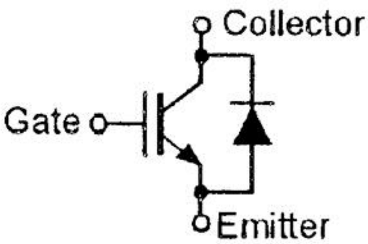
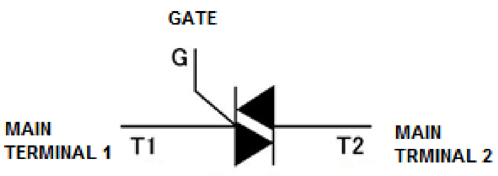


1 mark for any one symbol

4) TRIAC



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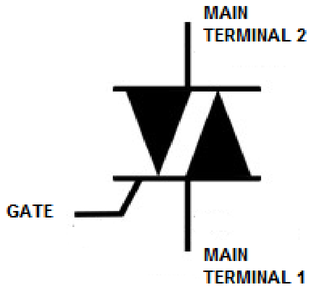


1 mark for any one symbol

1 a) ii) State the necessity of converters and give the classification of controlled converters.

Ans:

Necessity of Converters:

The converters are the circuit configurations whose output is controlled DC supply. There are many applications which require DC supply. A well-known DC source is battery, in which chemical energy is converted into electrical energy. The battery sources have limited energy capacity and discharge during their use. The discharged battery needs recharging for further use. To recharge the battery, it should be connected to another DC supply. Thus there is requirement of alternative DC source for charging the batteries. 2 marks

In present days, the AC supply is used in all stages of power system. It is possible to convert AC supply into DC supply. It eliminates the need of energy storage. The DC load can be fed from such DC supply, which is available as & when AC supply is there. Large DC loads, which are difficult to handle using batteries, can be effectively and continuously supplied from such DC supply. Thus whether small or large, the DC load can be supplied from the DC supply, which is obtained after converting AC into DC. Thus the converters are necessary to convert available AC supply into DC supply and to make power available for battery charging, light DC loads, large DC loads and even for transferring bulk amount of power over long distance transmission lines (High voltage DC transmission).

Classification of Controlled Converters:

The controlled rectifiers, usually called converters, are classified into two types according to the input AC supply as:

1) Single phase converter
2) Three phase converter

Each type is further subdivided into:

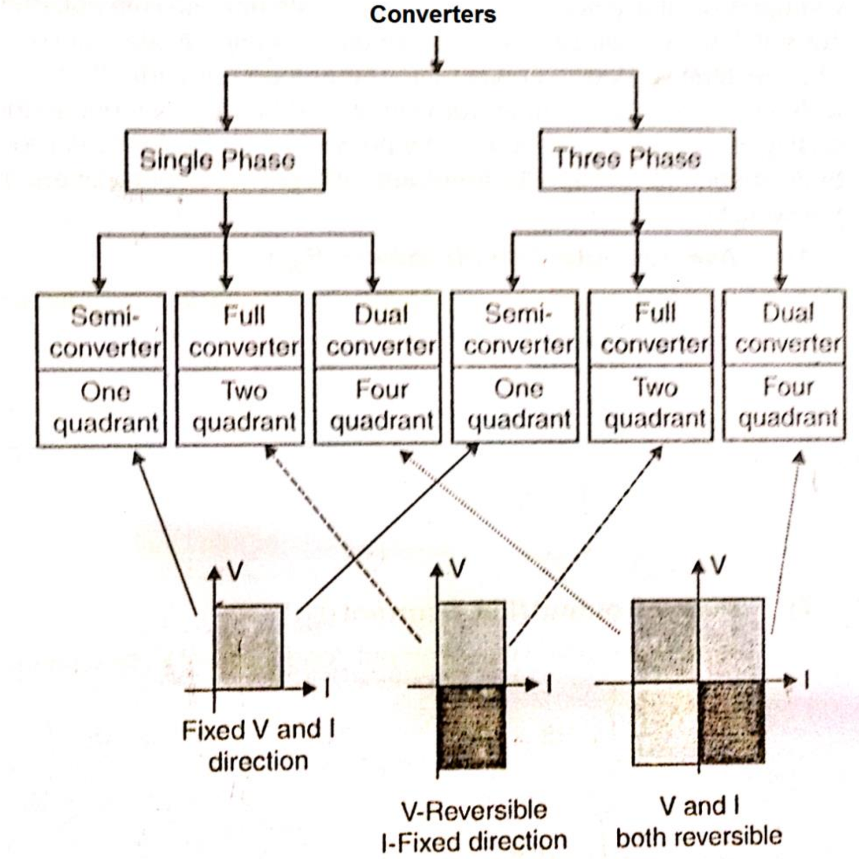
i) Semi converter
ii) Full converter
iii) Dual converter

2 marks (Block diagram is optional)

A "Semi converter" is a one-quadrant converter in the sense that it gives output voltage with fixed polarity and output current with fixed direction.

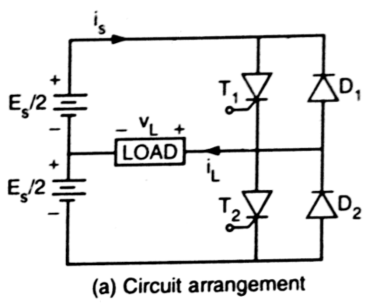
A "Full converter" is a two-quadrant converter in the sense that it gives output voltage of either polarity (i.e voltage can be reversed), however the output current has fixed direction.

A "Dual converter" is a four-quadrant converter in the sense that its output voltage polarity and output current direction can be reversed so as to operate the converter in all four quadrants.



1 a) iii)Draw and explain the working of single phase half bridge inverter.

Ans:



(a) Circuit arrangement

Single-phase half-bridge inverter:

The circuit diagram of single-phase 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.

1 mark for circuit diagram

(a) 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).

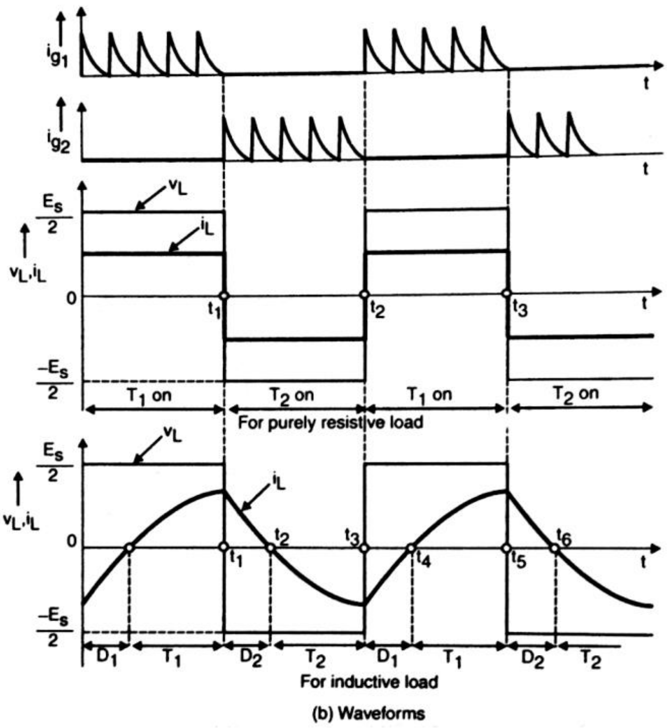
(b) Inductive Load:

When the load is inductive, the load current cannot be changed or interrupted instantly. When T_1 is on and T_2 is off, the current exponentially rises in the path through upper source, T_1 and load. The load voltage is positive.

2 marks for explanation (Inductive load optional)

At instant t = t_1, T_1 is turned off, however load current is not interrupted due to inductive nature of load. The load inductive voltage plays here important role to circulate the load current. The load current continues to flow through path consisting load, lower source and diode D_2. The lower source voltage appears across load. Thus load voltage becomes negative but current is still positive. Now the load current is opposed by lower source, hence it falls. Since Diode D_2 is conducting, a small reverse bias is maintained across T_2 which prevents it from turning on in presence of gate pulses.

At instant t = t_2, the load current falls to zero, voltage across T_2 rises to $E_s/2$ and gate pulse train turns T_2 on. Now the lower source delivers opposite current through load. Thus load current is reversed and starts developing in exponential manner. Both load voltage and load current are negative.



(b) Waveforms

At instant t = t_3, T_2 is turned off, however load current continues through load, upper source and diode D_1. The upper source voltage appears across load. Thus load voltage becomes positive but current is still negative. This current is opposed by upper source, hence it falls. Due to conducting diode D_1, small reverse bias is maintained across T_1, which prevents it from turning on.

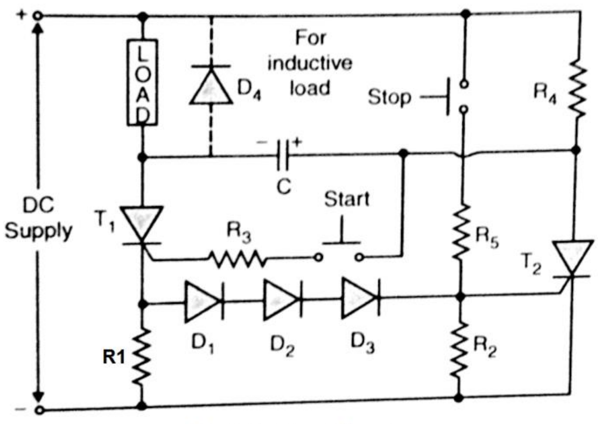
1 mark for waveforms (inductive load waveforms optional)

At instant t = t_4, the load current falls to zero, voltage across T_1 rises to $E_s/2$ and gate pulse train turns T_1 on. Now the upper source delivers positive current through load. Thus load current starts developing in exponential manner and cycle repeats.

1 a) iv) Draw and explain the working of DC static circuit breaker.

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.

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.

2 marks for Circuit diagram + 2 marks for explanation = 4 marks

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.

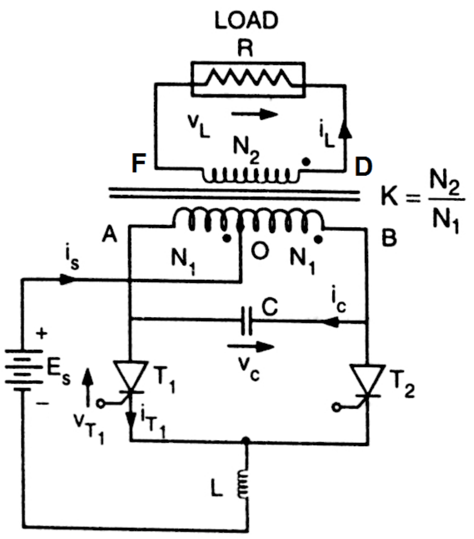
1 b) Answer any ONE of the following: 6 marks

1 b) i) Draw a neat circuit diagram of parallel inverter. Explain its working with necessary waveforms.

Ans:

Parallel Inverter:

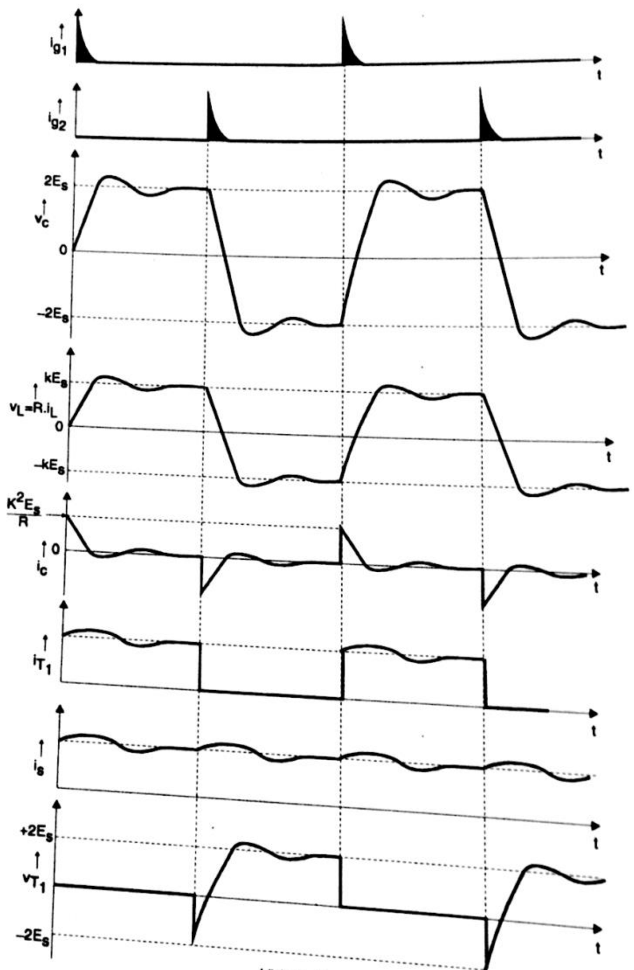
The circuit diagram of basic parallel inverter is shown in fig.(a). The load is connected on the secondary side of centre-tapped transformer. The commutating



(a) Circuit arrangement

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.

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.



(d) Waveforms

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 get 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,

2 marks for Circuit diagram
+
2 marks for explanation
+
2 marks for waveforms
=
6 marks.

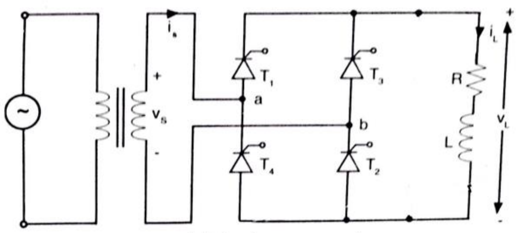
Incomplete answers be awarded proportionally reduced marks.

SCR current and capacitor current are shown in Fig.(b).

1 b) ii) Draw a neat circuit diagram of 1ϕ fully controlled bridge rectifier with RL load. Explain the working with waveforms.

Ans:

Single-phase Fully Controlled Bridge Rectifier:



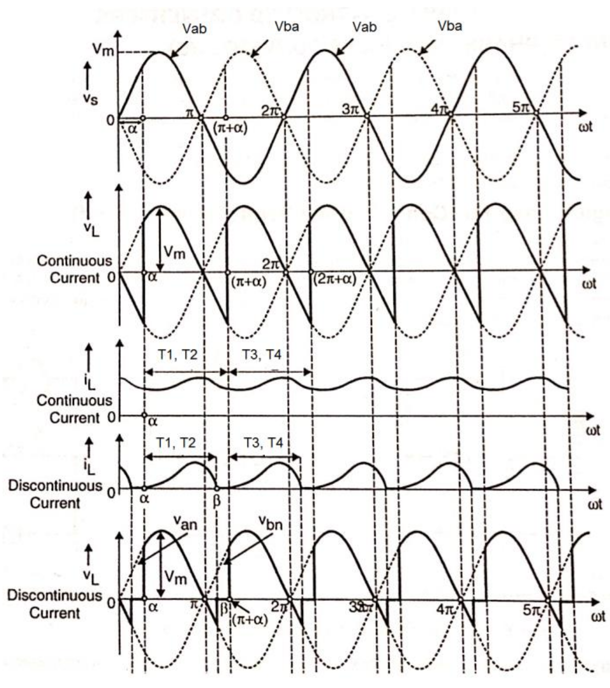
(a) Circuit arrangement

The circuit diagram of 1ϕ fully controlled bridge rectifier with RL load is shown in fig.(a). During positive half cycle of v_s, SCRs T_1 and T_2 are fired, so that v_{ab} appears across load. During negative half cycle of v_s, SCRs T_3 and T_4 are fired, so that v_{ba} appears across load. Thus alternate firing of SCR pairs results in repeated positive half cycles i.e pulsating DC across load. The delayed firing of SCR pairs provides phase control and control over output voltage. The waveforms are shown in fig.(b).

With RL load, there are two modes of operation:

(i) Continuous conduction

(ii) Discontinuous conduction



(b) Waveforms

In continuous conduction mode, the load current does not fall to zero because of highly inductive nature of load. During positive half cycle of v_s, at $\omega t = \alpha$, the SCRs T_1 and T_2 are fired and they conduct. Due to inductive nature, the load current cannot fall to zero at the end of this half cycle. The load current continues to conduct through T_1 and T_2 till the firing of next pair T_3, T_4. Therefore load voltage is v_{ab}, which is positive for $\omega t = \alpha$ to π and negative for $\omega t = \pi$ to $(\pi+\alpha)$

At $\omega t = (\pi+\alpha)$, the SCRs T_3 and T_4 are fired and they conduct and T_1, T_2 are turned off. The SCRs T_3 and T_4 conduct the load current till the firing of other pair T_1 and T_2. When T_3 and T_4 conduct, the load voltage is v_{ba}, which is positive for $\omega t = (\pi+\alpha)$ to 2π and negative for $\omega t = 2\pi$ to $(2\pi+\alpha)$. The average load voltage is positive.

1 mark for circuit diagram + 3 marks for waveforms diagram + 2 marks for explanation = 6 marks

In discontinuous conduction mode, the load current is discontinuous in the sense it falls to zero repeatedly. The discontinuous conduction occurs when load inductance is very small. In this mode, the load current falls to zero after the end of half cycle but before the firing instant of next pair. During positive half cycle of v_s, the T_1 and T_2 are fired at delay angle $\omega t = \alpha$. They conduct for interval $\omega t = \alpha$ to β. At $\omega t = \beta$, the load current falls to zero and T_1, T_2 are turned off. The next pair T_3, T_4 are fired at $\omega t = \pi+\alpha$. So during interval $\omega t = \beta$ to $(\pi+\alpha)$, no pair is conducting, hence load voltage and current are zero. The same thing is repeated in next half cycle.

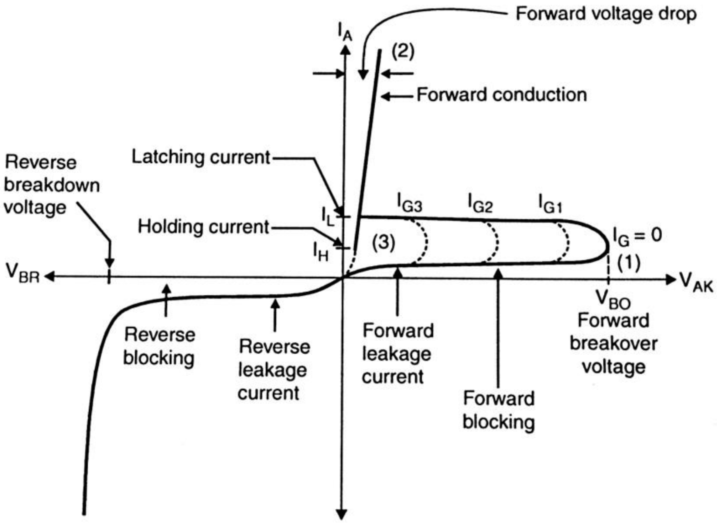
2 Answer any FOUR of the following. 16 marks

2 a) Draw the V-I characteristics of SCR. Define:

(i) Latching current
(ii) Holding current

Ans:

V-I characteristics of SCR:



V-I Characteristics of SCR

(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.

(ii) Holding Current:
Holding current is defined as the minimum anode current required to maintain the SCR in the on-state.

2 mark for V-I char. + 1 mark for each definition = 4 marks

2 b) Compare single-phase and three-phase converter on the basis of

(i) RMS voltage
(ii) Average voltage
(iii) Ripple factor
(iv) Efficiency

Ans:

Comparison of Single-phase and Three-phase Converters:

The single-phase and three-phase bridge type full converters can be compared on the basis of given points in a following manner.

Particulars	Single-phase Converter	Three-phase Converter

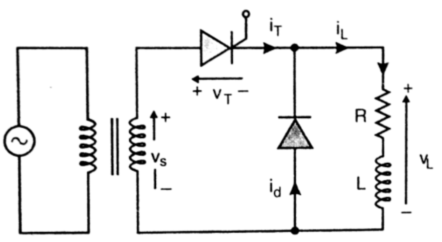
RMS Voltage	With continuous conduction and without free-wheeling diode, the output rms voltage is equal to the input rms voltage. $V_{rms} = \frac{V_m}{\sqrt{2}} = Vs$	With continuous conduction and without free-wheeling diode, the output rms voltage depends on the firing delay angle α. $V_{rms} = \sqrt{3}V_m\left[\frac{1}{2}+\frac{3\sqrt{3}}{4\pi}cos2\alpha\rig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

1 mark for each point = 4 marks

2 c) Draw and explain the working of 1ϕ half wave controlled rectifier with RL load. Explain the effect of free-wheeling diode.

Ans:

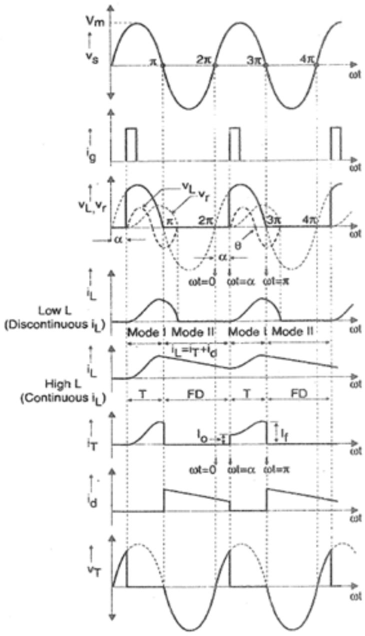
Single-phase half-wave controlled rectifier:



(a) Circuit diagram

The circuit diagram of 1ϕ half wave controlled rectifier with RL load and free-wheeling diode is shown in fig.(a). During positive half-cycle of v_s the SCR get forward biased. After the starting instant ωt = 0, at delay angle (α) gate pulse is provided to SCR and it is triggered. Once it conducts, the voltage v_s appears across load. As the load is inductive, the current starts from zero, then rises, attains peak and then falls. During positive half cycle, the reverse bias is maintained across free-wheeling diode through conducting SCR. At the end of positive half cycle, v_s becomes zero, but load inductance maintains current in the same direction through v_s and SCR. After ωt = π, the supply voltage is reversed, which causes forward bias across free-wheeling diode and it is turned on. Once the diode conducts, the reversed supply voltage appears across the SCR. The load inductance forces current through the diode. Thus the load current which was flowing through SCR, now shifted to free-wheeling diode D. The SCR is subjected simultaneously to reverse

1 mark for circuit diagram + 2 marks for explanation + 1 mark for waveforms = 4 marks



(b) Waveforms

voltage and zero current. Therefore, the SCR is turned off at ωt = π. When the free-wheeling diode conducts, the load voltage becomes zero. Thus the effect of free-wheeling diode is that the load voltage never becomes negative in presence of free-wheeling diode and hence the average value of the load voltage is improved. The load current continues to flow after ωt = π for some time depending upon the value of the load inductance. If the load inductance is less, the current becomes zero, prior to the next firing of SCR in the next positive half cycle. Thus we get discontinuous load current. However, if the load inductance is large, the current continues after ωt = π and does not become zero until the SCR is fired again in the next positive half cycle. Thus we get continuous load current without any zero value. The waveforms are shown in fig.(b).

2 d) State the classification of choppers.

Ans:

<u>Classification of Choppers:</u>

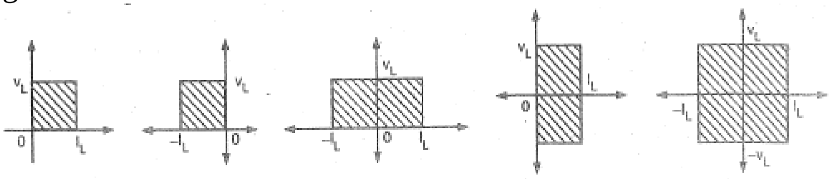
The choppers are classified according to following basis:

(1) According to input and output voltage levels:
- (i) Step-down chopper: The input voltage is stepped down i.e $V_{out} \le V_{in}$
- (ii) Step-up chopper: The input voltage is stepped up i.e $V_{out} \ge V_{in}$

(2) According to the directions 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

Each basis 1 Mark = 4 marks

The voltage and current directions for above classes are shown in the following fig.



(a) Class A (b) Class B (c) Class C (d) Class D (e) Class E

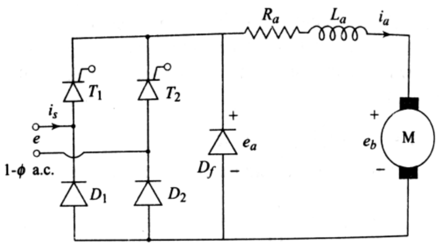
(3) According to operation:
- (i) Single-quadrant chopper: The output voltage is always positive, but the output current can be either positive (class A) or negative (class B).
- (ii) Two-quadrant chopper: The output voltage is positive and output current can be positive or negative (class C) or the output current is positive and the output voltage can be positive or negative (class D).
- (iii) Four-quadrant chopper: The output voltage and current both can be positive or negative.

(4) According to the Commutation method:
- (i) Voltage commutated chopper
- (ii) Current commutated chopper
- (iii) Load commutated chopper
- (iv) Impulse commutated chopper

2 e) Describe the speed control of dc series motor using single phase half controlled bridge converter.

Ans:

Speed control of dc series motor using single phase half controlled bridge converter:



(a) Power circuit

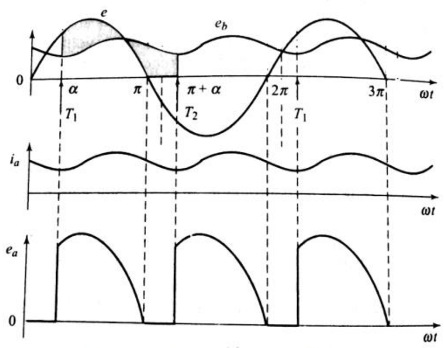
Fig.(a) shows the circuit diagram for the speed control of DC series motor using single phase half controlled bridge converter. The resistance R_a includes the resistance of armature winding and series field winding. Also, the inductance L_a includes the inductance of armature winding and series field winding. The back emf produced in the armature is due to the speed and the air-gap flux. Since the flux due to residual magnetism is small, most of the air-gap flux is produced by the armature current flowing through the series field winding. Thus the back emf is proportional to the motor current and speed.

$$E_b \alpha I_a N$$

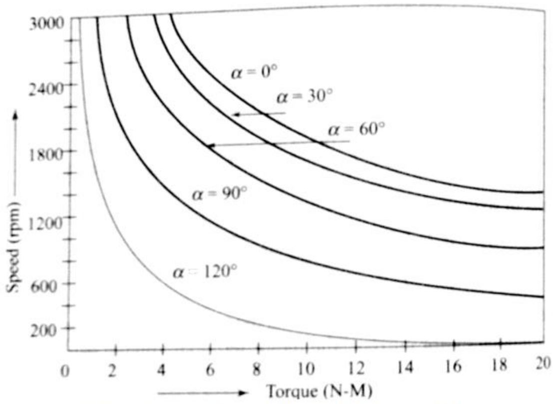
The torque developed is proportional to the square of the motor current.

$$T \alpha I_a^2 .$$

1mark for Circuit diagram + 1 mark for waveforms + 1 mark for explanation + 1 mark for characteristics = 4 marks



(b) Waveforms for continuous conduction



(c) Torque-speed characteristics of DC series motor speed control by single-phase half-controlled converter

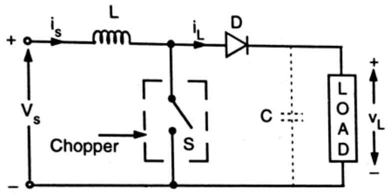
The voltage equation can be expressed as $E_a = R_a I_a + E_b$.

Under steady state condition with constant load torque, if an attempt is made to increase the applied voltage E_a by phase control of converter, the speed increases resulting an increase in back emf and maintaining the voltage balance. Over a wide range of speed control operation, the motor current is continuous. Only at high speed and low current condition, the motor current is likely to become discontinuous. The waveforms for continuous conduction are shown in fig.(b). The torque-speed characteristics under the assumption of continuous and ripple-free motor current for different values of the firing angle α are shown in fig.(c)

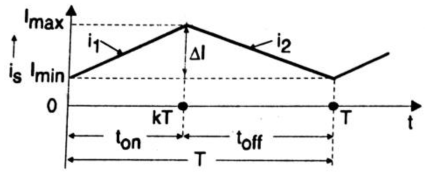
2 f) With a neat circuit explain the operation of step up chopper.

Ans:

Step-up Chopper:



(a) Basic circuit arrangement



(b) Current waveform

The circuit diagram for step-up chopper is shown in fig.(a). When the switch S is on (closed) for time t_{on} the inductor L is placed across the DC supply source V_s and the current through inductor rises linearly as shown in fig.(b). During this time interval, energy is stored in the inductor. If the switch is opened and maintained off for time t_{off} , the inductor voltage changes its polarity and aids the DC source to force the current through D and load. The load voltage is thus the sum of supply voltage V_s and inductor voltage v_l. During this time interval t_{off} , the energy stored in the inductor is given out and the current falls as shown in fig.(b). The waveform of supply current i_s for continuous conduction is shown in fig.(b). When the chopper is on, the voltage across inductor is given by:

$v_l = V_s = L\frac{di_s}{dt}$ for ($0<t<t_{on}$)

$$\therefore V_s = L\frac{(I_{max} - I_{min})}{t_{on}} = L\frac{\Delta I}{t_{on}}$$

Peak to peak ripple current in inductor is $\Delta I = \frac{V_s}{L}t_{on}$

When the chopper is off, i.e switch S is open, the instantaneous output voltage is:

$$v_L = V_s + L\frac{di_L}{dt} = V_s + L\frac{di_s}{dt} = V_s + L\frac{\Delta I}{t_{off}} = V_s + L\frac{V_s}{L}\frac{t_{on}}{t_{off}}$$

$$= V_s\left[1 + \frac{t_{on}}{t_{off}}\right] = V_s\left[1 + \frac{t_{on}/T}{t_{off}/T}\right] = V_s\left[1 + \frac{k}{(T - t_{on})/T}\right]$$

$$= V_s\left[1 + \frac{k}{1-k}\right] = V_s\left[\frac{1 - k + kt_{on}}{1-k}\right]$$

$$\therefore v_L = V_s\left[\frac{1}{1-k}\right]$$

From this equation, it is clear that for k<1, the load voltage v_L is greater than supply voltage V_s , and the circuit acts as a step-up chopper.

If a large capacitor C connected across the load, the output voltage will be continuously available. During t_{on} capacitor will charge and during t_{off} it will discharge and provide output voltage.

1 mark for circuit diagram + 1 mark for current waveform + 1 mark for explanation + 1 mark for mathematical equations = 4 marks

3 Answer any FOUR of the following: 16

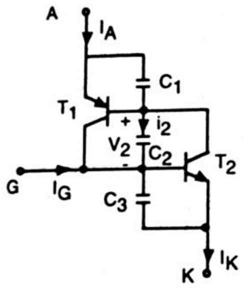
3 a) Describe $\frac{dv}{dt}$ triggering of SCR.

Ans:

SCR Turn on by Rate of Change of Voltage ($\frac{dv}{dt}$):

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



Two-traisistor transient model of thyristor

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:

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

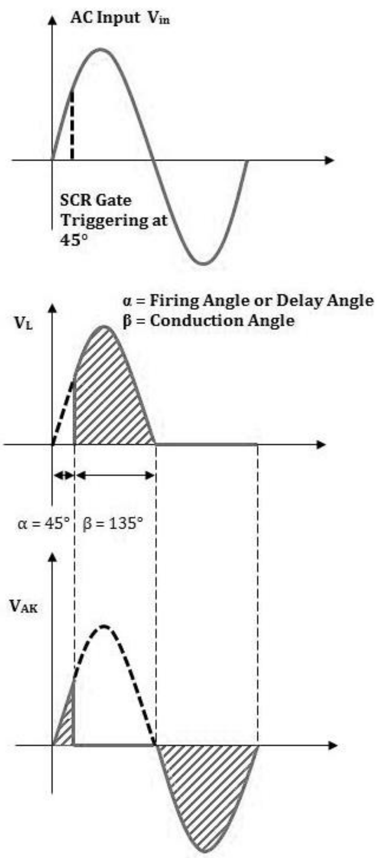
where, C_2 = capacitance of junction J_2
V_2 = voltage across junction J_2
q_2 = charge in the junction J_2

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.

1 mark for transient model + 3 marks for explanation = 4 marks

3 b) Define firing angle and conduction angle. Find the value of firing angle so as to get a conduction angle of 135°.

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.

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.

1 mark each definition + 1 mark for solution + 1 mark for diagram = 4 marks

In single-phase circuit, the load is connected to supply through SCR. The SCR appears in series with load. When SCR is off, supply voltage V_{in} appears across it and load voltage V_L is zero. When SCR is turned on, its voltage V_{AK} falls to zero whereas the supply voltage appears across load, causing $V_L = V_{in}$.

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: $\alpha + \beta = \pi \; radian \; or \; 180°$

Therefore, to get conduction angle of 135°, the required firing angle is
$\alpha = 180° - 135° = 45°$

3 c) Describe the four specifications of SCR.

Ans:

Specifications of SCR:

Following are few specifications of SCR.

1) V_{DWM} (Peak Working Forward Blocking Voltage):
   It is the maximum forward blocking voltage that the SCR can withstand during its working. It is the maximum value of the applied sinusoidal voltage, which the SCR can withstand.
2) V_{RRM} (Peak Repetitive Reverse Voltage):
   It is the peak reverse transient voltage that the SCR can withstand repeatedly or periodically in reverse blocking mode at maximum allowable junction temperature.
3) $I_{T(RMS)}$ (RMS Current):
   It is the RMS value of the on-state current the SCR can withstand without exceeding the maximum allowable temperature of device.
4) $I_{T(SM)}$ (Surge Current):
   It is the allowable peak non-repetitive (surge) current the SCR can withstand without exceeding the junction temperature limit, under momentary overload or short circuit fault condition.
5) I_{GT} (Gate Trigger Current):
   It is the minimum gate current needed to switch the SCR on.
6) V_{GT} (Gate Trigger Voltage):
   It is the minimum gate voltage required to trigger the gate terminal, which then turns on the SCR.
7) I_H (Holding Current):
   It is the minimum anode current required to maintain the SCR in the on state.

1 mark for each of any 4 specifications = 4 marks

3 d) Draw and explain a Jones chopper.

Ans:

Jones Chopper:

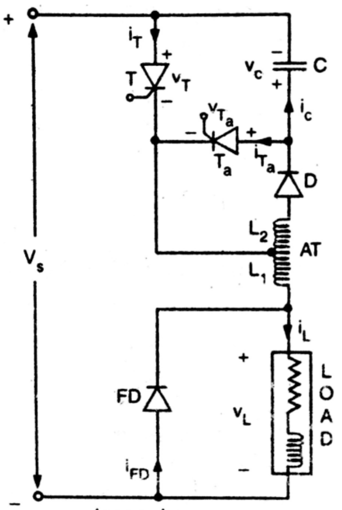
The circuit diagram of Jones Chopper is shown in the fig. It employs class D commutation technique in which a charged capacitor is switched by an auxiliary SCR to commutate the main SCR. The circuit operation can be divided into various modes as follows:

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.

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.

2 marks for circuit diagram + 2 marks for explanation = 4 marks

Mode 3: The inductance L_1 and load inductance try to maintain the load current



Jones chopper

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.

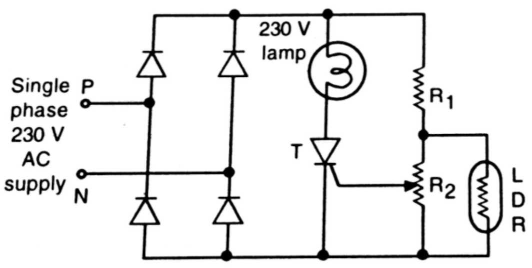
Mode 5: The capacitor voltage with upper plate positive is maintained till the next firing of T. The load current is continued through free-wheeling diode till the next conduction of main SCR T.

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.

3 e) 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 explanation = 4 marks

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 a) Answer any THREE of the following: 12

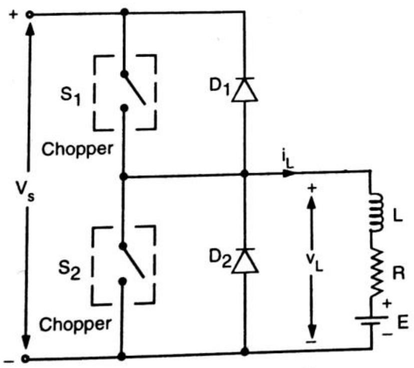
4 a) i) Draw and explain the operation of class C chopper.

Ans:

Class C Chopper:

The circuit configuration is shown in fig.(a). It is essentially a two-quadrant chopper in the sense that the load current can be either positive or negative but the load voltage is always positive, as shown in fig.(b). It is a combination of class A and class B chopper. Keeping switch S_2 inoperative, the circuit behaves as class A chopper and keeping S_1 inoperative, the circuit behaves as class B chopper.

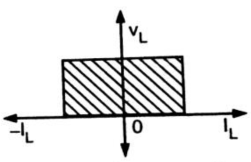
(i) Class A operation (Switch S_2 maintained off):



(a) Circuit arrangement

In this operation the switch S_1 is turned on and turned off alternately. When the switch S_1 is turned on, the DC source voltage get applied across the load and supplies load current. When the switch S_1 is turned off, the load inductance forces current through free-wheeling diode D_2 which makes the load voltage zero. Thus the load voltage is either positive or zero and the load current is positive as shown in the fig. (a). Thus the chopper is operated in first quadrant.

(ii) Class B operation (Switch S_1 maintained off):



(b) Two-quadrant operation

In this operation, the load current is opposite to that shown in the fig.(a). When the switch S_2 is turned on, the load voltage becomes zero, the emf E drives load current i_L through load parameters R-L and S_2. When switch S_2 is turned off (opened), the load inductive voltage reverses its polarity and aids the emf E to force current through D_1 and V_s. The load voltage thus becomes equal to V_s. Thus the load voltage is either zero or positive and the load current is negative. Thus the chopper is operated in second quadrant.

2 marks for circuit diagram + 2 marks for explanation = 4 marks

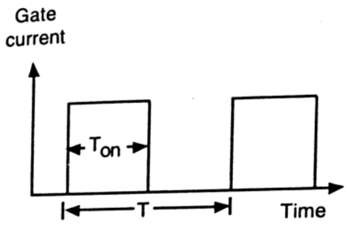
The class C chopper can operate either as a rectifier or as an inverter. This chopper is used for controlling the motoring and regenerative braking of DC motors.

4 a) ii) Explain pulse gate triggering of SCR.

Ans:

Pulse Gate Triggering of SCR:

In pulse triggering, a current pulse of sufficient width is supplied to SCR gate to allow the anode current to exceed the latching current and turn-on the device. The pulse current with widths beyond 100 μsec are treated as DC. If the pulse widths are less than 100 μsec, higher gate voltage and current can be applied for faster turn-on. SCR is considered as a charge controlled device on short term basis. Higher magnitude gate current pulse takes lesser time to inject the required charge



Gate Pulse Triggering

for turn on. In pulse triggering, with higher gate voltage and current, greater amount of gate power dissipation can be allowed, however it should be less than the peak instantaneous gate power dissipation P_{gm} as specified by the manufacturer. In any case, the average gate power dissipation should be less than or equal to the allowable average gate power dissipation P_{gav}. Thus if the gate pulse magnitude is such that instantaneous gate power dissipation is P_{gm}, pulse width is T_{on} and period is T, then

Average gate power dissipation ≤ Average gate power dissipation limit

i.e $\frac{P_{gm}T_{on}}{T} \leq P_{gav}$. If f = frequency of firing or pulse repetition rate in hz, f = 1/T

In the limiting case, $P_{gm}fT_{on} = P_{gav}$

And the frequency of firing is given by $f = \frac{P_{gav}}{T_{on}P_{gm}}$

For safety of device, it should be ensured that

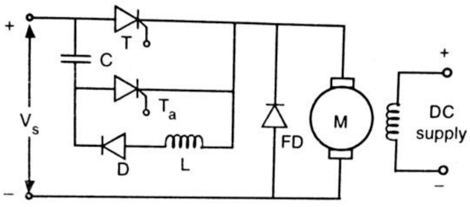
(Pulse voltage amplitude)(Pulse current amplitude)< P_{gm}

3 marks for explanation + 1 mark for diagram = 4 marks

4 a) iii) Draw and explain the working of a chopper controlled dc drive (step down)

Ans:

Chopper Controlled DC Drive:



Chopper Controlled DC Drive

The fig. shows the circuit arrangement of chopper controlled DC drive. At start, the T_a is triggered and turned on to carry the motor current. Due to the resonant circuit formed by armature resistance and inductance with capacitor C, the current initially rises, attains peak and then falls to zero. This turns off the auxiliary SCR Ta naturally. This current charges the capacitor C with upper plate positive. The capacitor thus forward biases the 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 and hence T_a can not be turned on when T is on. The load current now flows through T. The capacitor continue 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 one SCR commutates the other.

The variable DC voltage is obtained using either time-ratio control (TRC) or current-limit control (CLC).

2 marks for circuit diagram + 2 marks for explanation = 4 marks

4 a) iv) Define duty cycle of a chopper. Explain various control techniques used in chopper.

Ans:

Duty Cycle:

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 source 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,

$$V_o = \frac{T_{on}}{T_{on} + T_{off}} V_s = \frac{T_{on}}{T} V_s = kV_s$$

where k is the duty cycle.

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

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)

2 marks for duty cycle + 1 mark for TRC + 1 mark for CLC = 4 marks

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

Current Limit Control:

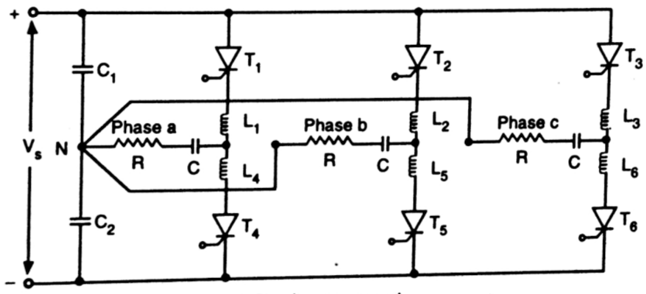
In this technique, the load current is allowed to vary only between a predetermined maximum and minimum limit. If the load current tends to increase beyond maximum limit, chopper switch is turned off and if the load current tends to fall below the minimum (lower) limit, the chopper switch is turned on.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

4 b) Answer any ONE of the following: 06

4 b) (i) Describe the operation of 3ϕ series inverter with i/p – o/p waveforms and circuit diagram.

Ans:

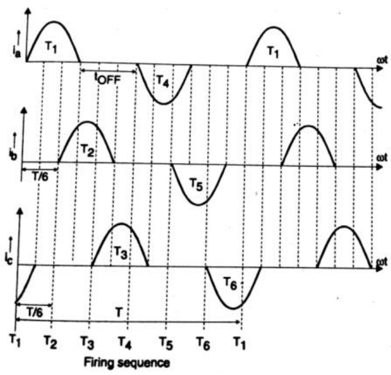
Three-phase Series Inverter:



(a) Circuit arrangement

The circuit diagram of three-phase series inverter is shown in fig.(a). It is basically a combination of three single-phase series inverters. The capacitors C_1 and C_2 are large enough to maintain a constant voltage at neutral N. Then each phase can work as an independent single-phase series inverter. The capacitor C in series with load resistance R resonates with series centre-tapped reactor to provide commutation. Under steady-state condition, when T_1 is fired, current flows through T_1, L_1, C and R of phase a. The underdamped combination R-C-L_1 causes a current pulse as shown in waveform of i_a in fig.(b). At the end of this pulse, current falls to zero and T_1 is commutated. At the end of this pulse, the capacitor C get charged to a voltage (with right plate

2 marks for circuit diagram + 2 marks for explanation + 2 marks for waveforms = 6 marks



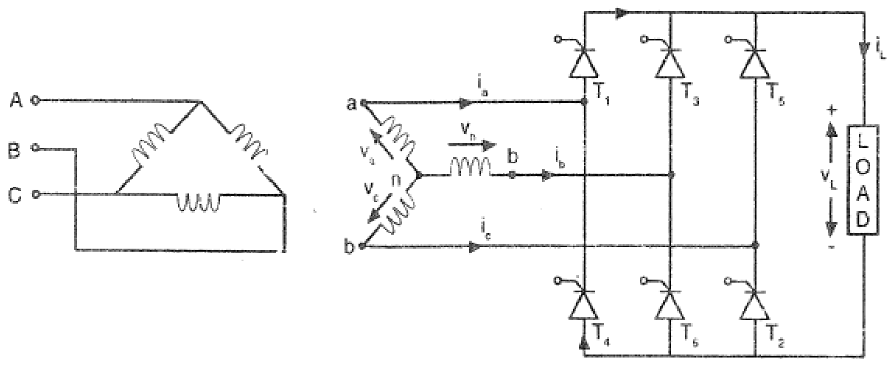
(b) Waveforms

positive) higher than that across C_1 and therefore a reverse bias is maintained across T_1. As independent operation of each phase is possible, the thyristor T_2 can be fired prior to the turning off of T_1. If T is the period of the output as shown on the waveforms, the thyristors are fired in sequence with time delay T/6 as shown. Precaution should be taken that a thyristor of a particular phase can be fired after the commutation of the other thyristor in the same phase. The approximate available circuit turn-off time (t_{off}) is the time gap between positive pulse and negative pulse.

4 b) (ii) Draw and explain a 3ϕ fully controlled bridge converter with R load. Explain the working with waveforms.

Ans:

<u>Three-phase Fully Controlled Bridge Converter</u>:

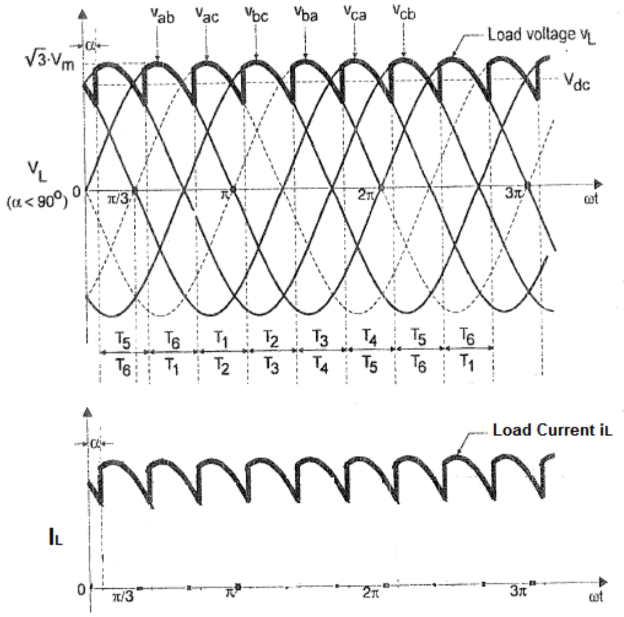


(a) Circuit arrangement

The circuit diagram of 3ϕ fully controlled bridge converter is shown in fig.(a). Six thyristors are connected in bridge to obtain full wave rectification. One of the upper thyristors T_1, T_3, T_5 carry current from secondary winding to load and one of the lower thyristors T_2, T_4, T_6 carry current back from load to secondary winding. The pair of the thyristors which is connected to those lines having a positive instantaneous line-to-line voltage is fired. If v_{ab} is positive, then the thyristor connected to phase a i.e T_1 and thyristor connected to phase b i.e T_6 are fired. The thyristors are fired at an interval of $\pi/3$ rad or 60°. Each thyristor conducts for $2\pi/3$ rad or 120°. The fig.(b) shows the waveforms of line voltage, output load voltage and load current.

2 marks for circuit diagram + 2 marks for explanation + 2 marks for waveforms = 6 marks

At $\omega t = 0$, the line voltage v_{cb} is higher than any other line voltage, hence thyristor T_5 connected to phase c and thyristor T_6 connected to phase b are fired at delay angle α. After firing T_5 and T_6, the load voltage becomes equal to v_{cb}. The upper load terminal gets connected to phase c and voltage v_{ac} appears across T_1 and voltage v_{bc} across T_3. As both v_{ac} and v_{bc} are negative, both T_1 and T_3 are reverse biased. Similarly the lower load terminal gets connected to phase b through T_6 and voltage v_{ba} appears across T_4 and voltage v_{bc} across T_2. As both v_{ba} and v_{bc} are negative, both T_4 and T_2 are reverse biased. Thus firing of a pair of thyristors causes all other thyristors to be reverse biased. This condition is continued till $\omega t = \pi/3$. After this the line voltage v_{ab} becomes higher than v_{cb}. At $\omega t = \pi/3$, the line voltage v_{ac} crosses zero value and becomes positive, due to which T_1 get forward biased. So a gate pulse is applied to T_1 at $\omega t = (\pi/3)+\alpha$. Once T_1 is turned on, the upper load terminal get connected to phase a, causing line voltage v_{ca} across conducting T_5. As v_{ca} is negative, T_5 get reverse biased and turned off. The load current get shifted fromT_5 to T_1. However, the thyristor T_6 remains on and continue to carry load current with T_1. The load voltage then becomes equal to v_{ab}. In this way the thyristors are fired in sequence and successively line voltages appear across load as shown in fig.(b).



(b) Waveforms

Since the load is purely resistive, the load current follows same variations as that of load voltage. The waveform of load current is similar to the load voltage waveform as shown in the fig.(b).

5 Answer any FOUR of the following: 16

5 a) Describe the principle of dielectric heating. State two applications of it.

Ans:

<u>Principle of Dielectric Heating</u>:

The non-conducting materials (also called insulators or dielectric materials) whenever subjected to an alternating electric field, some power loss takes place in them and heat is generated. This power loss is called "Dielectric Loss". The process wherein the heating takes place due to dielectric loss is known as "Dielectric Heating".

When dielectric material is subjected to an alternating electric field, the rapid reversal of the field distorts and agitates the molecular structure of the material. The internal molecular friction generates heat uniformly throughout all parts of the material. Even though the material is poor conductor of heat and electricity, thick layers of material can be heated in minutes instead of hours.

2 marks for principle + 1 mark for each of any two application s = 4 marks

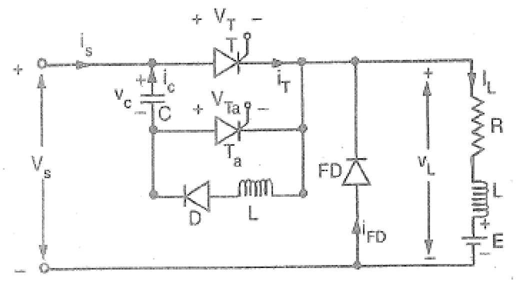
<u>Applications of dielectric heating</u>:

1) Food processing:
   (i) Defrosting of frozen foods which then proceeds to cook the food in few minutes.

(ii) Pasteurizing milk and beer inside the bottles or containers
(iii) For disinfecting grains and cereals by killing eggs of insects and pests.
(iv) For cooking foods without removing outer shell.
(v) For sterilizing food while sealed in their final container.

2) Plastic Processing:
Moulding and shaping plastic material.
3) Wood Processing:
In manufacture of plywood for drying the glue between the layers of wood.
4) Electronic Sewing:
For sewing plastic fabrics to produce raincoats, umbrellas, food packets, shower curtains etc.
5) Drying and heat treatment of textiles such as rayon, nylon, terylene etc.
6) Processing of –
(i) Chemicals during their manufacture
(ii) Rubber and synthetic material
(iii) Semiconductor devices
7) Producing artificial fever in human body for medical treatment.

5 b) With necessary circuit explain auxiliary commutation in chopper.
Ans:
Auxiliary Commutation in Chopper:

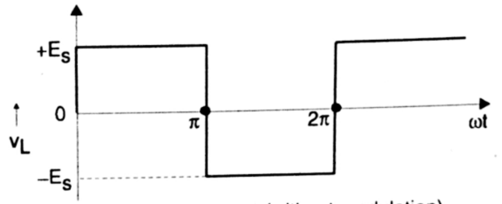


Voltage-commutated chopper

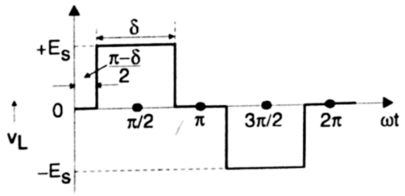
The fig. shows the circuit arrangement of voltage commutated chopper employing auxiliary commutation. At start, the T_a is triggered and turned on to carry the load current. Due to the resonant circuit R-L-C, the current initially rises, attains peak and then falls to zero. This turns off the auxiliary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

2 marks for circuit diagram + 2 marks for explanation = 4 marks

5 c) Describe harmonic reduction by single pulse width modulation.
Ans:
Harmonic Reduction by Pulse Width Modulation (PWM):



(a) Square wave output (without modulation)



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

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,

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

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.

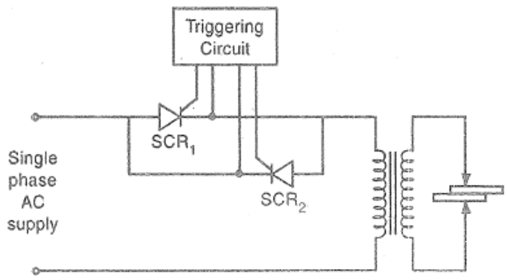
Thus the harmonic reduction is possible using single-pulse-modulation.

2 marks for waveforms + 2 marks for explanation = 4 marks

5 d) Draw and explain electric welding control circuit using SCR.

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 for circuit diagram + 2 marks for explanation = 4 marks

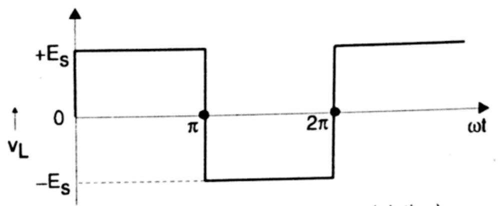
5 e) State the methods of o/p voltage control of inverters. Explain PWM control in detail.

Ans:

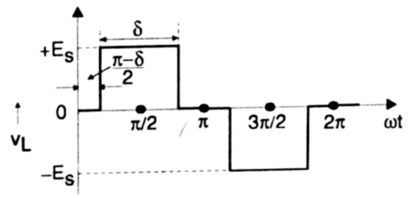
Methods of Voltage Control in Inverters:

1) External Control:
   a) Externally controlling the ac output voltage
      (i) AC voltage control: Using AC voltage controller between inverter & load ½ mark
      (ii) Series inverter control: Connecting two or more inverters in series
   b) Externally controlling the dc input voltage
      (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. 1 mark
      (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 ½ mark

Pulse-Width-Modulation (PWM) Control:



(a) Square wave output (without modulation)



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

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,

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

½ mark for waveforms

1 ½ mark for explanation

= 4 marks

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,

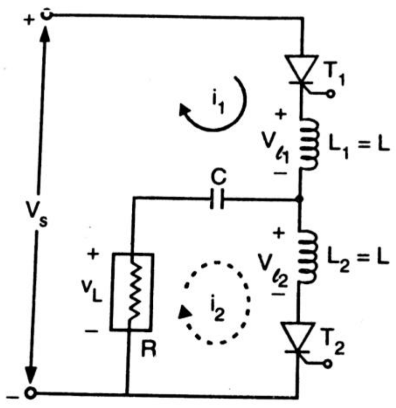
$$V_{Lnm\_Qsw} = \frac{4E_s}{n\pi}\, sin\left(\frac{n\delta}{2}\right)$$

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.

5 f) Draw and explain modified series inverter.
Ans:
Modified Series Inverter:



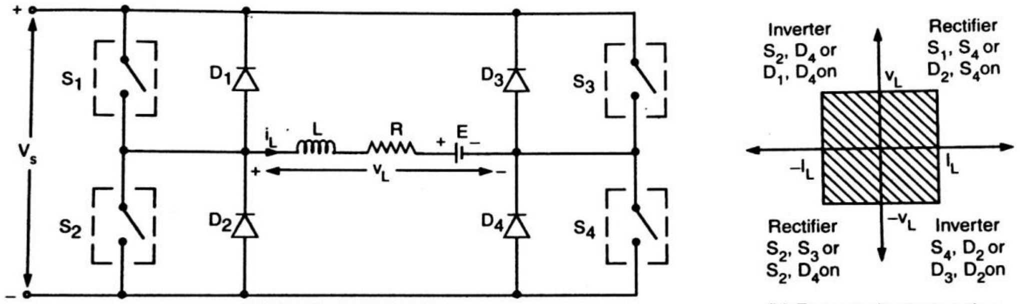
Circuit diagram

A modified series inverter employing coupled inductors is shown in fig. The underdamped combination RLC when switched across DC supply, it carries current in the form of pulse, which starts from zero, attains peak and then drops to zero again. When T_1 is fired, the current i_1 begins to rise, the voltage across L_1 appears with the polarity as shown in the fig. The capacitor starts charging with right plate positive. At the end of current pulse i_1, the capacitor get charged to voltage higher than the supply voltage V_s and as i_1 becomes zero, T_1 is commutated. The thyristor T_2 is forward biased by capacitor voltage. If T_2 is fired, current pulse i_2 flows. At the beginning of this pulse, i_2=0, hence V_L= i_2.R = 0 and capacitor v_c which is higher than V_s appears across L_2. As L_1 and L_2 are equal and closely coupled, the emf induced in L_1 is equal to the voltage across L_2. Thus capacitor voltage appears across L_1 and T_1 is maintained reverse biased. Due to i_2 capacitor discharges through L_2, T_2 and R and due to L_2 it is further charged with reverse polarity (Left plate positive). At the end of i_2 pulse, T_2 is commutated and reverse bias is maintained across it due to capacitor voltage. In this way, alternate firing of thyristors produce alternate current pulses in load.

2 marks for circuit diagram + 2 marks for explanation = 4 marks

6 Answer any FOUR of the following: 16

6 a) Draw the circuit diagram of class E chopper and explain its working.
Ans:
Class E Chopper:
Class E chopper is four-quadrant chopper in the sense that the load voltage and load current can be positive and/or negative. It is formed by combining two class C choppers as shown in the fig. The positive reference direction for i_L and positive reference polarity for v_L is as shown in the fig.



(a) Circuit arrangement (b) Four-quadrant operation

Class E chopper

<u>First-quadrant operation</u>:

When chopper switches S_1 and S_4 are on, the input dc source voltage V_s appears across load and it drives the load current i_L as shown in the fig. Thus both v_L and i_L are positive. The power flows from input dc source to load, hence the chopper is said to be operated as rectifier in the first quadrant. When S_1 is turned off, the load inductor voltage reverses itself and drives load current i_L in the same direction through S_4 and D_2. The load voltage v_L becomes zero.

2 marks for circuit diagram + ½ mark for each of quadrant operation = 4 marks

<u>Second-quadrant operation</u>:

When D_1 and D_4 are on, the load inductance voltage drives current through D_1, V_s and D_4. The load voltage v_L is positive and equal to V_s but load current i_L is negative. The power is fed back by load inductor to input dc source. Therefore the chopper is said to be operated as an inverter in the second quadrant. When S_2 is fired, D_1 is turned off and negative load current is maintained through S_2, D_4 and load. The load voltage then becomes zero.

<u>Third-quadrant operation</u>:

When chopper switches S_2 and S_3 are on, the input dc source is placed across load such that $v_L = -V_s$ and negative load current i_L flows. The power is supplied by input dc source to load, hence the chopper is said to be operated as rectifier in the third quadrant. If S_3 is turned off, the load inductor voltage reverses itself and drives load current i_L in the same direction through S_2 ,D_4 and load. The load voltage v_L then becomes zero.

<u>Fourth-quadrant operation</u>:

When diodes D_2 and D_3 are on, the energy stored in load inductor is given out and positive load current is maintained. The load voltage v_L is however negative and equal to $-V_s$. The power is fed back by load inductor to input dc source. Therefore the chopper is said to be operated as an inverter in the fourth quadrant. When S_4 is fired, D_3 is turned off and load current is maintained through S_4, D_4 and load. The load voltage then becomes zero.

6 b) Explain the principle of static VAR compensation.

Ans:

<u>Principle of Static-VAR-Compensation</u>:

In electrical power system, generally the real power is associated with the reactive power. While maintaining the balance between active power demand and active power generation, it is also necessary to maintain the balance between reactive power generation and absorption. In case of reactive power, if the balance is disturbed, the voltage profile along the transmission line get altered, can cause large amplitude variations in receiving end voltage, power swings occur, power system oscillations are observed and so many undesired effects affecting the power system stability are observed. Since the load and its nature changes from time to time, it is necessary to have fast acting reactive power management system which is capable of providing or absorbing the reactive power to control the dynamic conditions in the power system.

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 respectively.

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.

1 mark for need of comp + 1 mark for comp process + 2 mark for SVC explanation = 4 marks

6 c) Compare induction heating and dielectric heating on the basis of
(i) Material, (ii) rate of heating, (iii) frequency, (iv) applications

Ans:

Comparison between Induction and Dielectric Heating:

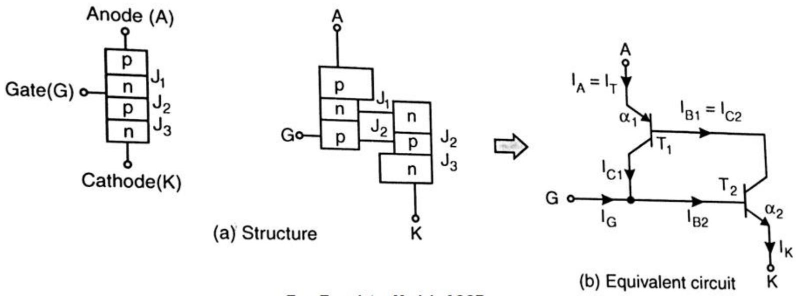
Sr. No.	Particulars	Induction heating	Dielectric Heating
1	Material	Only conducting materials can be heated	Only non-conducting materials can be heated
2	Rate of heating (ROH)	Proportional to square of current and square root of frequency i.e $ROH \alpha\, i^2$ and $ROH \alpha \sqrt{f}$	Proportional to square of applied voltage and frequency of supply i.e $ROH \alpha\, V^2$ and $ROH\ \alpha\, f$
3	Frequency	Upto 1 Mhz Change in frequency affect the depth of penetration of heat and also the rate of heating	Upto30 Mhz Change in frequency affect only the rate of heating
4	Applications	Surface hardening of steel, Annealing of metals, Brazing, welding, forging, drying, melting	Food processing, Plastic processing, Wood processing, Electronic sewing

1 mark for each of four points = 4 marks

6 d) Explain the two transistor model of SCR.

Ans:

Two-Transistor Model of SCR:



Two Transistor Model of SCR

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 fig. 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,

$I_A = \alpha_1 I_A + I_{CBO1} + \alpha_2 (I_A + I_G) + I_{CBO2}$

$= I_A(\alpha_1 + \alpha_2) + \alpha_2 I_G + I_{CBO1} + I_{CBO2}$

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

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

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. In this way, the gate triggering can be explained using two-transistor model of SCR.

1 mark for structure + 1 mark for equivalent circuit + 1 mark for math formulation + 1 mark for explanation = 4 marks

6 e) State the speed control methods of 3ϕ induction motor. Explain variable frequency control.

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:

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.

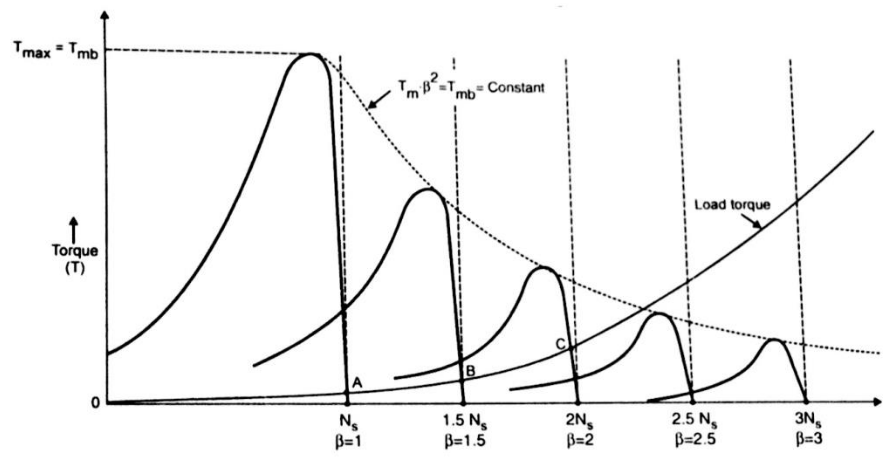
If the supply frequency f is changed to f* such that f* = β.f, the synchronous speed at new frequency f*becomes,

$N_S^* = \frac{120f^*}{P} = \frac{120\beta f}{P} = \beta N_S$ 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. From fig. it is clear that with rated supply frequency f, the motor runs at stable operating point A and when the supply frequency is increased to 1.5f and 2f, the operating point is shifted to B and C respectively and motor speed is increased.

1 mark for speed control methods
+
1 mark for concept
+
1 mark for plot
+
1 mark for explanation
=
4 marks



Torque-speed Characteristics with Frequency Control