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 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/figures 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 (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.

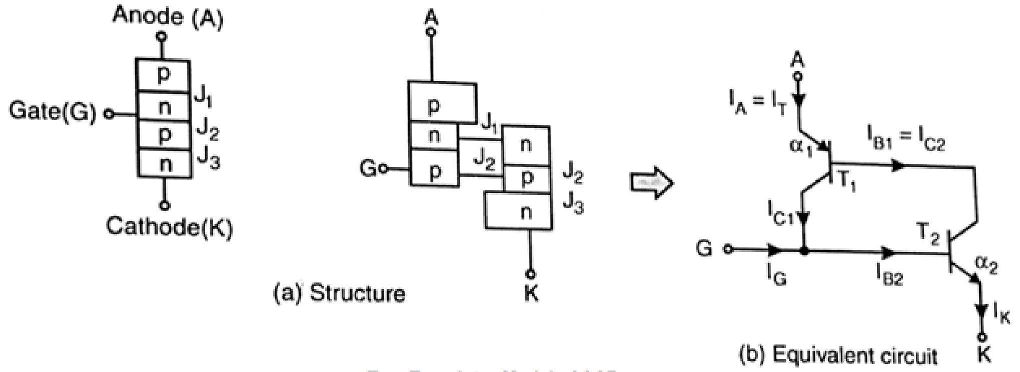
7) For programming language papers, credit may be given to any other program based on equivalent concept

1 a) Attempt any THREE of the following **12 marks**

1 a) i) Draw construction of SCR using two transistor models. Explain its operation.

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

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

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

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

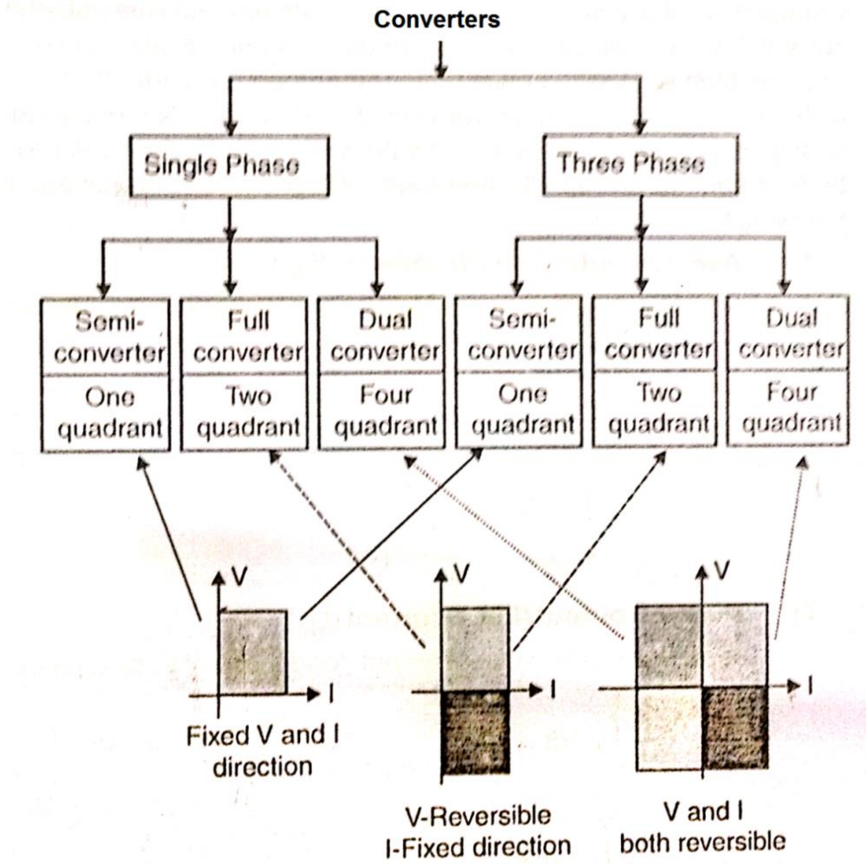
Ans:

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.

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). 2 marks

Classification of Controlled Converters:



2 marks (Block diagram is optional)

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

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) List drawbacks of harmonics at the output of inverter. Explain PWM method of harmonic reduction.

Ans:

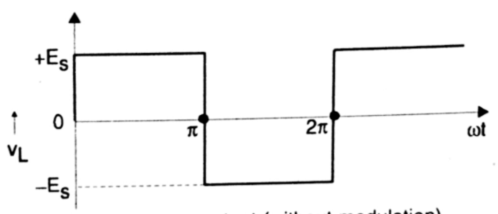
Drawbacks of harmonics in the output of Inverters:

Harmonics are voltage and current components at frequencies which are integral multiple of fundamental frequency. The harmonics are injected into the load supplied from the inverter and have following undesired effects:

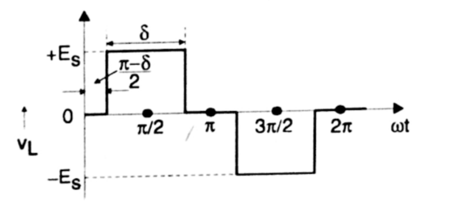
1 mark for drawbacks

1) Overheating of neutral conductor because of high neutral current with harmonics
2) Overheating of motors and transformers due to additional losses caused by harmonics.
3) Torque pulsation of induction motor because of multiple torque production due to harmonics.
4) Drop in efficiency of motors and transformer as losses are increased due to the harmonics.
5) Maloperation of relay and switchgear due to high frequency harmonics.
6) Possibility of overvoltage because of resonance at harmonic frequency.
7) Interference with the communication networks.

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,

1 mark for waveforms

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

2 marks for explanation

= 4 marks

In single-pulse modulation (SPM), the output pulse is delayed at start and advanced at the end by equal interval $(\pi-\delta)/2$, 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.

1 a) iv) Describe the working of full converter and drives for speed control of DC series motor.
Ans:
<u>Full Converter Drive for Speed Control of DC Series Motor:</u>
The basic characteristics of DC series motor are mathematically described as:

(i) Torque is directly proportional to magnetic flux and armature current,
$T \propto \emptyset\, I_a$ $\therefore T = K_t\, \emptyset\, I_a$

(ii) For series field winding, magnetic flux is proportional to armature current, $\emptyset \propto I_a$ $\therefore \emptyset = K_1 I_a$

(iii) Torque, therefore becomes proportional to the square of armature current, $T \propto I_a^2$ $\therefore T = K_t K_1 I_a^2 = K_2 I_a^2$

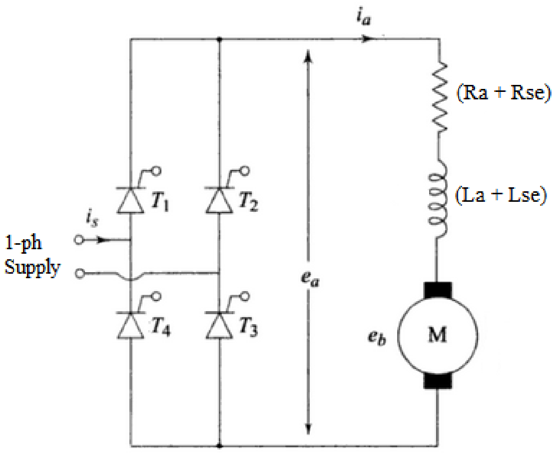
(iv) For constant current, the voltage equation of DC series motor is, 1 mark for principle
$V = (R_a + R_{se})I_a + E_b$

(v) Back emf is proportional to magnetic flux and speed,
$E_b \propto \emptyset\omega$ $\therefore E_b \propto I_a\omega$ $\therefore E_b = K_3 I_a \omega$

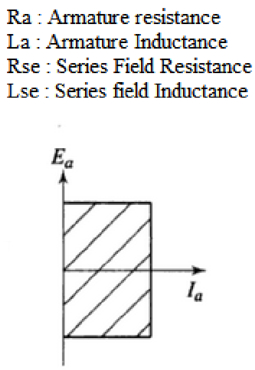
(vi) The voltage equation becomes, 1 mark for circuit diagram
$V = (R_a + R_{se})I_a + K_3 I_a \omega$ $\therefore V = (R_a + R_{se} + K_3\omega)I_a$
$$\therefore I_a = \frac{V}{(R_a + R_{se} + K_3\omega)}$$

(vii) The torque can be expressed as, 2 marks for explanation
$T = \frac{K_2 V^2}{(R_a + R_{se} + K_3\omega)^2}$ $\therefore T \propto \frac{V^2}{\omega^2}$
Thus for constant torque T, the speed is directly proportional to applied voltage. $Speed\ \omega \propto V$
Thus by controlling the voltage supplied to motor, its speed can be controlled.

The circuit configuration of full-converter drive for speed control of DC series motor is shown in Fig.(a). A full converter is a two quadrant converter in which the voltage polarity at the output can reverse but the current remains unidirectional as shown in Fig.(b), as the SCRs block the reverse current. The voltage applied to the motor armature is controlled by using firing angle control. The operation may be with continuous current or discontinuous current.



(a) Power circuit



(b) Quadrant

1) Continuous armature current:
   In this case, the SCRs T_1 and T_3 are simultaneously triggered at α during positive half-cycle of input AC and the SCRs T_2 and T_4 are simultaneously triggered at $(\pi+\alpha)$ in the negative half-cycle. The turning on of second pair i.e T_2 and T_4 causes turning off of first pair i.e T_1 and T_3. The motor is always connected to supply and motor current is continuous and do not fall to zero during the operation. The current is automatically shifted from one pair to the other. The continuous conduction is observed when motor current is large and also the motor inductance is large. During the interval from π to $(\pi+\alpha)$, negative voltage get applied across motor. The negative voltage reduces the average voltage across the motor. In order to prevent the negative voltage from appearing across motor, free-wheeling diode may be connected across the motor.
2) Discontinuous armature current:
   In this case, the SCRs T_1 and T_3 are simultaneously triggered at α during positive half-cycle of input AC and the armature current flows. This armature current falls to zero at an angle β, prior to the firing of second pair of SCRs T_2 and T_4. Thus the first pair is turned off before the firing of the second pair. The armature current flows for conduction angle $(\beta - \alpha)$. For period from β to $(\pi+\alpha)$ there is no conduction and the armature current is zero. The motor current is thus discontinuous. Lower armature current and less motor inductance are responsible for discontinuous conduction.

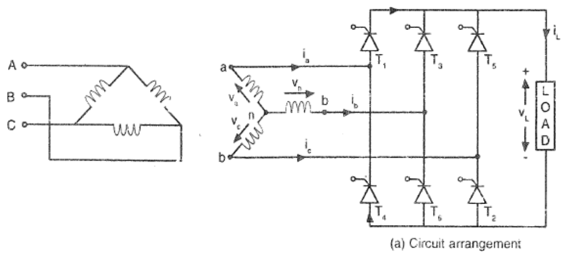
1 b) Attempt any ONE of the following: 6 marks

1 b) i) Draw and explain the three phase full converter thyristor bridge for resistive load. For this converter, do the following:

1) Sketch waveforms for three phase input voltage $v_{ab}, v_{ac}, v_{bc}, v_{ba}$ etc.
2) From (1) sketch waveforms of the output voltage v_o for a firing angle of zero degree and overlap angle is 30°. Indicate the conduction of various SCRs.

Ans:

Three-phase Fully Controlled Bridge Converter:



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 voltages and output load voltage.

2 marks for circuit diagram

2 marks for explanation

1 mark for each waveform

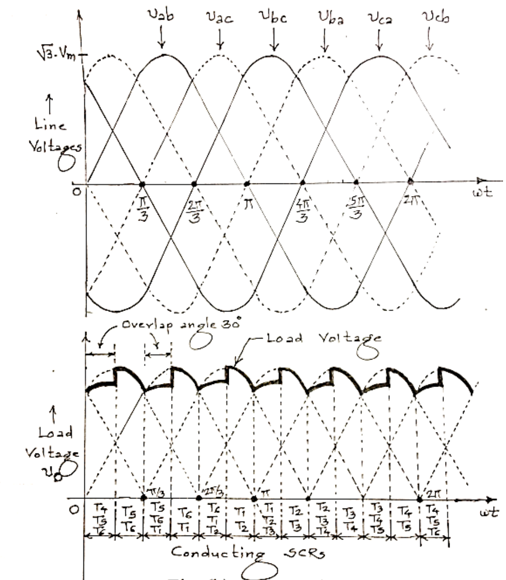


Fig. (b)

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).

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).

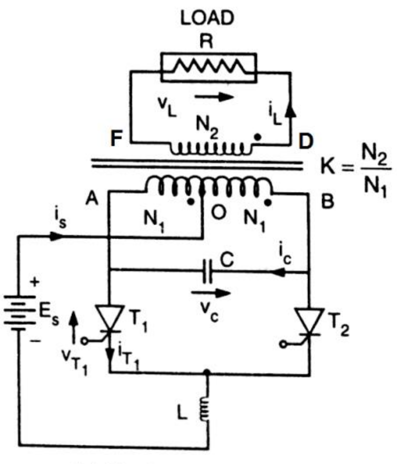
Due to source inductance, the commutation or transfer of current from one SCR to other is not instantaneous. Therefore two SCRs conduct simultaneously and during this overlap, the output voltage is the average of two line voltages. e.g at $\omega t = \pi/3$

the SCR T_1 is fired. It is turned on but already conducting SCR T_5 is not turned off. Thus both T_1 and T_5 conduct along with T_6 and the output voltage during overlap is the average of two line voltages v_{ab} and v_{cb}.

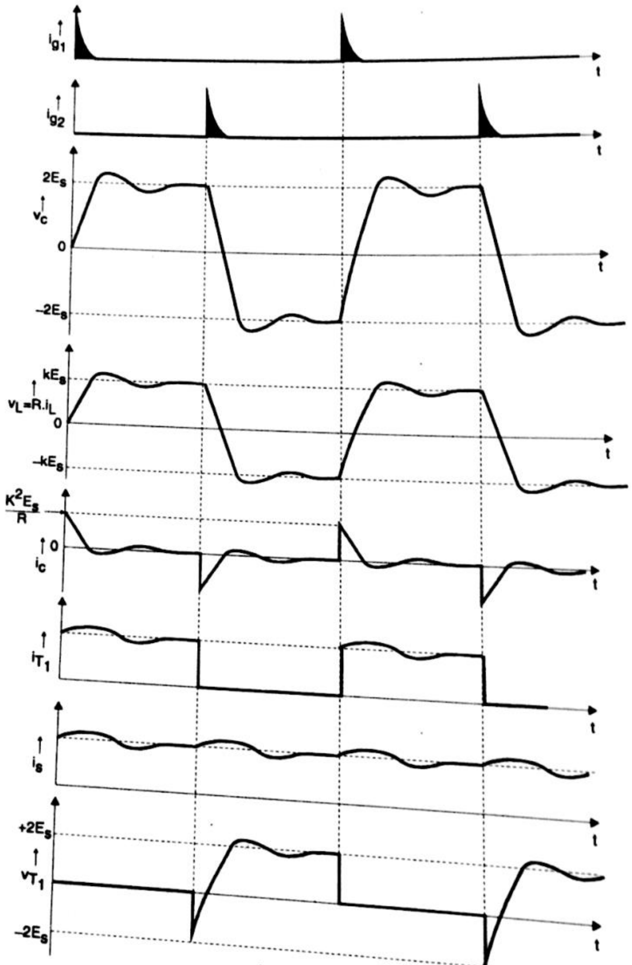
1 b) ii) Describe the operation of parallel inverter and state its advantages.

Ans:

Parallel Inverter:



(a) Circuit arrangement



(d) Waveforms

2 marks for circuit diagram

2 marks for explanation of circuit operation

1 mark for waveforms

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.

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.

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).

Advantages of Parallel Inverter:

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.

1 mark for advantages

2 Attempt any FOUR of the following: 16 marks

2 a) State different SCR triggering methods. Explain dv/dt triggering methods.
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

2 marks for methods

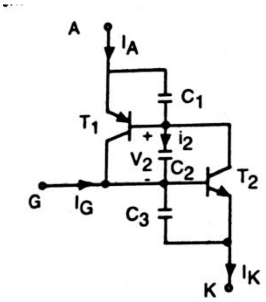
dv/dt Triggering of SCR:

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:

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

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

2 marks for dv/dt triggering method



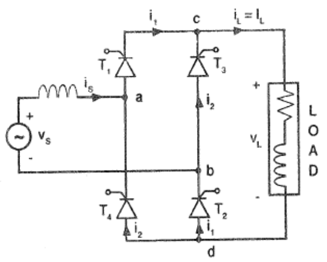
Two-traisistor transient model of thyristor

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.

2 b) State the effect of source inductance on the performance of single phase fully controlled converter indicating clearly the conduction of various thyristors during one cycle.

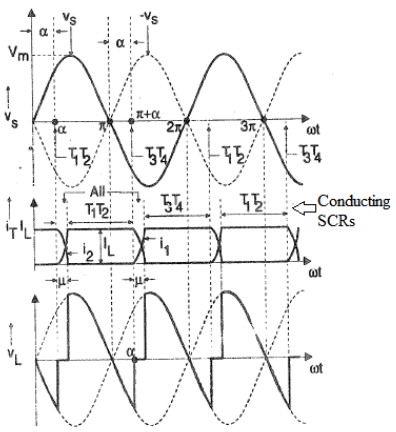
Ans:

Effect of source inductance on the performance of single phase fully controlled converter: — Circuit diagram is optional



(a) Circuit diagram

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



(b) Waveforms

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

1) If the source impedance is purely resistive, then voltage drop across it causes reduction in input voltage and ultimately in the output voltage of converter. — 2 marks for effects

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

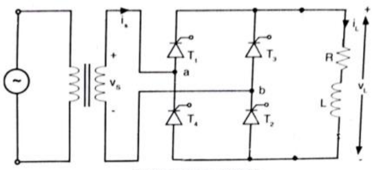
$$V_{dc} = \frac{2V_m}{\pi} cos\alpha - \frac{\omega L_s}{\pi} I_L$$

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

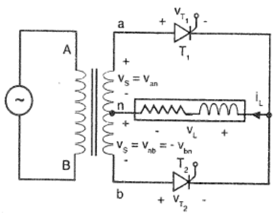
2 c) Draw circuit for single phase full wave converter with R-L load and draw its load voltage and current – waveform.

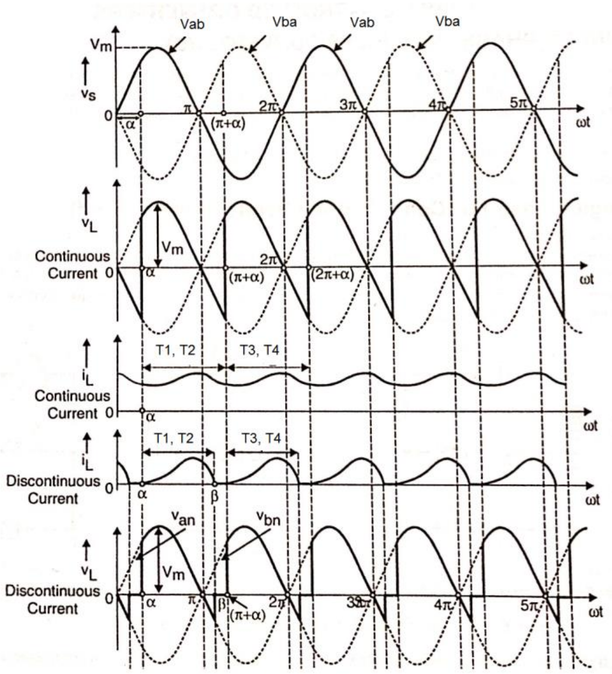
Ans:

2 marks for any one circuit diagram



(a) Circuit arrangement





(b) Waveforms

2 marks for waveforms (1 mark for continuous conduction + 1 mark for discontinuous conduction)

2 d) Explain principle of step up chopper with neat circuit diagram. Derive the expression of output voltage.

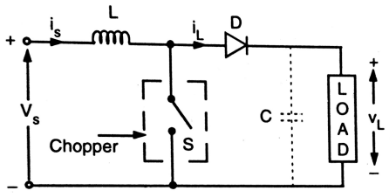
Ans:

1 mark for principle

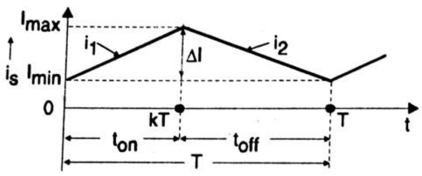
1 mark for circuit diagram

2 marks for mathematical derivation

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. Therefore, the output load voltage is greater than the input dc voltage. Hence it is termed as Step-up chopper. 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:

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

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

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

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

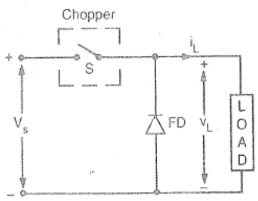
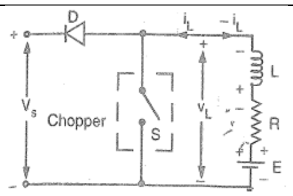
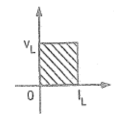
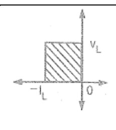
From this equation, it is clear that for k<1, the load voltage v_L is greater than supply voltage V_s , and the circuit acts as a step-up chopper.

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.

2 e) Write comparison of type A and type B choppers.

Ans:

<u>Comparison of type A and type B choppers:</u>

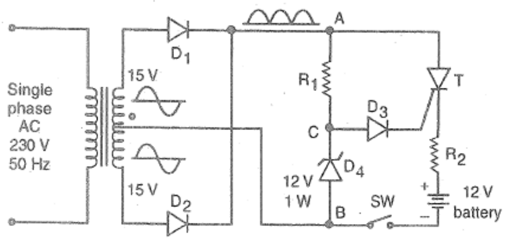
Particulars	Type A Chopper	Type B Chopper
Circuit Diagram	 (a) Circuit arrangement	 (a) Circuit arrangement
Quadrant of operation	 (b) Single-quadrant operation	 (b) Single-quadrant operation
Power Transfer	From source of higher voltage to the load of lower voltage	From load of lower voltage to the source 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

1 mark for each of any four points

2 f) Describe with neat circuit diagram of battery charging using SCR.

Ans:

Battery Charging Using SCR:



Automatic battery charger using SCR

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

2 marks for circuit diagram

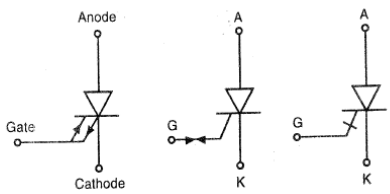
2 marks for explanation

3 Attempt any <u>FOUR</u> of the following: **16 marks**

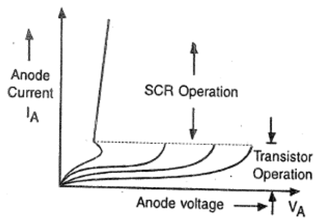
3 a) Draw symbol and characteristics of GTO, SUS, LASCR, IGBT power semiconductor and its important information and application.

Ans: (Any one symbol of each device is enough)

1) GTO:



GTO Symbols



V-I characteristics of GTO

Important Information:

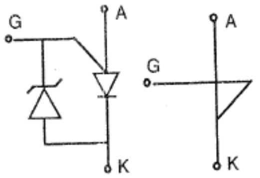
i) Turned on by positive gate pulse and turned off by negative gate pulse.

ii) Offers increased flexibility in controlling power in DC circuits without use of elaborate commutation circuitary.

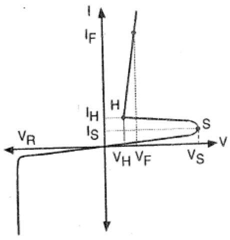
Application: AC/DC machine drives, UPS, Static VAR compensators, induction heating, Photo-voltaic and fuel cell converters.

¼ mark for symbol
¼ mark for characteristics
¼ mark for Imp info
¼ mark for application
= 1 mark for each of 4 devices

2) SUS:



SUS Symbol



v-i characteristic of SUS

Important Information:

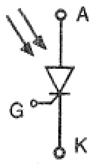
i) It has built in low voltage avalanche diode between gate and cathode.

ii) Due to breakdown of the avalanche diode under forward bias, SUS is turned on at a fixed voltage.

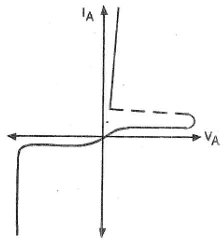
iii) It offers negative resistane region.

Application: Relaxation oscillator, logic and timing circuits.

3) LASCR:



LASCR symbol



v-i characteristic of LASCR

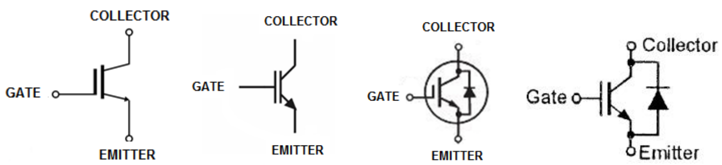
Important Information:

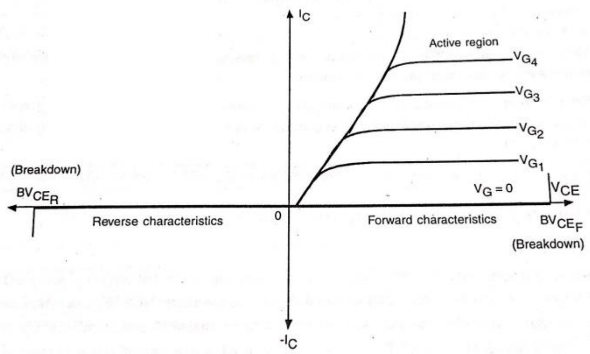
i) Turned on by light falling on the gate-cathode junction.

ii) Complete isolation between triggering circuit and anode-cathode power circuit.

Applications:Static VAR compensators, HVDC

4) IGBT:





V-I characteristics of IGBT

Important Information:

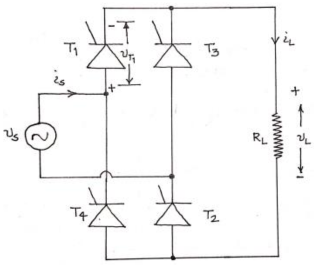
i) Voltage-controlled device
ii) Latch-proof device i.e it is not latched into on-state.
iii) Turn-on and turn-off times are less than SCR.

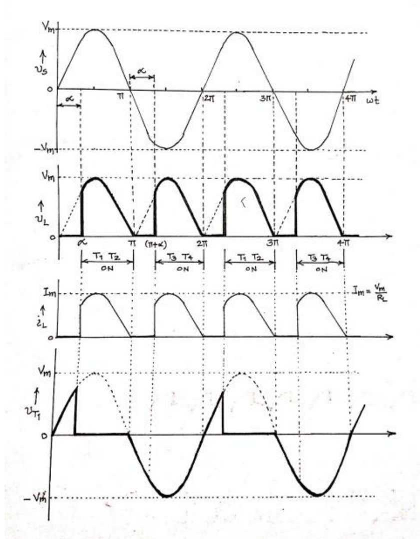
Applications: Medium power applications such as AC/DC motor drives, SMPS, solid-state relays and contactors.

3 b) Draw and explain the circuit diagram and waveform of full wave control bridge converter with resistive load.

Ans:

Full wave Controlled Bridge Converter (Single-phase):





1 mark for circuit diagram

1 mark for waveforms

2 marks for explanation

It consists of four SCRs connected in bridge as shown in the circuit diagram. 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 diagram.

In each half cycle, the respective SCRs are fired at firing or delay angle α, as shown. Before conduction of any pair, the load is isolated from input source, hence load current and voltage are zero. Once SCR pair conducts (at delay angle in each half cycle), the input source voltage appears across load till the end of that half cycle. Thus output DC voltage is in the form of pulses. The magnitude of average load voltage depends upon the firing angle α.

$$V_{dc} = \frac{V_m}{\pi}(1 + cos\alpha)$$

Since load is purely resistive, load current is given by $i_L = \frac{v_L}{R_L}$

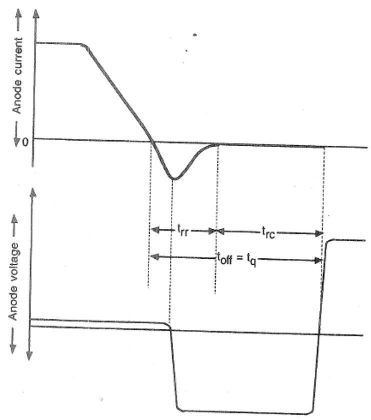
Therefore, the waveform of load current is just similar to that of load voltage.

When any SCR is on, its voltage is approximately zero, and when it is off, the voltage across it is equal to alternating supply voltage. The waveform of voltage across T_1 is shown.

3 c) Explain the SCR turn off process with waveforms of voltage and current.

Ans:

SCR Turn-off Process:



Dynamic turn-off characteristics

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.

2 marks for waveforms

2 marks for explanation

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.

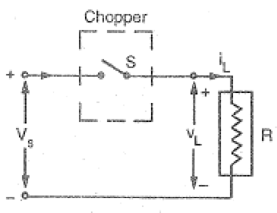
Recombination Time (t_{rc}): It is the time require to recombine the excess carriers trapped at junction J_2.

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

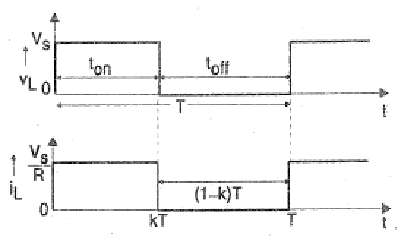
3 d) Describe the principle of DC chopper operation. Derive an expression for its average output voltage.

Ans:

Principle of DC chopper:



(a) Basic circuit



(b) Waveforms

1 mark for principle of operation

1 mark for circuit diagram

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, 1 mark for waveforms

$$V_{Lav} = \frac{1}{T}\int_0^T v_L dt = \frac{1}{T}\left[\int_0^{t_{on}} v_L dt\right] = \frac{1}{T}\int_0^{t_{on}} V_s dt = \frac{V_s(t)_0^{t_{on}}}{T}$$

1 mark for derivation

$$= \frac{t_{on}}{t} V_s = k\, V_s$$

where k is the duty cycle.

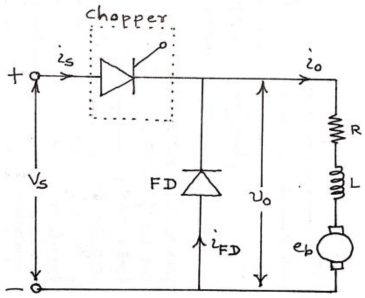
Duty cycle of chopper is defined as the ratio of the on time t_{on} of chopper to the period T (= t_{on} + t_{off}) of the on-off cycle of chopper.

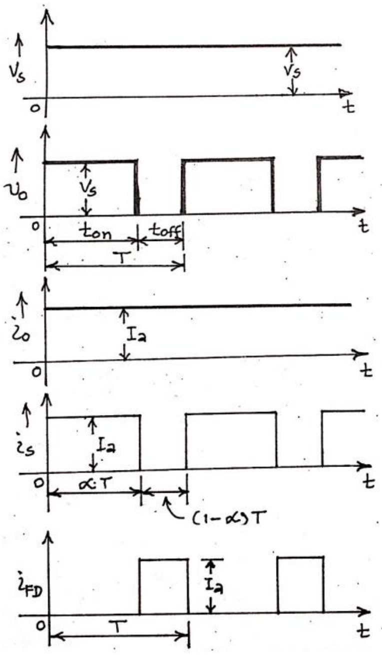
3 e) Draw and explain the speed control of DC series motor with single phase step down chopper.

Ans:

Speed control of DC series motor with single phase 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.





1 mark for circuit diagram

1 mark for waveforms

1 mark for explanation

1 mark for mathematical treatment

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

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

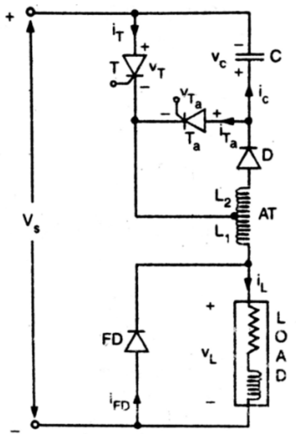
It is seen that by varying the duty cycle α of the chopper, armature terminal voltage can be controlled and thus speed of the dc series motor can be regulated.

4 a) Attempt any THREE of the following: **12 marks**

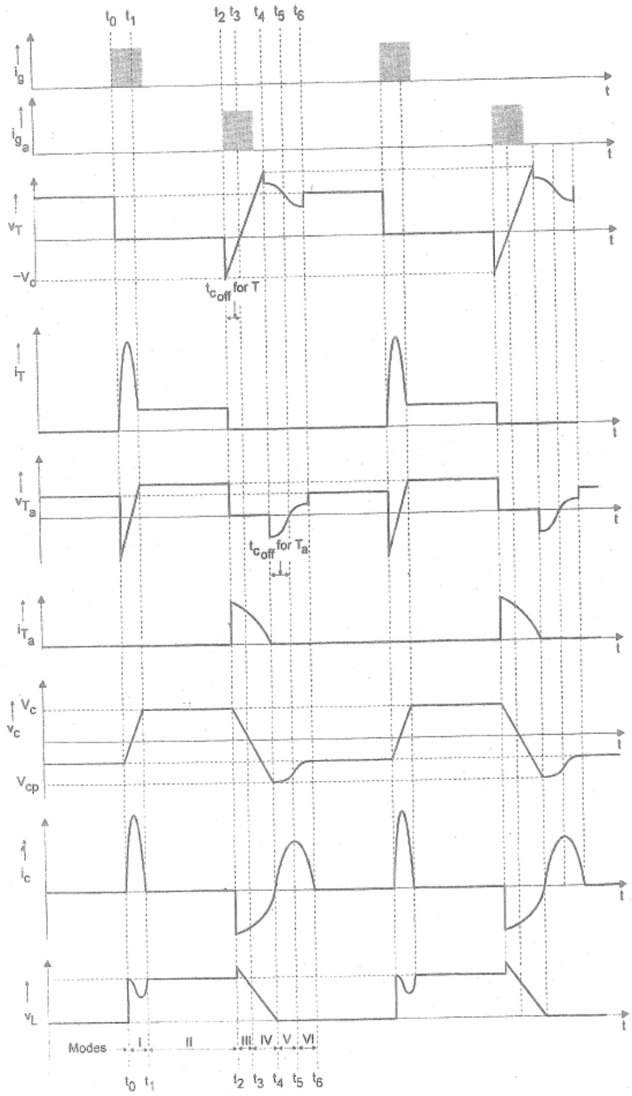
4 a) i) With the circuit diagram and waveform, explain the working of Jones chopper.

Ans:

Jones Chopper:



Jones chopper



1 mark for circuit diagram

1 mark for waveforms

2 marks for explanation

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.

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.

4 a) ii) Explain the selection factors of SCR and its testing.

Ans:

Selection factors of SCR:

1) Voltage and Current ratings of the circuit in which SCR is to be used.
2) Duty cycle of SCR operation.
3) Form factor of current waveform.
4) Switching losses in high frequency applications.
5) Peak current (starting or intermittent) in motor applications.
6) Circuit turn-off time.
7) Static and reapplied dv/dt in the circuit.

Any 6 factors (3marks)

Testing of SCR:

Faulty SCR can be identified easily by using multimeter. The resistance of SCR is checked by using multimeter.

If the resistance from anode to cathode is found to be high and the resistance from cathode to anode is also found to be high, then we can say that the SCR is in good condition.

If any one of these resistances is found to be low, the SCR is faulty.

It is because during forward bias condition of SCR, junction J_2 gets reverse biased and offers high resistance. During reverse bias condition of SCR, junctions J_1 and J_3 get reverse biased and offer high resistance. Thus under normal working voltage conditions SCR must offer high resistance for both forward and reverse current. Otherwise it is faulty.

1 mark for Testing

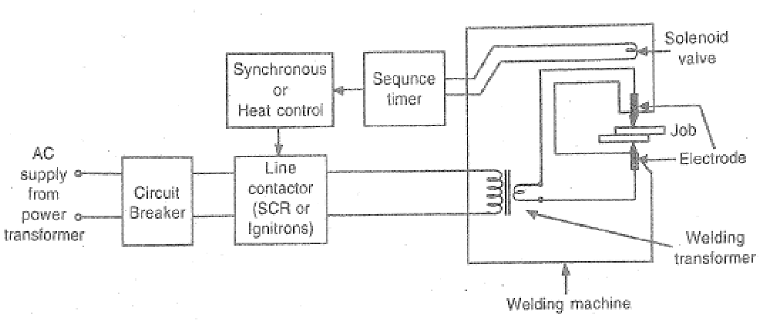
4 a) iii) Describe the working of resistance welding method with diagram.

Ans:

Resistance Welding:

The block diagram of general resistance scheme is shown in the figure. The AC supply is obtained from power transformer. The circuit breaker is used to switch on and off the supply either manually or automatically under normal or abnormal conditions. The functions of other blocks are as follows:

1) Line Contactor: It is basically a switch which permits the welding current to flow to heat the metal pieces and make the weld. Since the welding current



Resistance welding scheme

needs to flow for short duration, the contactor must close and then open quickly. For precise and noise free operation, it can be implemented by solid-state devices such as SCR.

2 marks for circuit

2) Synchronous or Heat Control: An electronic circuit is used to control the firing of SCRs, which controls the voltage supplied to primary winding of welding transformer. By controlling the primary voltage, the welding current in the secondary is controlled to control the heat and weld.

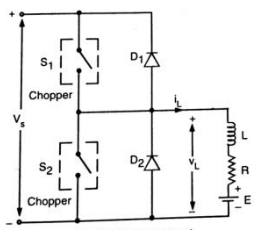
2 marks for explanation

3) Sequence Timer: It is an electronic timing circuit that provides timing signals to carry out the welding process in a particular sequence. The signals are provided in following sequence:
   i) The signal is provided to solenoid valve, which when opened, applies air pressure so that the electrodes come together and squeeze the metal pieces.
   ii) The signal is then given to heat control unit to start the flow of welding current for welding.
   iii) The signal is then given to heat control unit to stop the welding current.
   iv) The signal is then given to solenoid valve to close it, so that the air pressure is reduced and electrodes are separated.
   v) Finally signal is generated to recycle the operation.

In this way, the resistance welding scheme works.

4 a) iv) Sketch output voltage, output current, source current and thyristor current waveform for type-C chopper. Indicate the conduction of various devices.

Ans:



(a) Circuit arrangement

Basically Type C chopper is a combination of Type A and Type B choppers, as shown in figure. So depending upon the requirement, it can be operated as type-A (excluding S_2 and D_1) or type-B chopper (excluding S_1 and D_2).

The waveforms for both operations are shown separately in the following figure.

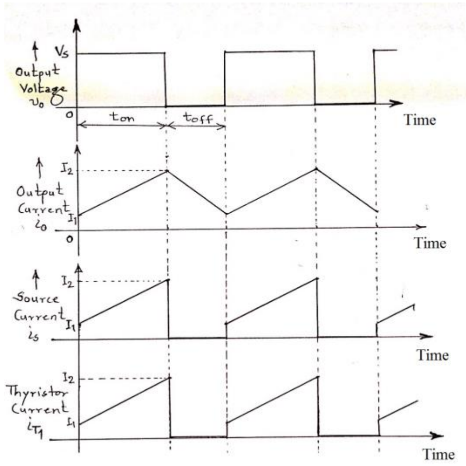
2 marks for waveforms of type-A operation

Conducting Devices:

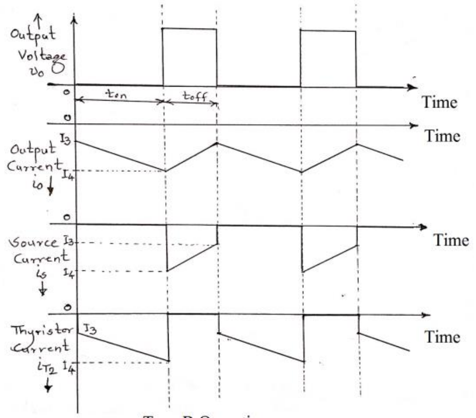
Type A operation: During t_{on}: S_1 (SCR T_1) and during t_{off}: D_2

Type B operation: During t_{on}: S_2 (SCR T_2) and during t_{off}: D_1

2 marks for waveforms of type-B operation



Type A Operation



Type B Operation

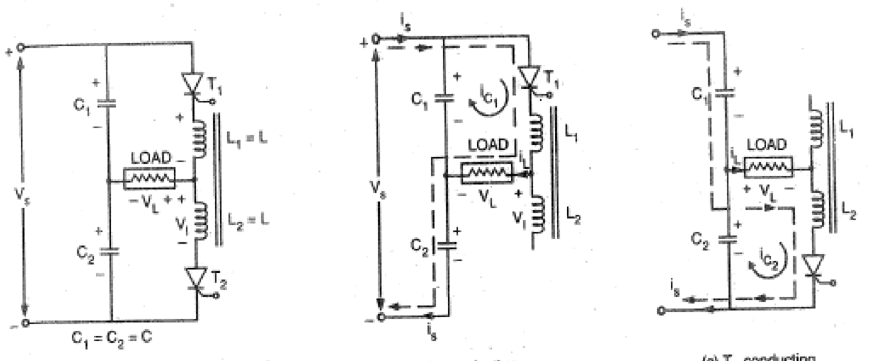
4 b) Attempt any ONE of the following: 6 marks

4 b) i) Discuss the method of overcoming the intermittent power flow in a basic series inverter. Illustrate your answer with relevant circuit and waveform.

Ans:

Method of overcoming the intermittent power flow in basic series inverter:

2 marks for circuit diagram



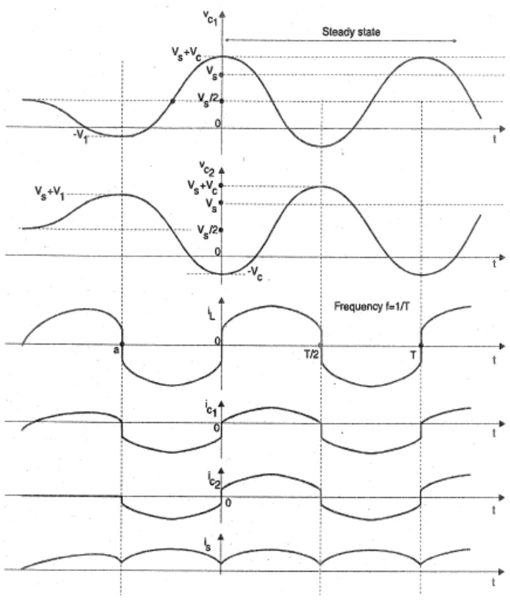
(a) Circuit diagram (b) T_1 conducting (c) T_2 conducting

2 marks for explanation

In basic series inverter, when main SCR is on, the DC source supplies power to load a well as L and C. Since series RLC combination is underdamped, we get positive half cycle pulse of load current and at the end of pulse, the SCR is naturally turned off. To get negative half cycle of load current, another SCR is fired. The charged capacitor forces current in the reverse direction. The inductor also helps to maintain the current. Thus the DC source supplies power only during positive half cycle of load voltage or current and power flow is intermittent.

To have continuous power flow from input DC source to load, the half-bridge

2 marks for waveforms



series resonant configuration can be used as shown in the figure. It is seen that when T_1 is triggered, the DC source forces current through the upper loop and we get positive half cycle of load current. Due to resonating underdamped RLC combination, current naturally drops to zero and T_1 is commutated. When T_2 is triggered, the DC source forces current through the lower loop and we get negative half cycle of load current. Due to resonating underdamped RLC combination, current naturally drops to zero and T_2 is commutated. The waveforms of load current, capacitor currents and source current are shown in the figure.

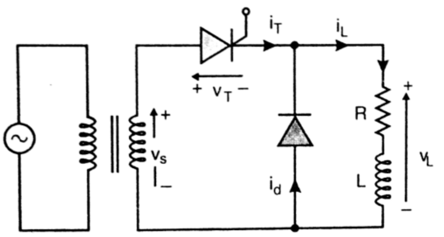
4 b) ii) For a single phase fully controlled half wave converter system, sketch waveforms for load voltage and load current for

1) RL load and
2) RL load with free-wheeling diode across RL.

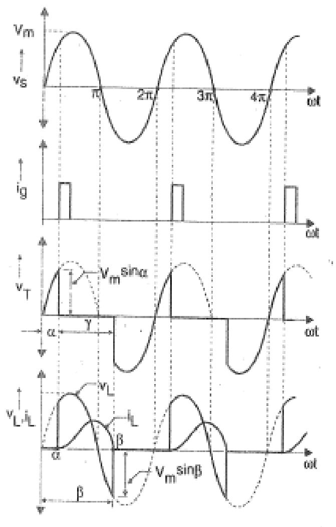
From a comparison of these waveforms, discuss the advantages of using a free-wheeling diode.

Ans:

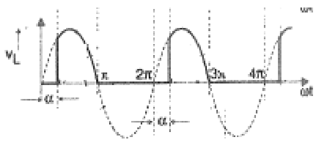
Single phase fully controlled half wave converter:



(a) Circuit diagram



Without freewheeling diode



With freewheeling diode

On comparing the waveforms of output load voltage with and without freewheeling diode, it is seen that when the freewheeling diode is not used, the output voltage get reversed after positive half cycle. This is because 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. When the freewheeling diode is used, the load inductance forces current through it after every positive half cycle. When diode conducts, the load voltage is maintained at approximately zero. Thus load voltage is prevented from becoming negative. The negative voltage appearing across load reduces the average load voltage. Thus the use of freewheeling diode helps to increase the average load voltage. For some sensitive loads, the negative voltage is undesirable. In such cases also the use of freewheeling diode is advantageous.

1 mark for circuit diagram

2 marks for waveforms

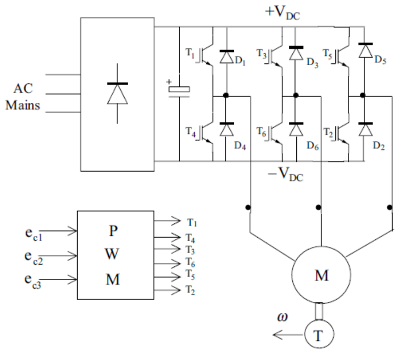
1 mark for discussion

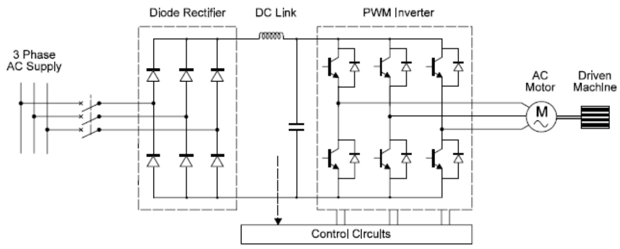
5 Attempt any FOUR of the following: 16 marks

5 a) Draw the circuit diagram and explain the variable frequency control of induction motor.

Ans:

Variable frequency control of induction motor:





2 marks for circuit diagram (any one)

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.

2 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.

5 b) Draw and explain single phase cycloconverter.

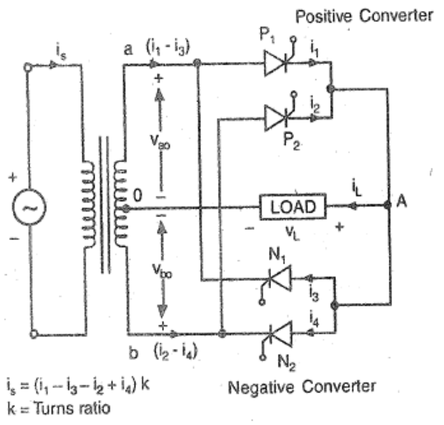
Ans:

<u>Single phase cycloconverter:</u>

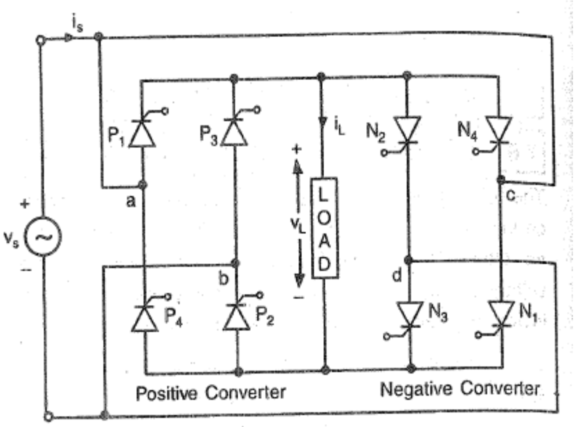
1 mark for circuit diagram (any one)

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.

1 mark for explanation



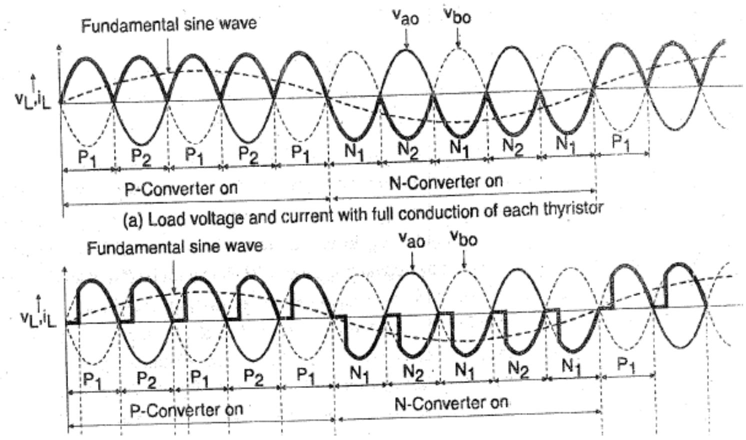
(a) Single-phase Mid-point cycloconverter



(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 1/5th of input supply frequency.

2 marks for waveforms



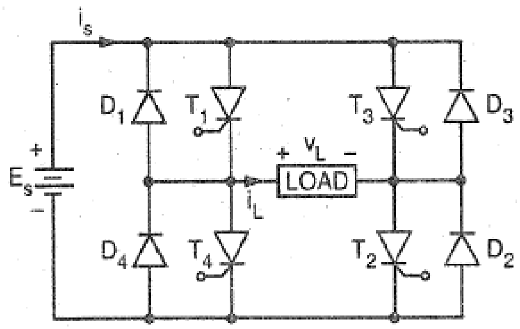
5 c) Draw the circuit diagram of a single phase SCR full bridge inverter. Explain how power can flow either direction in this circuit.

Ans:

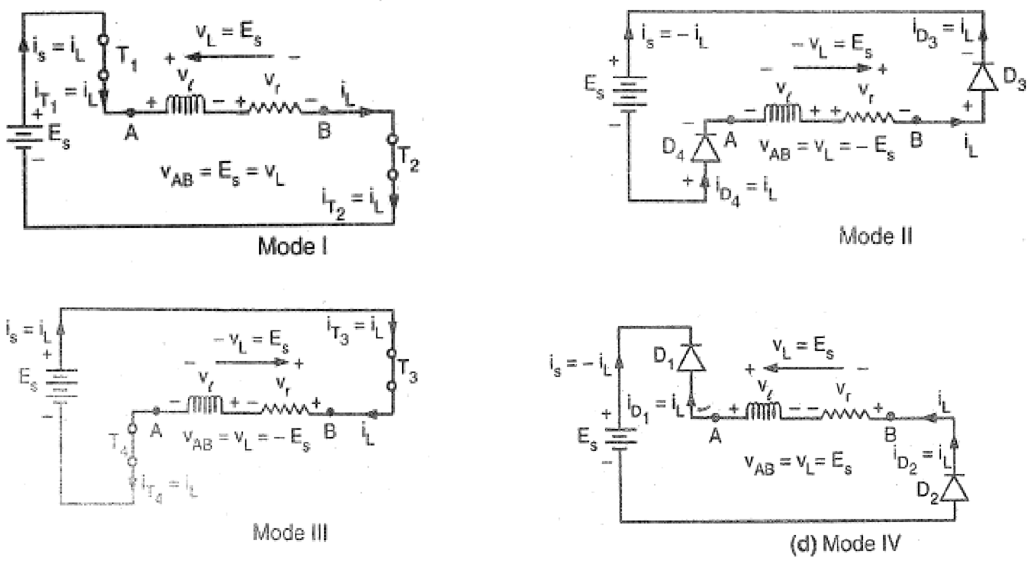
<u>Single phase SCR full bridge inverter:</u>

The circuit arrangement for single-phase SCR full bridge inverter is shown in fig.(a). The load is RL load. All the SCRs are forward biased by the input DC source. When T_1 T_2 are turned on, load voltage becomes positive and when T_3 T_4 are turned on the load voltage becomes negative. For inductive load the circuit operation is divided in four modes:

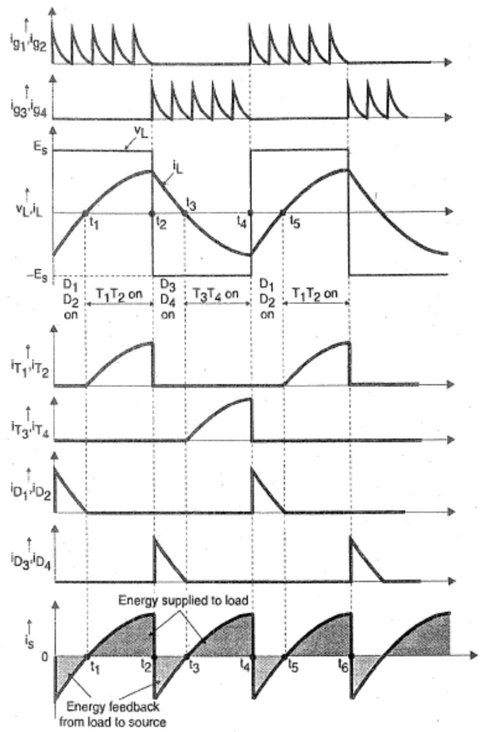
1 mark for circuit diagram



(a) Circuit arrangement



2 marks for explanation



Single-phase, full-bridge inverter waveforms

1 mark for waveforms

Mode I (t_1 to t_2): By gate pulses, the SCRs T_1 T_2 are turned on at t_1. The supply voltage E_s appears across load, the load current starts rising gradually due to inductive nature of load. The power flows from input DC source to load. During this mode the energy received by load is partly stored by its inductance.

Mode II (t_2 to t_3): At t_2 the gate pulses of T_1 T_2 are prohibited and they are turned off by commutating components. Due to load inductance, the load current cannot be reduced to zero suddenly. The load current is maintained in the same direction by load inductance voltage. The load current flows through diode D_3, DC source E_s, diode D_4 and load. Due to conduction of diodes D_3 and D_4, the load voltage appears to be negative. The load power therefore becomes negative i.e load returns or supplies back power to DC source. With energy feedback, load inductance loses its energy. So the load current slowly decreases and finally falls to zero. So far diodes are conducting, reverse bias is maintained across T_3 T_4 and they cannot be turned on.

Mode III (t_3 to t_4): At t_3 the SCRs T_3 T_4 are turned on by gate pulses. The DC source voltage E_s appears as reversed voltage across load. The load current is also reversed and starts to establish. Since load inductance has already lost its energy, it starts absorbing energy from DC source. Thus during this mode, the load receives energy from DC source, just similsr to mode I, but with reversed voltage and current. At t_4 gate pulses of T_3 T_4 are prohibited and they are turned off by forced commutation circuit.

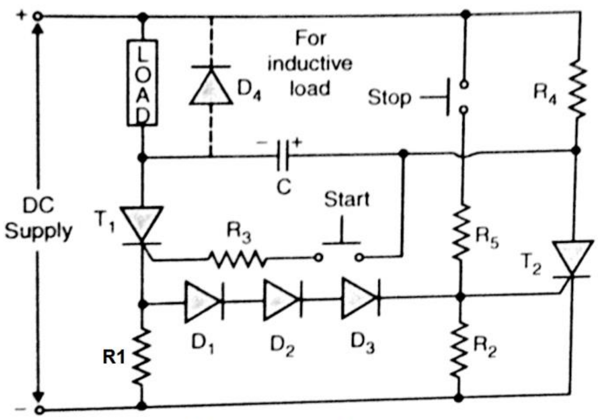
Mode IV <u>(t_4 to t_5) or (0 to t_1):</u> The turning off of T_3 T_4 would block the current, but due to load inductance, the load current is maintained in the same reversed direction by forcing it through diodes D_1 and D_2 and DC source E_s. Through diodes D_1 and D_2, the load voltage appears to be positive, making load power negative i.e load returns or feedback the power to load.

The waveforms of load voltage, load current, SCR currents, diode currents are shown in the figure.

5 d) Draw the circuit diagram and explain DC static circuit breaker.

Ans:-

<u>DC Static Circuit Breaker</u>:



DC static Circuit Breaker

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

2 marks for circuit diagram

2 marks for explanation

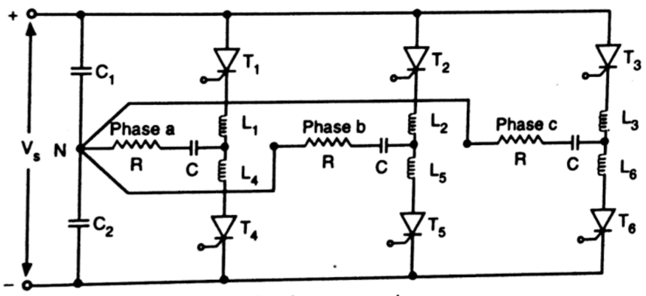
If we attempt to break the DC load current i.e switch off the load, using mechanical contact type switch, since current is DC, heavy arcing may damage the switch. Instead, if we use this circuit configuration, the load current can be interrupted by turning off the SCR T_1. When 'Stop' button is pressed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

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

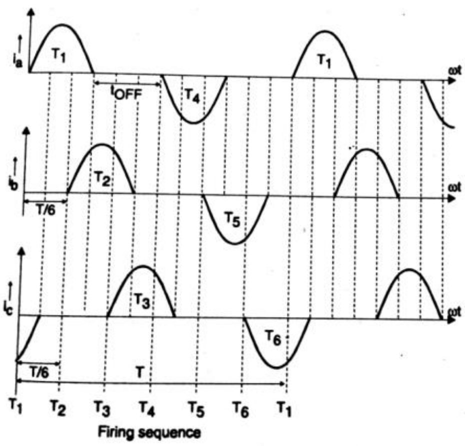
5 e) Draw and explain the three phase series inverter.

Ans:

Three-phase Series Inverter:



(a) Circuit arrangement



(b) Waveforms

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 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.

1 mark for circuit diagram

2 marks for explanation

1 mark for waveforms

5 f) Describe briefly and compare the various methods employed for the control of output voltage of inverter.

Ans:

Methods of Voltage Control in Inverters and their comparison: 2 marks for methods

1) External Control:

a) Externally controlling the ac output voltage

(i) AC voltage control: Using AC voltage controller between inverter & load

- Additional AC voltage controller is needed.

(ii) Series inverter control: Connecting two or more inverters in series.
- Additional inverter is needed.

b) Externally controlling the dc input voltage

(i) Obtaining controlled dc supply for inverter from fully controlled rectifier & filter arrangement.
- Additional Fully controlled rectifier and filter required at input.

(ii) Obtaining controlled dc supply for inverter from uncontrolled rectifier, chopper & filter arrangement.
- Additional uncontrolled rectifier, chopper and filter required at input.

2 marks for comparison

(iii) Obtaining controlled dc supply for inverter from AC voltage controller, uncontrolled rectifier, filter arrangement.
- Additional AC voltage controller, uncontrolled rectifier and filter required at input.

(iv) Obtaining controlled dc supply for inverter from chopper & filter arrangement.
- Additional chopper and filter required at input.

2) Internal Control: By controlling the operation of inverter itself – PWM technique
- Circuit complexity increases.

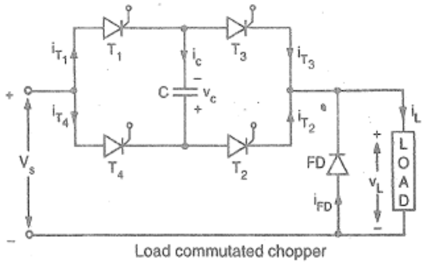
6 Attempt any FOUR of the following: 16 marks

6 a) Discuss the working of a load-commutated chopper with relevant voltage and current waveforms. Show voltage variation across each pair of SCRs as a function of time.

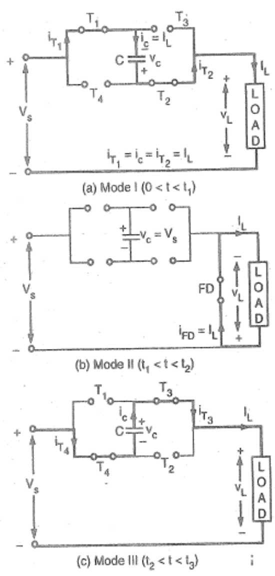
Ans:

Load-commutated chopper:

1 mark for circuit diagram (Modes circuit diagram optional)



Load commutated chopper



Operating modes of load commutated chopper

The circuit diagram, operating modes and waveforms are shown in the figure. When T_1 T_2 are on, the capacitor charges with upper plate positive and when T_3 T_4 are on, the capacitor charges with lower plate positive to supply voltage V_s by the load current. Prior to the firing of T_1 & T_2 the other pair T_3 T_4 was on, hence the capacitor has been charged to supply voltage V_s with polarity as shown in the figure.

2 marks for circuit operation

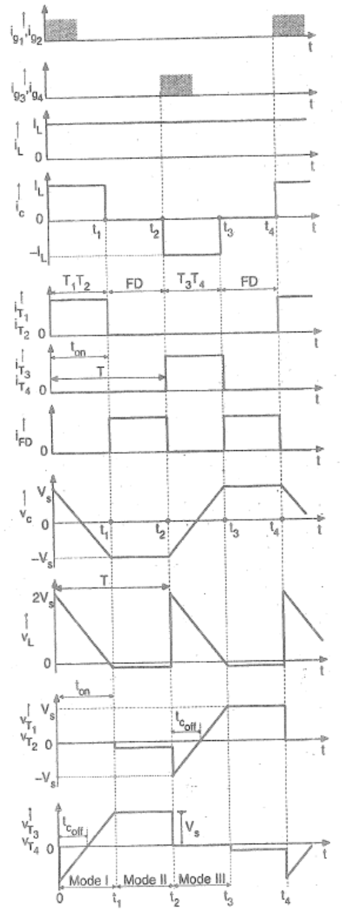
Mode I ($0<t<t_1$): The SCRs T_1 T_2 are turned on at t = 0, the load current flows through T_1, C, T_2 and load. At t = 0, the load voltage suddenly rises to $2V_s$ ($=V_s + v_c$) from zero. Since load current is constant, the capacitor discharges linearly to zero and then charges linearly with opposite polarity to Vs. During this change the load voltage drops to zero at $t = t_1$. Due to capacitor voltage reversal, the SCRs T_3 T_4 get forward

biased. The SCRs T_1 T_2 are turned off by commutation circuit at $t = t_1$.

Mode II ($t_1<t<t_2$): At the beginning of this mode, the capacitor is slightly overcharged, making load voltage slightly negative. The SCRs T_1 T_2 are not completely turned off. The freewheeling diode gets forward biased and then conducts the load current I_L.

Mode III ($t_2<t<t_3$): The SCRs T_3 T_4 are forward biased by capacitor voltage. So they are fired at $t = t_2$. Once T_3 T_4 conducts, the load voltage jumps from 0 to $2V_s(=V_s + v_c)$. The SCRs T_1 T_2 are reverse biased by the capacitor voltage and hence turned off completely. The load current flows through T_4, C, T_3 and load. The capacitor discharges linearly to zero and then charges linearly to Vs. During this change the load voltage drops to zero at $t = t_3$. At the end of this mode, the capacitor gets slightly overcharged, making load voltage slightly negative. The freewheeling diode gets forward biased and then conducts the load current I_L. The load current gets shifted from T_3 T_4 to FD and mode II repeats.

The waveforms of load voltage, load current, capacitor voltage, SCR currents, diode current, SCR voltages are shown in the figure.



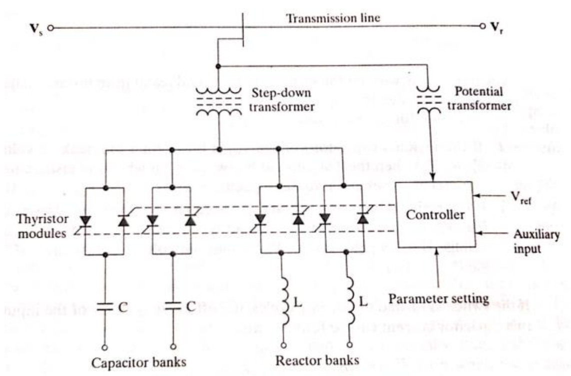
Waveforms of load commutated chopper

1 mark for waveforms

6 b) Describe with circuit diagram the working of static VAR compensator.

Ans:

<u>Static VAR compensator:</u>



General arrangement of static VAR compensator

2 marks for diagram

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.

2 marks for discription

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

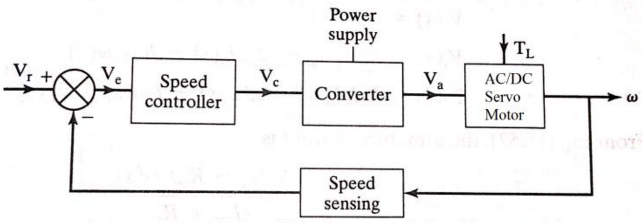
peak load condition, most of the loads are inductive and they demand the reactive power. In this situation, TSC is used to insert capacitors in power system to generate the reactive power.
In fact, SVC comprises combinations like (TCR+TSC), (TCR+FC) as per the need.
In TCR, phase control is used to vary the effective inductance of the inductor.
In TSC, the integral-cycle control is employed to vary the effective capacitance of the capacitor.

6 c) Describe the working of closed loop speed control method for AC servomotor and DC servomotor.

Ans:

(Examiner is requested to consider any other correct scheme as valid answer)

Closed loop speed control method for AC servomotor and DC servomotor:



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

2 mark for block diagram

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.

2 marks for explanation

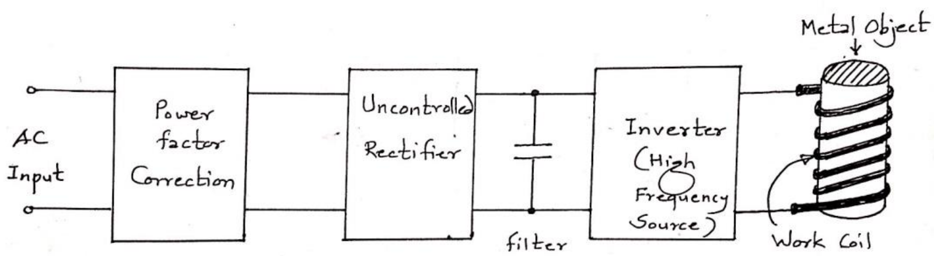
If the speed of servomotor does not match with the set speed, the speed error V_e increases. The speed controller responses with as increased control signal V_c. This control signal changes the operation of converter and voltage supplied to servomotor is changed so as to minimize the speed error.

6 d) State the principle of induction heating. Draw the block diagram of it using thyristor circuit.

Ans:

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

2 marks for Principle



2 marks for block diagram

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. The object, being conductor, offers many short-circuited paths. So the circulating current flow through these paths. The currents are in the form of eddies (circular in nature), hence called "eddy currents". The eddy currents flowing through resistive paths in metal object cause power loss (i^2R loss) and heat is produced. Since the heat is produced by eddy currents, which are induced by electromagnetic induction, this heating is called "Induction heating".

6 e) Define the following terms relating to SCR and discuss their significance.

1) Forward break over voltage
2) On-state voltage drop
3) Latching current
4) Holding current

Ans:

1) Forward break over voltage: It is the forward voltage at which the breakdown of junction J_2 occurs in absence of any gate current and SCR starts conducting the forward current.
   Significance: It specifies the limit for the forward blocking voltage of the SCR.

½ mark for each definition

2) On-state Voltage drop: It is the voltage between anode and cathode at specified forward current and junction temperature.
   Significance: It specifies the effect of its insertion in the circuit with regards to voltage. It also indirectly reflects the on-state power loss in the SCR.

½ mark for each significance

3) Latching current: It 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.
   Significance: It specifies the circuit condition required to turn-on of SCR satisfactorily.
4) Holding current: It is defined as the minimum anode current required to maintain the conducting SCR in the on-state.
   Significance: It specifies the circuit condition required to turn-off the SCR satisfactorily.