Summer – 2018 Examinations
Model Answer **Subject Code: 17638 (PEL)**

Important Instructions to examiners:

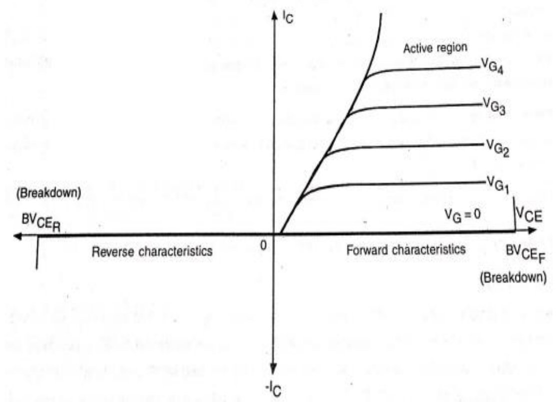
1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner should assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling errors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

Ans:

Characteristics of IGBT:



V-I characteristics of IGBT

Characteristics of IGBT 2 Marks

Explanation:

a) The VI characteristics of IGBT are shown in above figure.
b) The **forward characteristics** are similar to those of bipolar transistor. The only difference here is that the controlling parameter is gate to emitter voltage V_{GE} and parameter being controlled is collector current I_C.
c) IGBT is voltage control device, controlled by gate-emitter voltage V_{GE}.
d) The collector current I_C increases with increase in voltage between gate and emitter V_{GE} at constant value of V_{CE}.
e) Here V_{GE} or V_G(gate voltage) is positive and $V_{G4} > V_{G3} > V_{G2} > V_{G1}$
f) BV_{CEF} is forward breakdown voltage, this is the value of V_{CE} at which avalanche breakdown takes place, and at this point voltage across the device and current through it both are high. Therefore power dissipated is also very large.
g) In **reverse characteristics** BV_{CER} is reverse breakdown voltage.

Explanation 2 Marks

1 a) (ii) State the need of converters. Define firing angle.

Ans:

Need 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.

Need of Converters 2 Marks

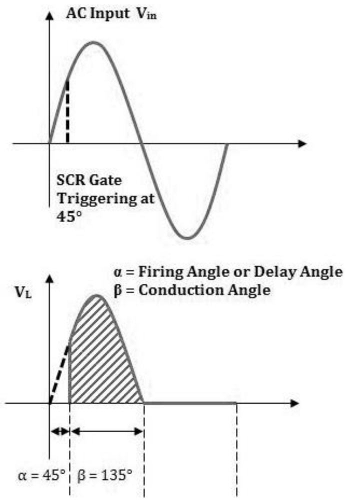
In present days, the AC supply is used in all stages of power system. It is possible to convert AC supply into DC supply. It eliminates the need of energy storage. The DC load can be fed from such DC supply, which is available as & when AC supply is there. Large DC loads, which are difficult to handle 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).

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.

OR

Firing angle or delay angle can be defined as the angle measured from the angle that gives maximum average output voltage (0° in figure) to the angle when the SCR is actually triggered or fired (45° in figure) by gate pulse.



Definition of firing angle 2 Marks

1 a) (iii) Compare MOSFET inverter with thyristor based inverter.

Ans:

Comparison between MOSFET based inverter and thyristor based inverter:

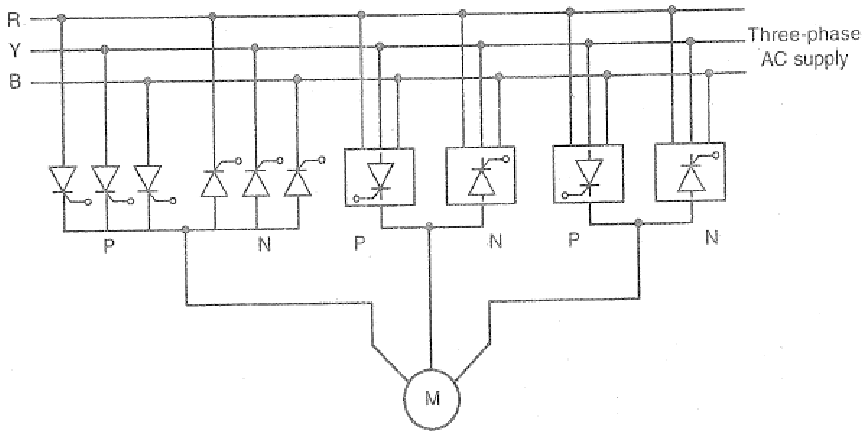
Sr.no.	MOSFET inverter	Thyristor based inverter
1	These are based on Power MOSFET as switching device.	These are based on SCR as switching device.
2	Power MOSFETs are voltage-controlled devices and triggering circuit consumes less power.	SCRs are current controlled devices and triggering circuit consumes more power.
3	Fast turn-ON and turn-OFF as compared to SCR	Slow turn-ON and turn-OFF as compared to MOSFET.
4	Inverters operate at higher switching frequency.	Inverters operate at comparatively lower switching frequency
5	Switching losses are less.	Switching losses are more.
6	Operate at smaller power rating	Operate at higher power rating.
7	Quality of the inverter output waveform can be improved by increasing switching frequency	Quality of the output waveform is less and cannot be improved.

1 mark for each point (any 4 points) = 4 marks

1 a) (iv) Describe the working of speed control of 3ϕ induction motor by variable frequency control using cycloconverter.

Ans:

Speed Control of 3ϕ induction motor by Variable frequency control using cycloconverter:



Cycloconverter drive

2 Marks for any one Circuit diagram

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

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.

The schematic of cycloconverter feeding a three-phase induction motor is shown in figure above. Each motor terminal is connected to three-phase supply through P-converter & N-converter. Only one converter, either P or N is 'on' at a time. When P-converter is on, the positive voltage half cycle of a phase is connected to the motor terminal, whereas when N-converter is 'on', the negative voltage half cycle of a phase is connected to the motor terminal. Number of only positive half-cycles can be applied in sequence to motor terminal by switching only P-converter. Similarly, only negative half-cycles can be applied in sequence to motor terminal by switching only N-converter. The output frequency is less than the supply frequency.

2 Marks for Explanation

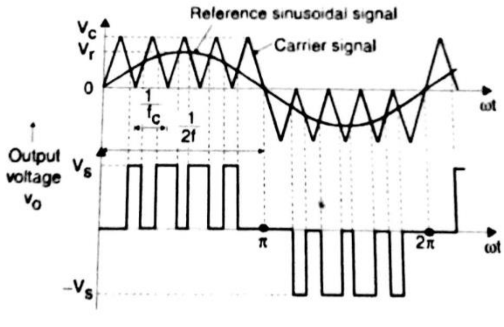
The cycloconverter is a single-stage frequency converter. Cycloconverter gives sinusoidal output voltage when output frequency is limited to 1/3 of the supply frequency. The speed control range is limited to 33% of base speed. Within this range, the motor operates smoothly without any torque pulsations. However, any attempt to increase the frequency beyond 33% results in waveform distortion. Using cycloconverter, the voltage and frequency can be adjusted independently. The cycloconverter allows power flow in either direction, hence regenerative braking and four quadrant operation is possible.

1b) Attempt any <u>ONE</u> of the following: 6

1b) (i) With the help of waveforms, explain the working of sinusoidal pulse width modulation.

Ans:

Sinusoidal Pulse Width Modulation: (Sin PWM)



Sinusoidal-pulse-width modulation (Sin M)

In this modulation technique, several pulses per half cycle are used to fabricate output AC waveform. The pulse width is a sinusoidal function of the angular position of the pulse in the half cycle. The gating signals for turning on the thyristors are generated by comparing a high frequency carrier signal v_c with a sinusoidal reference signal v_r of desired frequency. The trigger pulse is generated at the intersection point of v_c and v_r. The thyristor is maintained on during the interval when $v_r > v_c$. When v_r becomes equal to v_c the on thyristor is commutated by forced commutation. In fact, the comparison of v_c and v_r is carried out in comparator and when $v_r > v_c$, the comparator output is high, otherwise it is low. The comparator output is processed in such manner that the output voltage has pulse width in agreement with the comparator output pulse width.

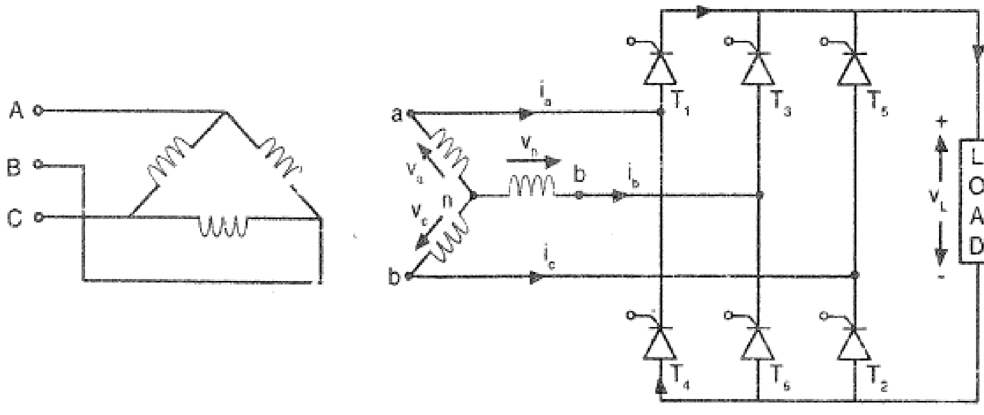
3 marks for explanation

3 marks for waveform diagram

1b) (ii) Draw and explain 3 ϕ fully controlled bridge converter with 'R' load.

Ans:

Three-phase Fully Controlled Bridge Converter with R load:



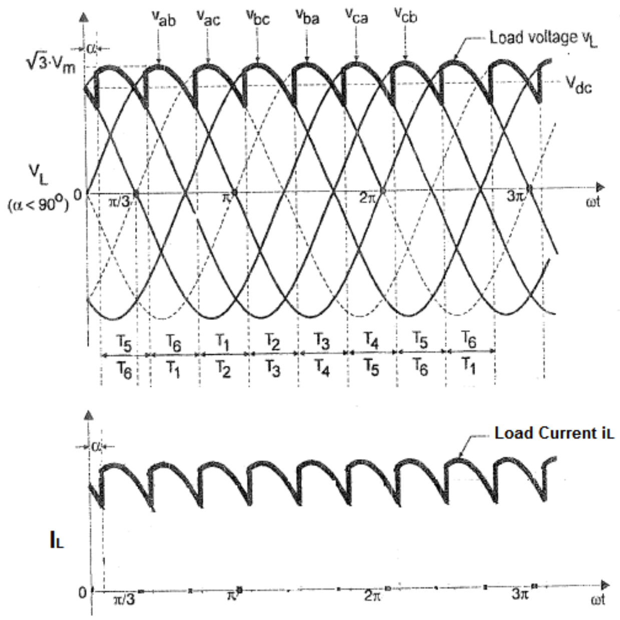
(a) Circuit arrangement

2 marks for circuit diagram (Equivalent circuit may please be considered)

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 operation explanation

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



(b) Waveforms

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 gets 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).

2 marks for waveforms

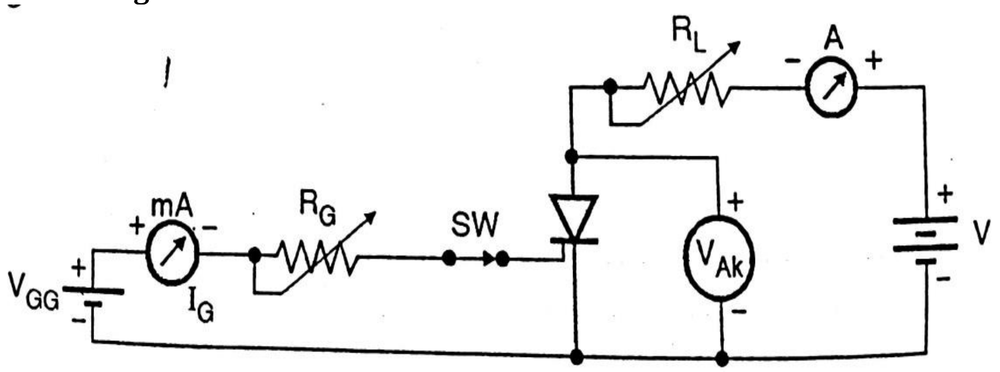
Since the load is purely resistive, the load current follows same variations as that of load voltage. The waveform of load current is similar to the load voltage waveform as shown in the fig.(b).

2 Attempt any FOUR of the following: 16

2 a) With suitable circuit diagram, explain the VI characteristics of SCR.

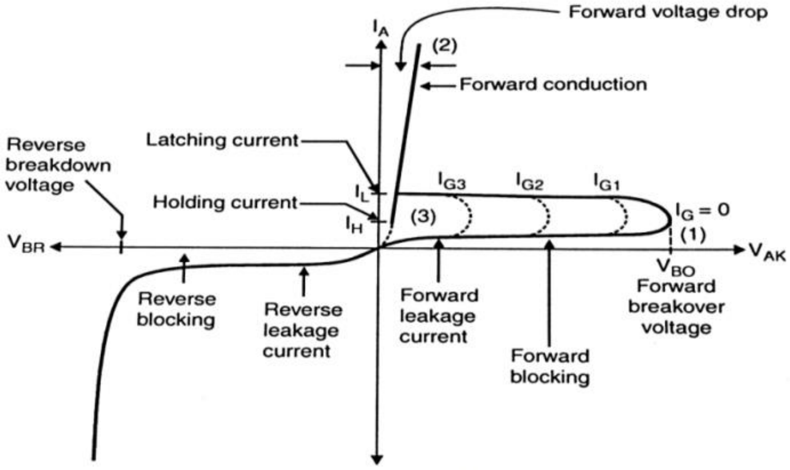
Ans:

Circuit Diagram of SCR:



1 mark for labeled diagram

V-I characteristics of SCR:



V-I Characteristics of SCR

1 mark for characteristics

Operating regions:

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

2 marks for explanation.

2b) Compare 3ϕ and 1ϕ converters, on the basis of efficiency, ripple factor, RMS values and average values.

Ans:

Comparison of 3ϕ and 1ϕ Converters:

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

Particulars	3ϕ Converter	1ϕ Converter
Efficiency	For constant load current, the rectification efficiency is more and given by, $$\eta = \frac{3cos\alpha}{\pi\left(\frac{1}{2}+\frac{3\sqrt{3}}{4\pi}cos2\alpha\right)^{\frac{1}{2}}}$$	For constant load current, the rectification efficiency is less and given by, $$\eta = \frac{2\sqrt{2}}{\pi}cos\alpha$$
Ripple factor (RF)	RF = $\sqrt{\left[\frac{\pi^2}{9cos^2\alpha}\left(\frac{1}{2}+\frac{3\sqrt{3}}{4\pi}cos2\alpha\right)-1\right]}$	RF = $\sqrt{\left[\frac{\pi^2}{8cos^2\alpha}-1\right]}$

1 mark for each point = 4 marks

	Less voltage ripple factor for same firing angle.	More voltage ripple factor for same firing angle.
RMS Values	With continuous conduction and without free-wheeling diode, the output rms voltage depends on the firing delay angle α. $V_{rms} = \sqrt{3}V_m\left[\frac{1}{2}+\frac{3\sqrt{3}}{4\pi}cos2\alpha\right]^{\frac{1}{2}}$	With continuous conduction and without free-wheeling diode, the output rms voltage is equal to the input rms voltage. $V_{rms} = \frac{V_m}{\sqrt{2}} = Vs$
Average Values	More average or DC voltage for same firing angle and phase voltage. $V_{dc} = \frac{3\sqrt{3}V_m}{\pi}cos\alpha$	Less average or DC voltage for same firing angle and phase voltage. $V_{dc} = \frac{2V_m}{\pi}cos\alpha$

2 c) State the function of freewheeling diode. Also state the effect of source impedance on converter.

Ans:

Function of Freewheeling Diode (FWD):

a) Freewheeling diodes are used across inductive loads such as coils, dc motor armature etc. to prevent voltage spikes across these loads when the switching device is turned off. It is used to bypass the stored energy in inductive elements when the switching device is turned off.

b) In absence of FWD, the stored energy in inductance will maintain forward current through the power semiconductor device and prevent it from being turned off.

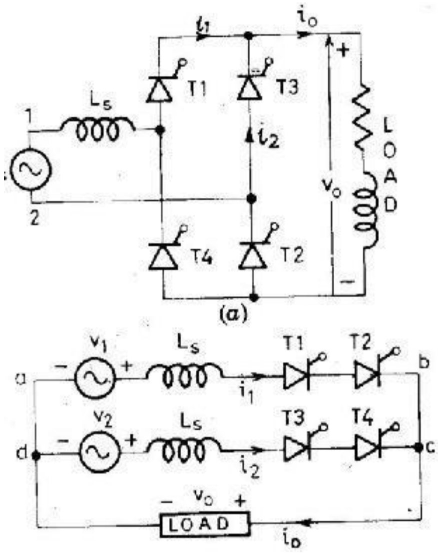
c) When the power semiconductor device in series with load is turned off, FWD is forward biased and the current in load bypassed through FWD and switching device can be turned off.

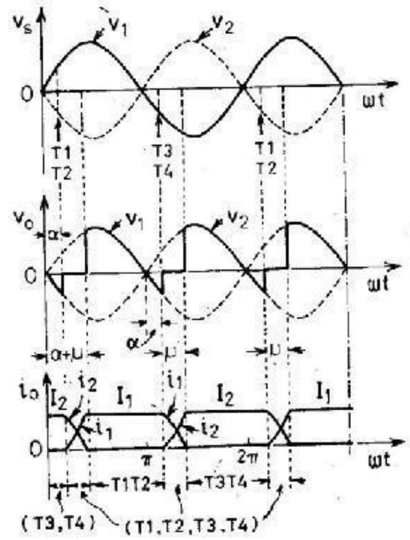
2marks for function of freewheeling diode

Effect of Source Impedance On Converter:

1. The effect of source inductance is delay in commutation of thyristors, as it takes a finite time for the current to decay to zero in the outgoing thyristor, while the current will rise at the same rate in the incoming thyristor.
2. Thus, in practice, the commutation process may occupy a quite significant period of time, during which both the "incoming" and "outgoing" thyristors are simultaneously in conduction.
3. This period, during which both the outgoing and incoming thyristors are conducting, is known as the over-lap period and the angle for which both devices share conduction is known as the overlap angle or commutation angle, as shown in the waveforms below.
4. The output average voltage is dropped due to loss of output voltage during commutation angle.
5. If the source impedance is purely resistive, it causes voltage drop and output voltage is reduced by that amount.

2 marks for effect of Source impedance on converter

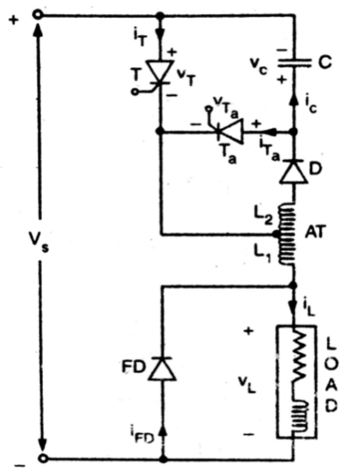




2 d) Draw circuit of Jones chopper and describe its working principle.

Ans:

Jones chopper:



Jones chopper

The circuit diagram of Jones Chopper is shown in the figure. 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:

2 marks for circuit diagram

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

2 marks for operation

<u>Mode 2</u>: 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.

<u>Mode 3</u>: 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.

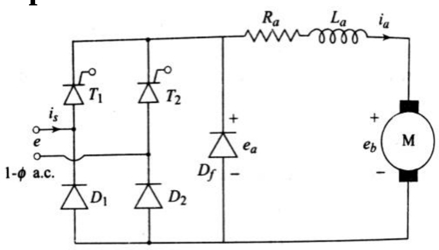
Mode 5: The capacitor voltage with upper plate positive is maintained till the next firing of T. The load current is continued through free-wheeling diode till the next conduction of main SCR T.

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.

2 e) Explain working of speed control of DC series motor with 1ϕ half control converter.

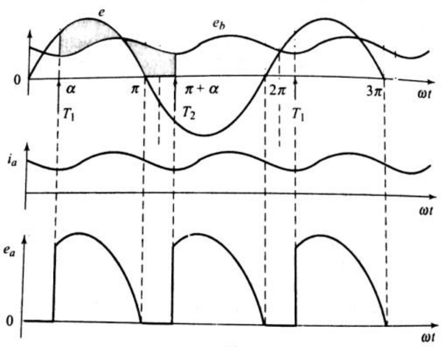
Ans:

Speed control of DC Series Motor using 1ϕ half control 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.

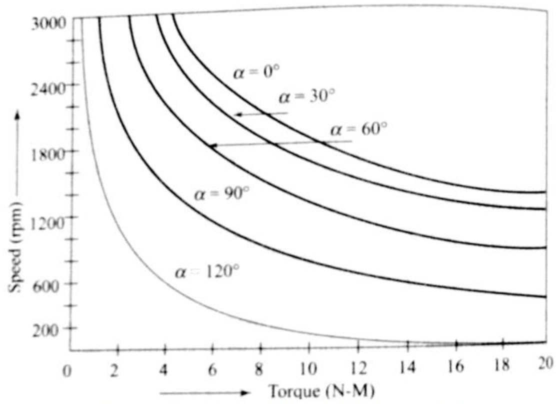


(b) Waveforms for continuous conduction

$$E_b \alpha I_a N$$

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

$$T \alpha I_a^2 \ .$$



(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

1mark for Circuit diagram + 1 mark for waveforms + 1 mark for explanation + 1 mark for characteristics = 4 marks 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) State necessity of chopper and give its classification.

Ans:

Necessity of Chopper:

1. Chopper is a switch which connects and disconnects the load across DC input supply.
2. Due to switching action the voltage across the load is rectangular waveform and by changing on or off time, it is possible to change the average DC voltage across the load.
3. Thus the chopper circuits convert a fixed DC voltage at their input into a variable DC voltage at output.
4. Hence the chopper is known as DC to DC converter.
5. There are many applications which require variable DC supply for their operation and available supply is fixed DC. It includes DC motor control in battery-operated vehicles, electric cars, onboard-regulated DC power supplies for aeroplanes and spaceships, solar & wind energy conversion, power supplies in computers, consumer electronics, electronics instruments etc. In all these applications chopper is necessary.

1 mark for necessity of chopper

Classification of Chopper

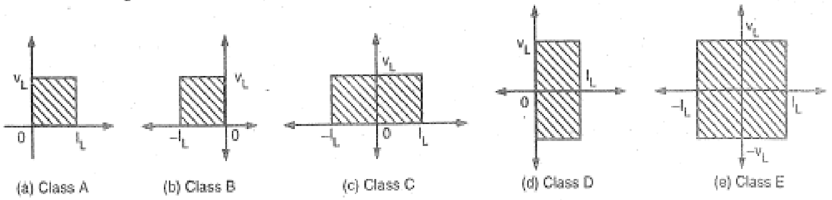
The choppers are classified according to following basis:

(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

3 marks for classification on any three basis

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

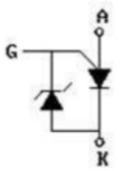
3 Attempt any FOUR of the following: 16

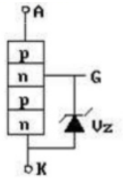
3 a) Draw and Explain characteristics of SUS.

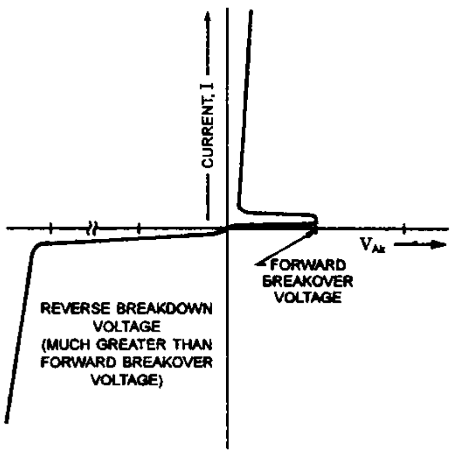
Ans:

V-I characteristics of SUS:

The v-i characteristics of SUS is as shown in the figure below. The SUS has characteristics similar to that of SCR. It has built-in low voltage avalanche diode between gate and cathode. Due to breakdown of the avalanche diode under forward bias, SUS is turned on at a fixed voltage. It offers negative resistane region.







2 Marks for v-i characteristics

V - I Characteristics of SUS

The SUS is usually used in the basic relaxation oscillator circuit. The major difference in function between the SUS and UJT in relaxation oscillator circuitry is that the SUS switches at a fixed voltage, determined by its internal avalanche diode rather than a fraction(η) of another voltage. Also it should be noted that the switching current I_s is much higher in the SUS than in the UJT, and is also very close to I_H. These factors restrict the upper and lower limits of frequency or time delay which are practical with the SUS. For suchronization, lock-out or forced switching, bias or pulse signals may be applied to the gate terminals of the SUS.

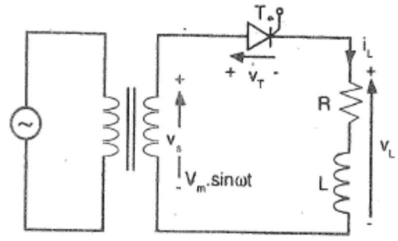
2 marks for explanation

3 b) With suitable circuit diagram and waveforms, explain 1 ϕ fully controlled half wave converter with RL without freewheeling diode.

Ans:

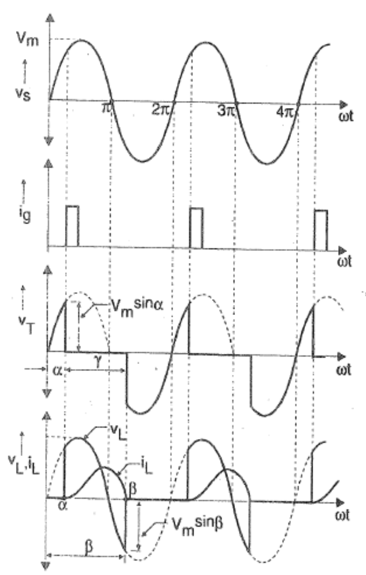
Single phase fully controlled half wave converter:

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



(a) Circuit arrangement

1 mark for circuit diagram



(b) Waveforms

2 marks for explanation

1 mark for waveforms

3c) Enlist triggering methods of SCR. Explain dv/dt triggering in details.

Ans:

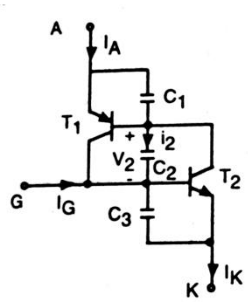
SCR Triggering Methods:

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 any four triggering methods

dv/dt Turn-on or Triggering of Thyristor:

Any p-n junction has capacitance. Under transient conditions, these capacitances influence the characteristics of SCR. Fig. shows two-transistor transient model of SCR wherein the junction capacitances have been shown external to the transistors. If SCR is in forward blocking state and



Two-traisistor transient model of thyristor

2 marks for explanation of dv/dt triggering method

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

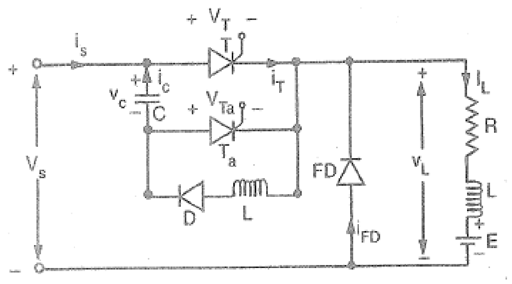
q_2 = charge in the junction J_2

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

3 d) Draw and explain Auxiliary commutation method.

Ans:

Auxiliary Commutation:



Voltage-commutated chopper

2 marks for circuit diagram

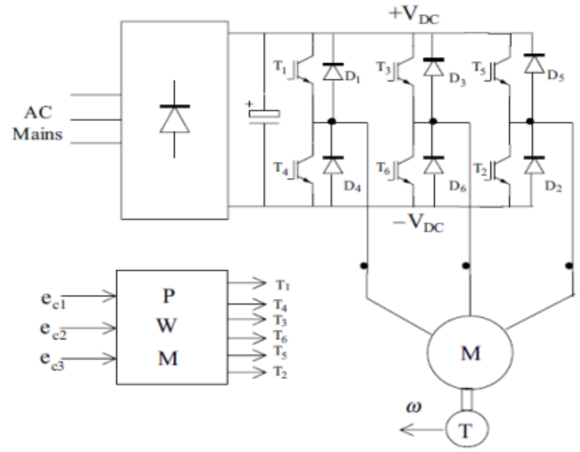
The fig. shows the circuit arrangement of voltage commutated chopper employing auxiliary commutation. At start, the T_a is triggered and turned on to carry the load current. Due to the resonant circuit R-L-C, the current initially rises, attains peak and then falls to zero. This turns off the auxiliary 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 explanation

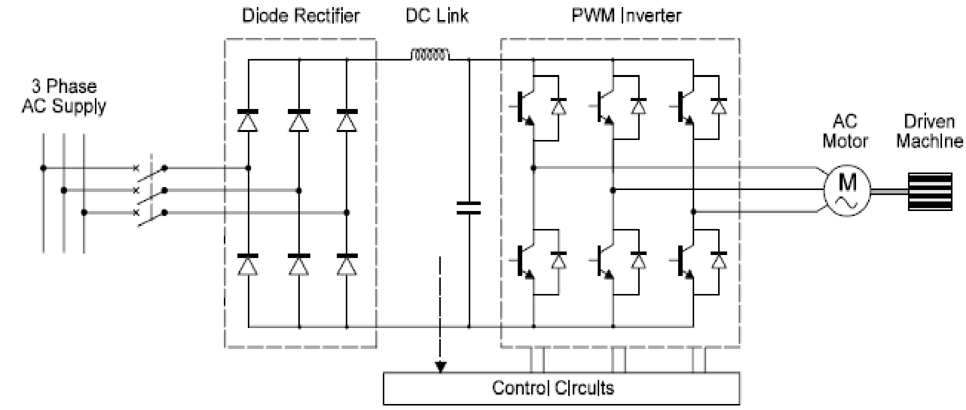
3 e) Explain operation of speed control of 3ϕ induction motor by voltage source inverter.

Ans:

Speed control of 3 ϕ Induction Motor using Voltage Source Inverter:



2 marks for circuit diagram (any one)



The speed of an induction motor can be controlled by varying the supply voltage and frequency. The torque is proportional to the square of air-gap flux. But air-gap flux is directly proportional to supply voltage with frequency kept constant. Thus by controlling the supply voltage at fixed frequency, the torque and ultimately speed can be controlled. When the supply frequency is changed, the synchronous speed N_s (=120f/P) is changed and accordingly the motor speed get changed.

2 mark for description

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 reactance in the equivalent circuit are changed and therefore circuit currents are also changed. If the frequency is increased above its rated value, the reactance are also increased, the currents fall, the flux and maximum torque get decreased but synchronous speed is increased and motor speed is also increased. If the frequency is reduced, the reactances are also reduced and motor current increases. To maintain the motor current within the limit, it is highly essential to change supply voltage with frequency so that air gap flux is maintained.

4 a) Attempt any <u>THREE</u> of the following: 12

4 a) i) Describe different control techniques of chopper.

Ans:

Chopper Control Techniques:

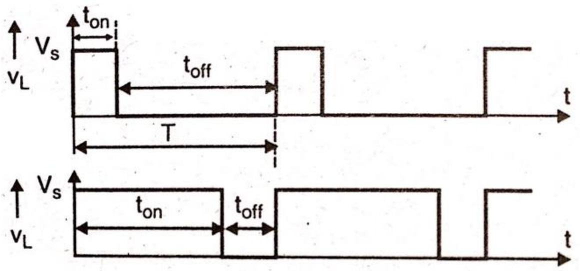
There are two ways of controlling the chopper operation:

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

<u>Time Ratio Control</u>:

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

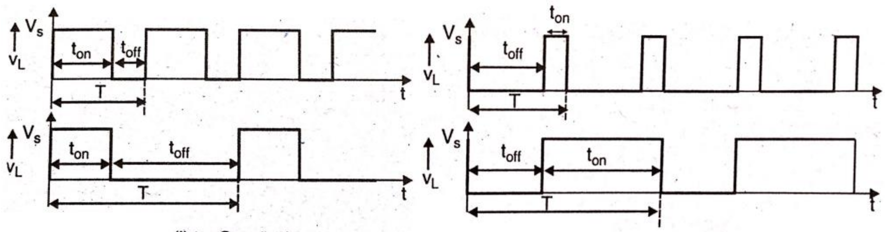
(i) Vary T_{on} keeping frequency constant i.e time period T=1/f constant



(a) Constant frequency TRC

1 mark

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

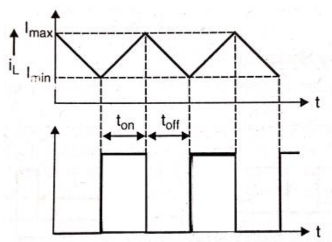


(i) t_{on} Constant (ii) t_{off} Constant

1 mark

<u>Current Limit Control</u>:

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



Current Limit Control

2 marks for current limit control

4 a) ii) What are the factors to be considered while selecting SCR. Enlist any four specification of SCR.

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.

2 marks for any four selecting factors

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**.**

2 marks for any four specifications (Description is optional)

OR

1. Voltage Rating:

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

2. Current Rating:

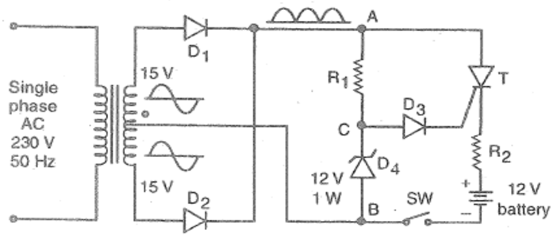
i) Average on-state current I_{TAV}
ii) RMS current I_{Trms}
iii) Surge current rating I_{TSM}

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

4 a) iii) Draw circuit diagram of battery charger control and describe its operation.

Ans:

Battery charger control using SCR:



Automatic battery charger using SCR

2 marks for circuit diagram

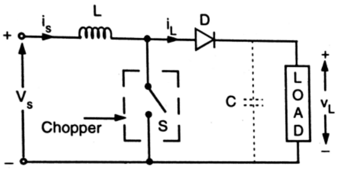
The figure shows the automatic battery charging circuit using SCR. A 12V discharged battery is connected in the circuit and switch SW is closed. The single-phase 230V supply is stepped down to (15-0-15)V by a centre-tapped transformer. The diodes D_1 and D_2 forms full wave rectifier and pulsating DC 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 operation explanation

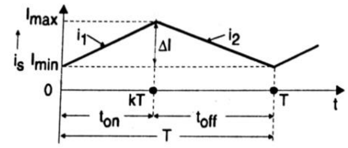
4 a) iv) Describe the working step-up chopper with circuit diagram.

Ans:

Step-up chopper:



(a) Basic circuit arrangement



(b) Current waveform

2 marks for circuit diagram

Explanation:

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: 2 marks for Description

$v_l = V_s = L\frac{di_s}{dt}$ 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:

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

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

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

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

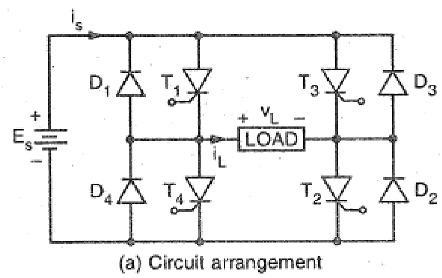
From this equation, it is clear that for k<1, the load voltage v_L is greater than supply voltage V_s, and the circuit acts as a step-up chopper. If a large capacitor C connected across the load, the output voltage will be continuously available. During t_{on} capacitor will charge and during t_{off} it will discharge and provide output voltage.

4 b) Attempt any ONE of the following. **6**

4 b) i) Describe the working of single phase full bridge inverter with suitable diagram.

Ans:

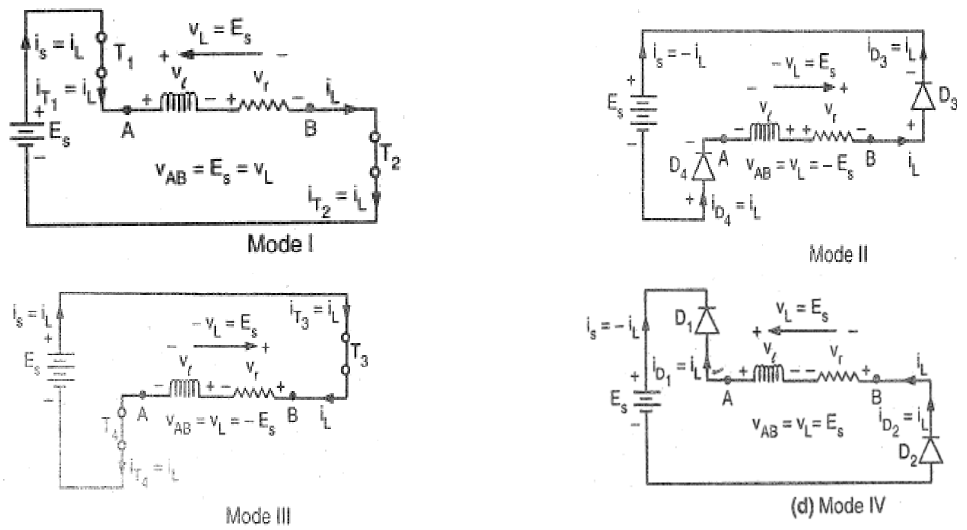
Single phase SCR full bridge inverter:



(a) Circuit arrangement

2 marks for circuit diagram

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 equivalent circuit diagrams of modes

Description:

Mode I (t_1 to t_2): By gate pulses, the SCRs T_1 T_2 is 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.

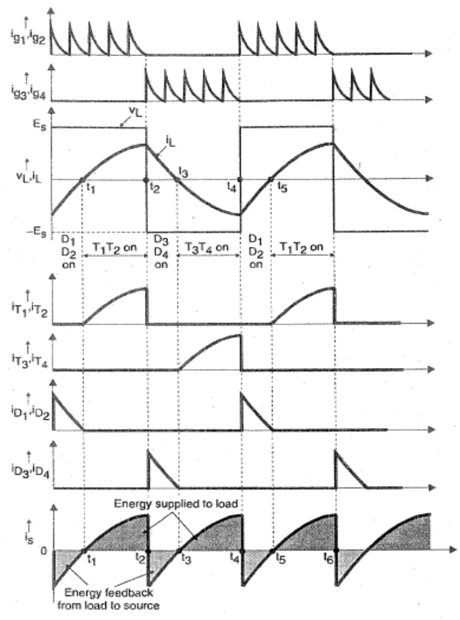
Mode II (t_2 to t_3): At t_2 the gate pulses of T1 T_2 are prohibited and they are turned off by commutating components. Due to load inductance, the load current cannot be reduced to zero suddenly. The load current is maintained in the same direction by load inductance voltage. The load current flows 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.

2 marks for description

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 similar 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 (t_4 to t_5) or (0 to t_1): 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, and diode currents are shown in the figure.



Single-phase, full-bridge inverter waveforms

1 mark for waveforms

4 b) ii) With the help of waveform, explain operation of 1 ϕ cycloconverters.

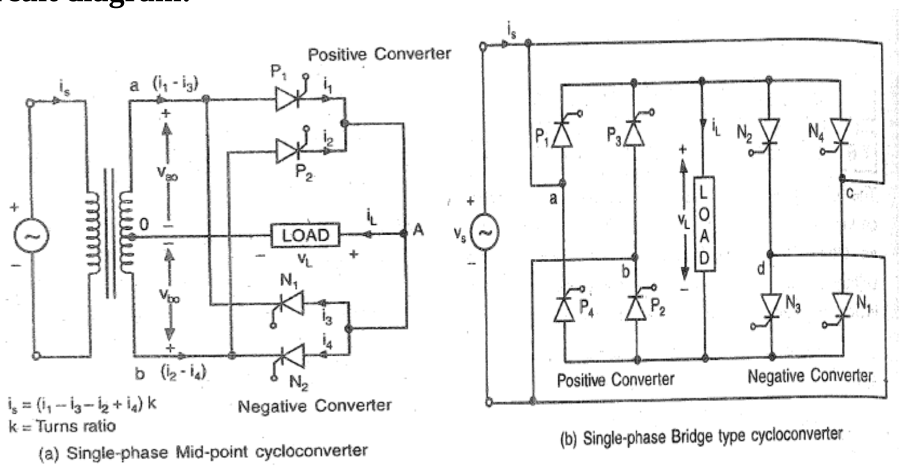
Ans:

<u>Single phase cycloconverter:</u>

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

2 marks for circuit diagram (any one)

Circuit diagram:

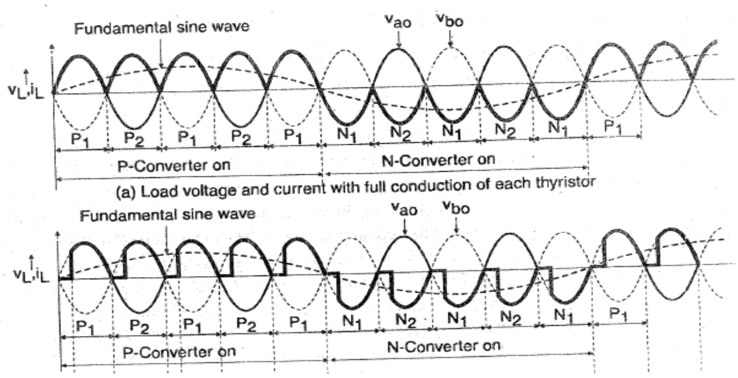


(a) Single-phase Mid-point cycloconverter

(b) Single-phase Bridge type cycloconverter

2 marks for circuit operation of any one type

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



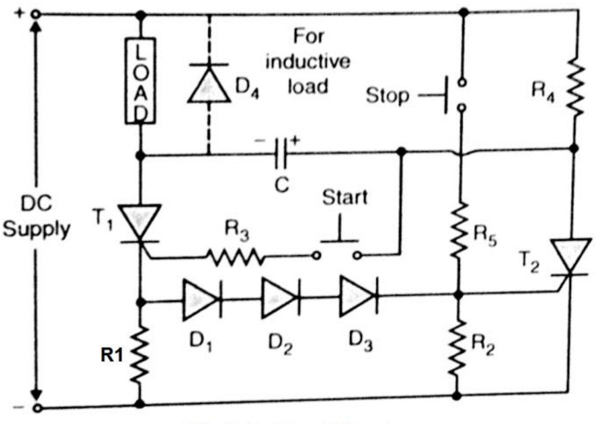
2 marks for waveforms

5 Attempt any <u>FOUR</u> of the following 16

5 a) Describe the operation 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.

2 marks for circuit diagram

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 operation

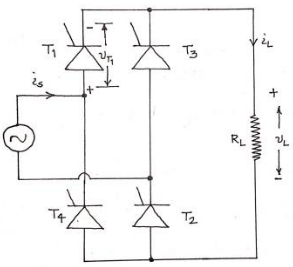
The load current can be automatically interrupted under overload condition. With T_1 on and carrying load current, if overload occurs, the voltage drop across R_1 exceeds the forward voltage drop of string of diodes D_1, D_2, D_3 and gate-cathode junction of T_2. Therefore, gate current is provided to 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.

5b) Describe the working of single phase fully controlled bridge converter with resistive load.

Ans:

Single phase full wave controlled converter with R load:

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.



1 mark for circuit diagram

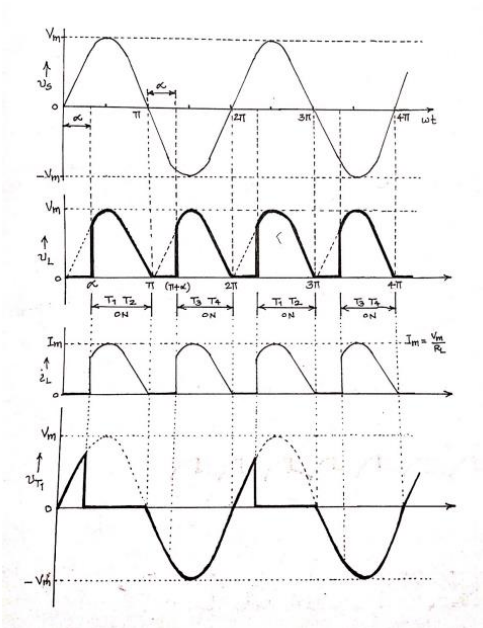
2 marks for circuit operation

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

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.



1 mark for waveforms

5c) With suitable circuit diagram and waveforms, explain the working of parallel inverter.

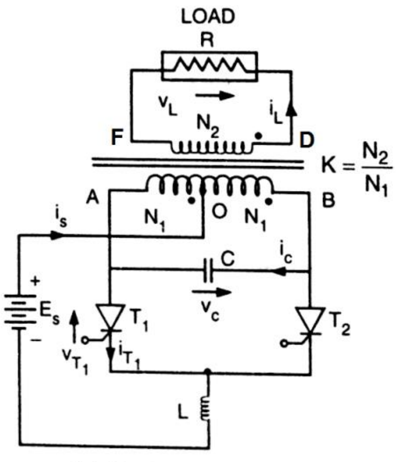
Ans:

Parallel Inverter:

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

The commutating capacitor C is connected across full primary winding, hence appears effectively in parallel with load. This is the reason why the inverter is termed as parallel inverter.

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



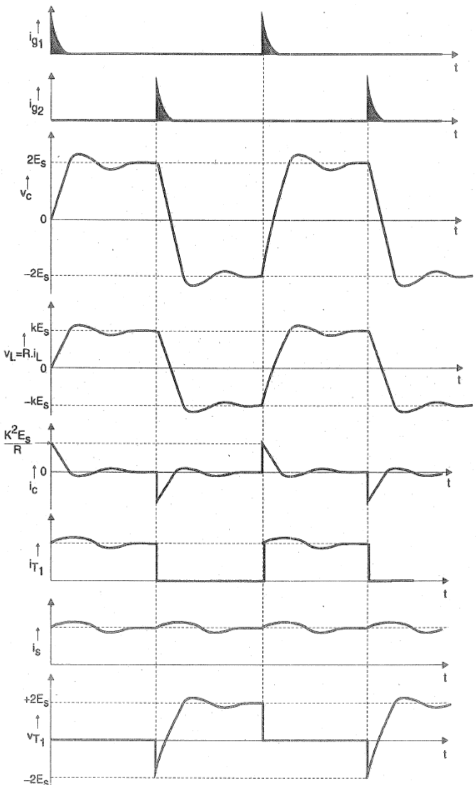
(a) Circuit arrangement

1 mark for circuit diagram

2 marks for circuit operation

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

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



(d) Waveforms

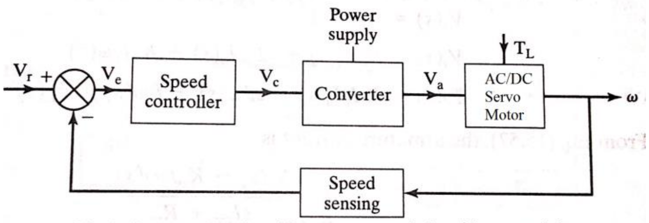
1 mark for waveforms

5 d) Describe the operation of closed loop speed control method for AC servomotor with the help of diagram.

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.

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 mark for block diagram

2 marks for operation

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.

5 e) Enlist methods used for output voltage control. Describe external control of dc voltage.

Ans:

1) External Control:
   a) Externally controlling the ac output voltage
      (i) AC voltage control: Using AC voltage controller between inverter & load
      (ii) Series inverter control: Connecting two or more inverters in series.
   b) Externally controlling the dc input voltage
      (i) Obtaining controlled dc supply for inverter from fully controlled rectifier & filter arrangement.
      (ii) Obtaining controlled dc supply for inverter from uncontrolled rectifier, chopper & filter arrangement.
      (iii) Obtaining controlled dc supply for inverter from AC voltage controller, uncontrolled rectifier, filter arrangement.
      (iv) Obtaining controlled dc supply for inverter from chopper & filter arrangement.
2) Internal Control: By controlling the operation of inverter itself – PWM technique Circuit complexity increases.

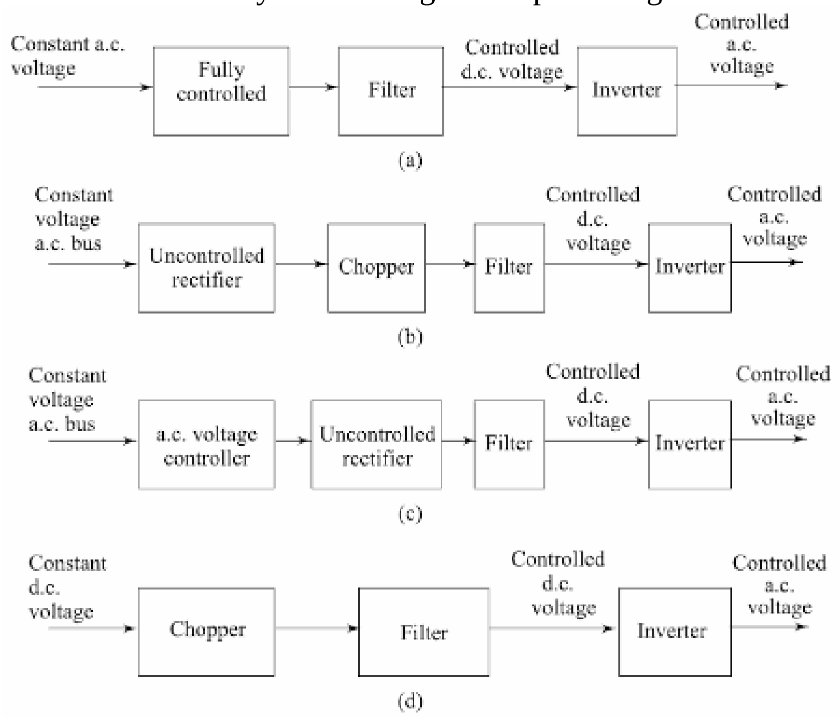
2 marks for listing methods

External control of dc voltage:

The d.c. voltage input to the inverter is controlled when the available voltage source is a.c. It can be controlled by fully controlled rectifier (fig a) or an uncontrolled rectifier & chopper (fig b) or through an a.c. voltage controller & uncontrolled rectifier (fig c). In case if available voltage source is d.c. then d.c. input voltage to inverter is controlled by chopper (fig d). These methods improve the output waveform and its harmonic contents

1 mark for description

remain unaffected. The efficiency of inverter improves if d.c. input to the inverter is varied to compensate for source voltage fluctuations. These methods are limited to very limited range of output voltage.

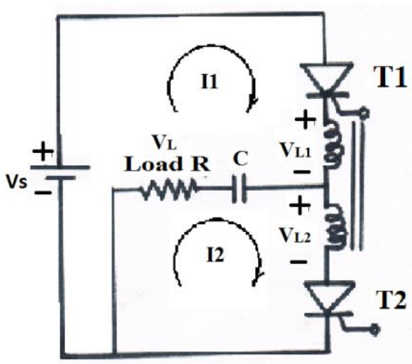


Any one diagram 1 mark

5 f) Describe the working of modified series inverter operation with the help of diagram.

Ans:

Modified Series Inverter:



2 mark for 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

2 marks for circuit operation

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.

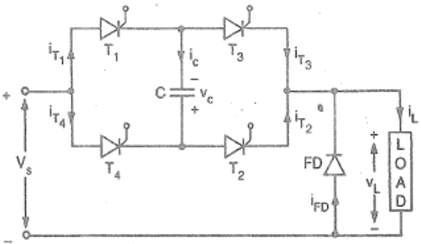
6 Attempt any <u>FOUR</u> of the following **16**

6 a) Describe the working of load commutation of chopper.

Ans:

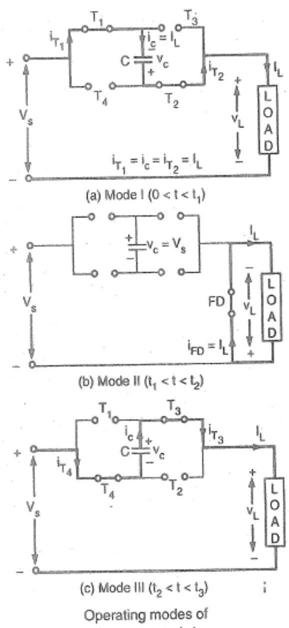
Load commutation of chopper:

The circuit diagram, operating modes and waveforms of Chopper employing load commutation 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.



Load commutated chopper

2 marks for circuit diagram (Modes circuit diagram optional)



Operating modes of load commutated chopper

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.

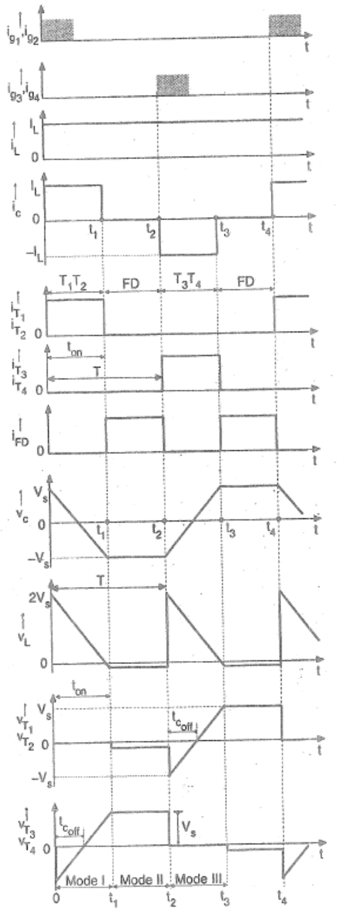
2 marks for circuit operation

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.

(Waveforms are optional)

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



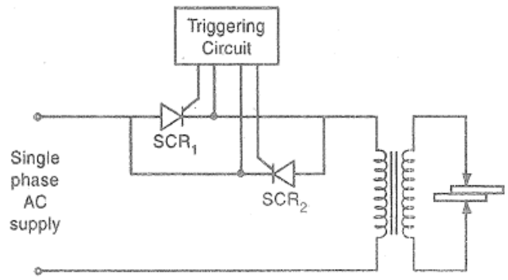
Waveforms of load commutated chopper

6b) Draw the diagram of electric welding control and describe its operation.

Ans:

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.



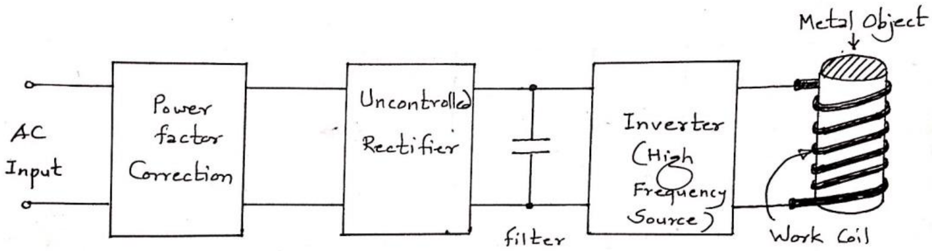
Electric Welding Control Circuit using SCR

2 marks for circuit diagram + 2 marks for explanation

6c) Describe the operation of induction heating with diagram.

Ans:

Principle of Induction Heating:



2 marks for 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 currents 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".

2 marks for operation

6 d) Describe the operation of static VAR compensation system with the help of diagram.

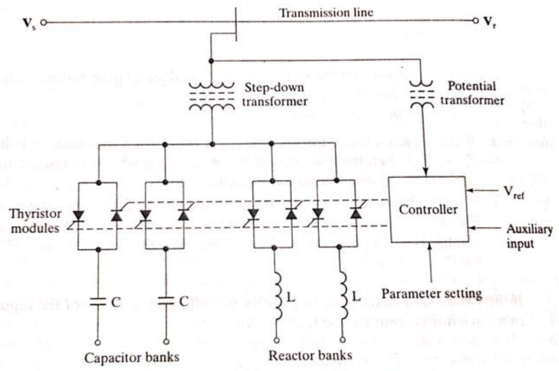
Ans:

Static VAR compensator:

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

2 marks for operation

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.



General arrangement of static VAR compensator

2 marks for diagram

In fact, SVC comprises combinations like (TCR+TSC), (TCR+FC) as per the need.

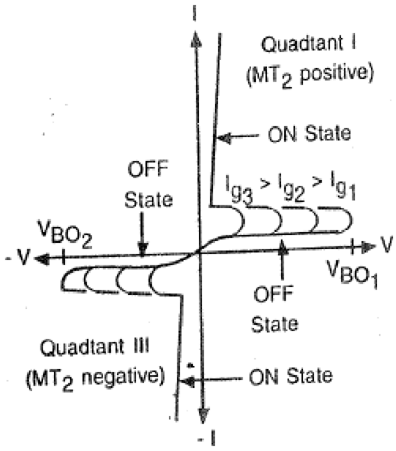
In TCR, phase control is used to vary the effective inductance of the inductor.

In TSC, the integral-cycle control is employed to vary the effective capacitance of the capacitor.

6 e) Draw labelled characteristics of Triac. State its two applications.

Ans:

V-I Characteristic of TRIAC:



V-I Characteristics

2 marks for V-I characteristic

Applications of TRIAC:

1) Lamp dimmer
2) Fan regulator
3) Heating control
4) Zero voltage switched relay
5) Small AC motor control

2 marks for any two applications