**WINTER – 2016 Examinations**

**Model Answer**

**Subject Code: 17638: Power Electronics**

**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 toassess 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 maygive 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

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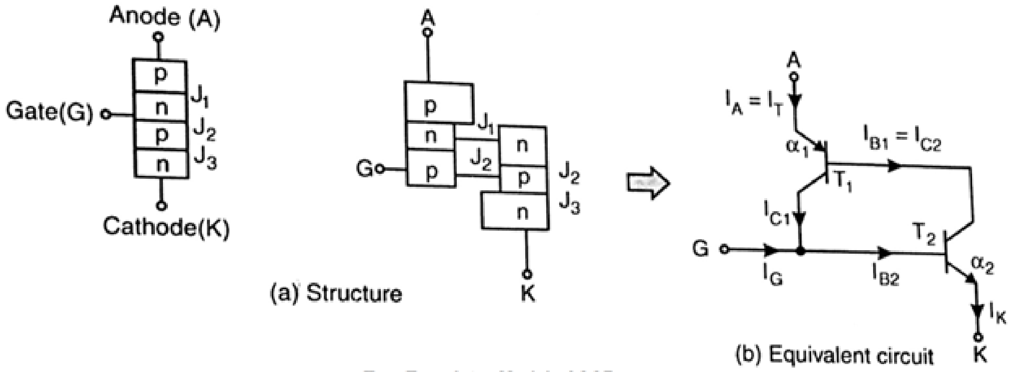
**Model Answer**
**Subject Code: 17638: Power Electronics**

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

1 a) i) Draw construction of SCR using two-transistor model. 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, $\alpha$ = common-base current gain

$I_{CBO}$= leakage current from collector to base with emitter open

For transistors $T_1$ and $T_2$, we can write,

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

From KCL applied to $T_1$, we can write

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

From KCL applied to entire equivalent circuit,

$I_K = I_A + I_G$ and substituting in above equation,

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

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

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

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 $\alpha_1$. 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 $\alpha_2$. 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

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1 a) ii) Draw waveform of the following power electronic circuit; also identify the name of the circuit. Refer Fig. No. 1

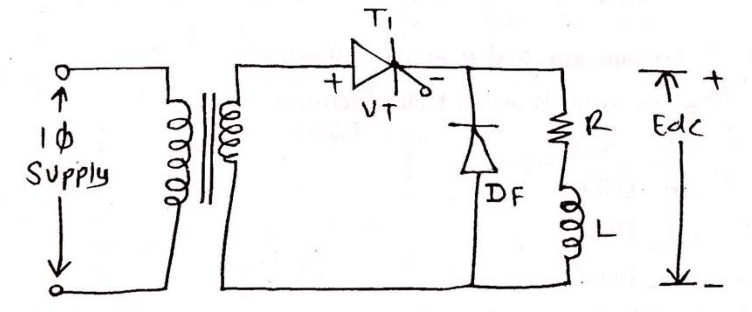
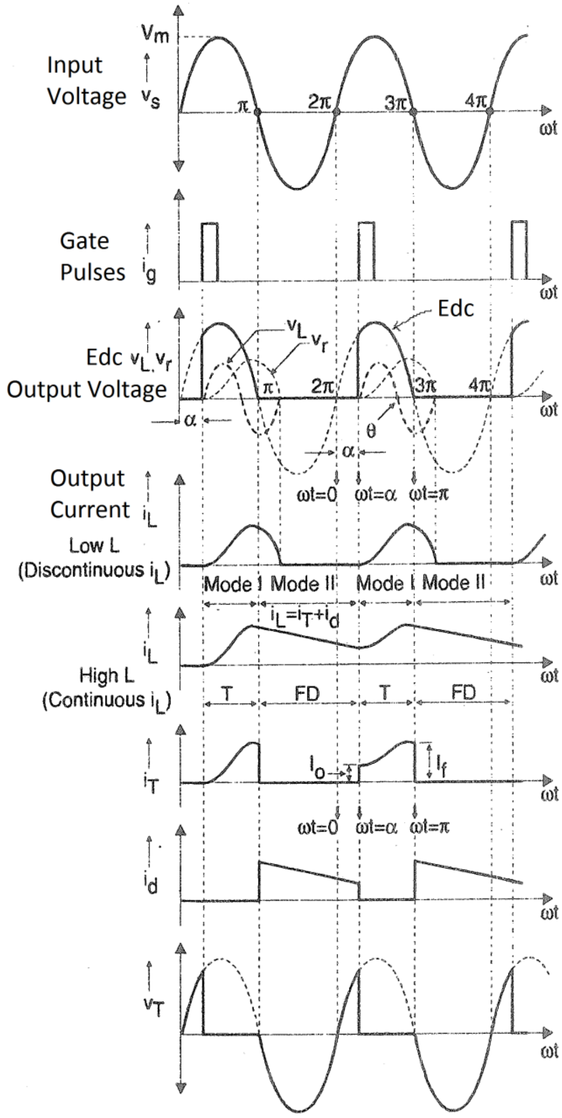



**Fig. No. 1**

**Ans:**

Name of the circuit:

**Single-phase half-wave Controlled rectifier with RL load and freewheeling diode.**




Waveforms

1 mark for identification of circuit + 1 mark for waveform of $E_{bc}$ + 1 mark for load current $I_L$ + ½ mark for thyristor current $I_T$ + ½ mark for free-wheeling diode current $I_d$ = 4 marks

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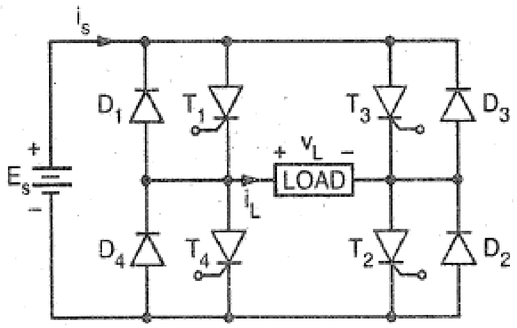
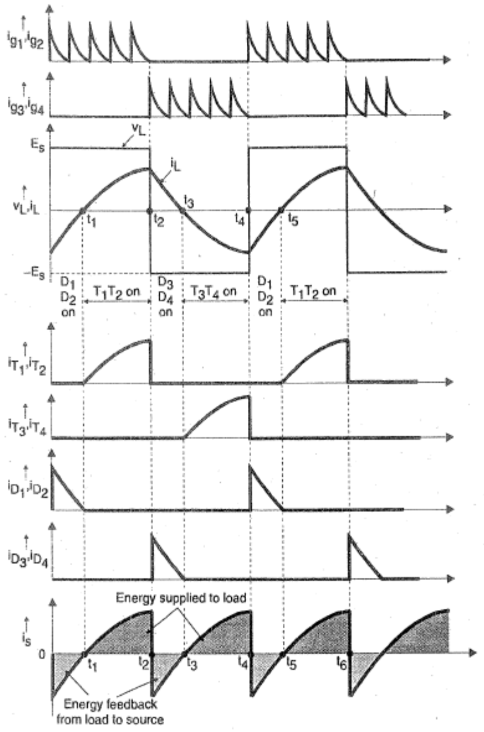
1 a) iii) Draw circuit diagram of single-phase full bridge inverter. Draw waveform of load voltage and load current for RL load.

**Ans:**

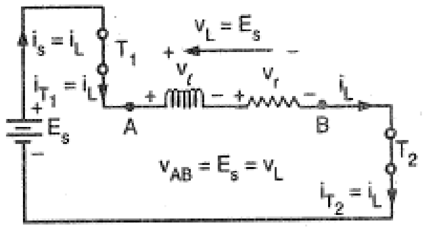
**<u>Single phase full bridge inverter:</u>**



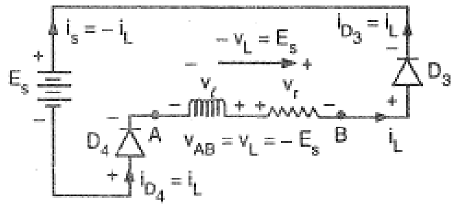

(a) Circuit arrangement



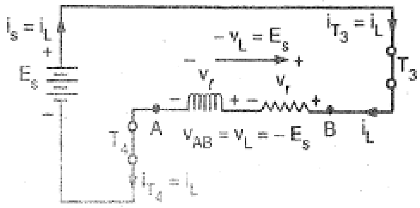

Single-phase, full-bridge inverter waveforms



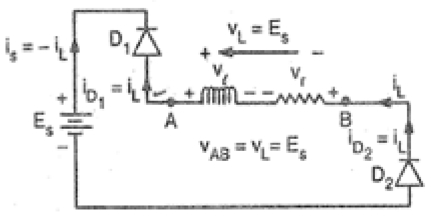

Mode I




Mode II




Mode III




Mode IV

2 marks for Circuit diagram + 1 mark for waveform of load voltage + 1 mark for waveform of load current = 4 marks

(Circuit diagrams of modes is optional)

1 a) iv) State the classification of chopper commutation methods and describe any one of them.

**Ans:**

**Classification of chopper commutation methods:**

(i) Voltage commutation
(ii) Current commutation
(iii) Load commutation
(iv) Impulse commutation

1 mark for classification

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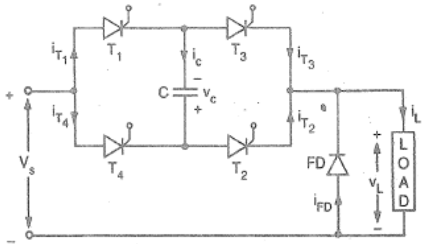
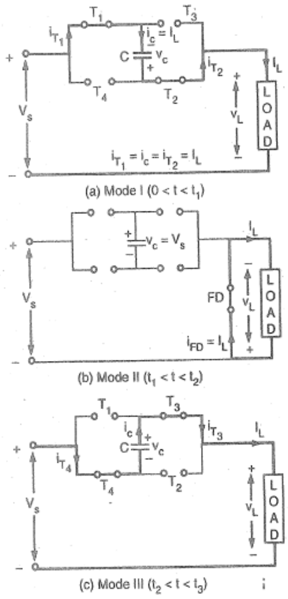
**Load-commutated chopper:**

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



Operating modes of load commutated chopper

1 mark for circuit diagram of chopper employing any one of specified commutation method + 2 marks for explanation of working

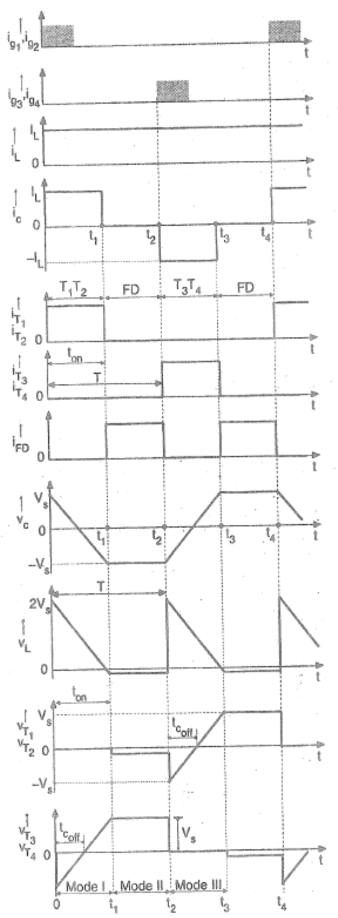
(Modes and waveforms are optional)

**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

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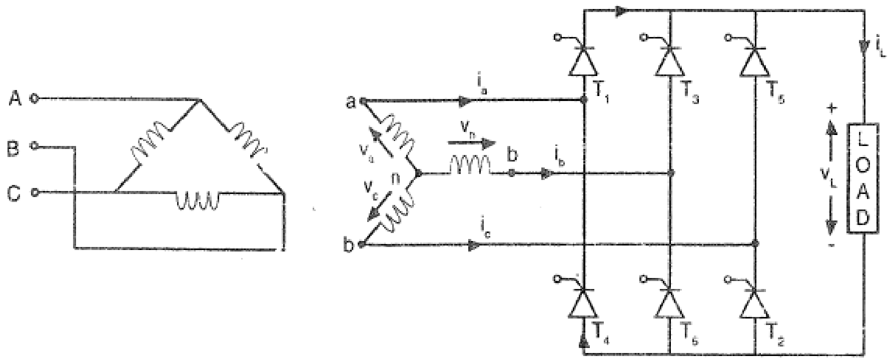
**1 b) Attempt any ONE of the following:** **6**

1 b) i) Describe operation of 3ϕ full controlled bridge converter with RL load using neat circuit diagram. Sketch different i/p, o/p waveform.

Ans:

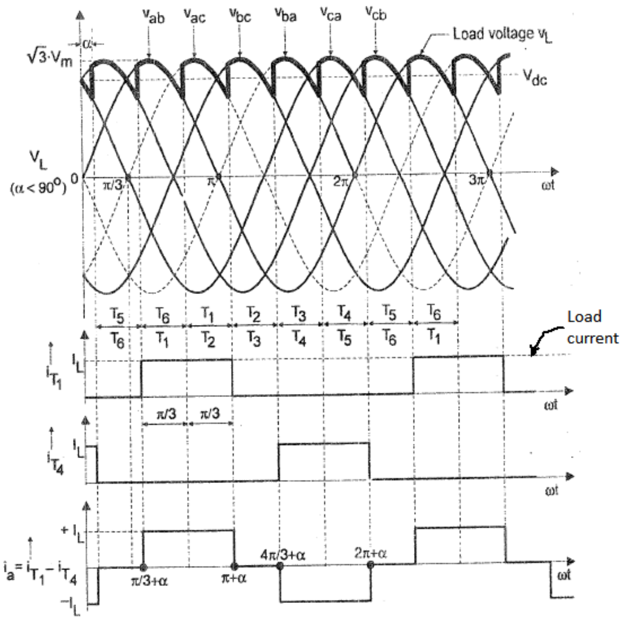
**Three-phase full controlled bridge converter:**



(a) Circuit arrangement

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

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, thyristor currents, line current and load current.



(b) Waveforms

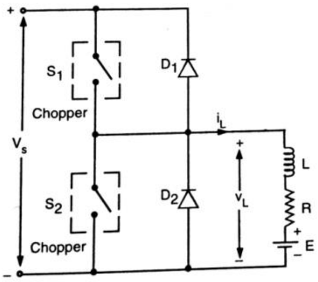
At ωt = 0, the line voltage $v_{cb}$ is higher than any other line voltage, hence thyristor $T_5$ connected to phase c and thyristor $T_6$ connected to phase b are fired at delay angle α. After firing $T_5$ and $T_6$, the load voltage becomes equal to $v_{cb}$. The upper load terminal gets connected 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 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 from$T_5$ 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 inductive (R-L), for highly inductive nature, the load current becomes constant. The thyristors carry current in the form of rectangular pulses and input line current has quasi-square waveform.

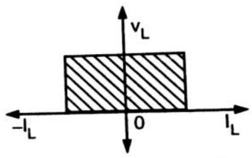
1 b) ii) With the help of neat circuit diagram and necessary waveform, explain class C chopper.

**Ans:**

**Class C Chopper:**




(a) Circuit arrangement



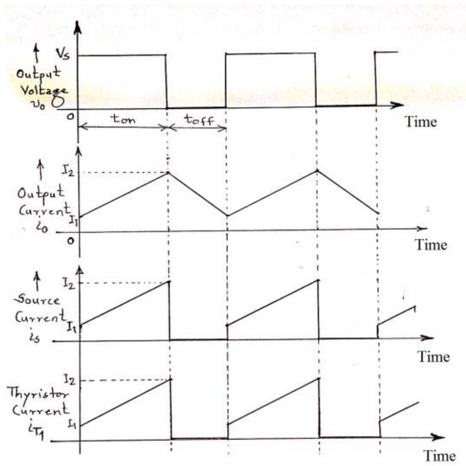

(b) Two-quadrant operation

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

2 mark for circuit diagram + 1mark for explanation of each of class A and class B + 1 mark for waveforms of each of class A and class B = 6 marks

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

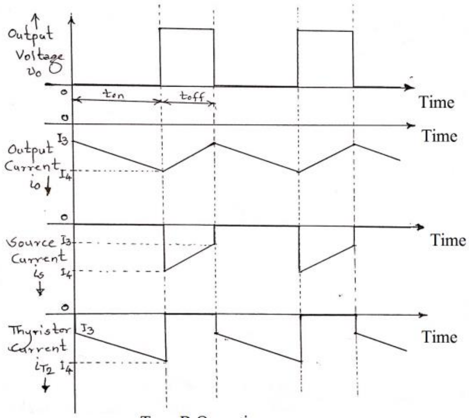
In this operation the switch $S_1$ is turned on and turned off alternately. When the switch $S_1$ is turned on, the DC source voltage gets applied across the load and supplies load current. When the switch $S_1$ is turned off, the load inductance forces current through free-wheeling diode $D_2$ which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




Type A Operation

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

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




The class C chopper can operate either as a rectifier or as an inverter. This chopper is used for controlling the motoring and regenerative braking of DC motors.
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.
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** **Attempt any <u>FOUR</u> of the following:** **16**

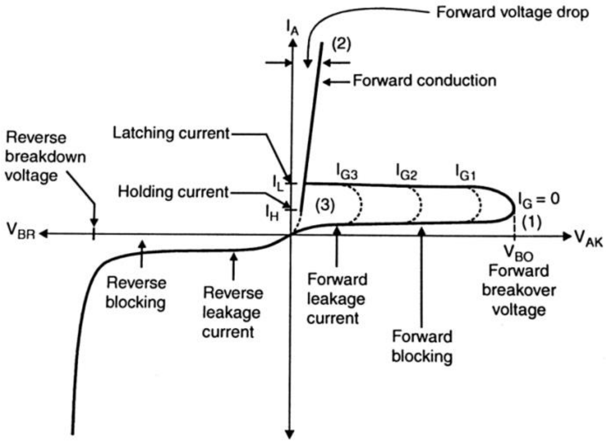
2 a) State the meaning of holding current and latching current. Label them on the VI characteristics of SCR.

**Ans:**

**(i) Latching Current:**
Latching current is defined as the minimum anode current required to maintain the SCR in the on-state immediately after the SCR has been turned on and the gate signal has been removed. 1 marks

**(ii) Holding Current:**
Holding current is defined as the minimum anode current required to maintain the already conducting SCR in the on-state. 1 marks

**V-I characteristics of SCR:**



V-I Characteristics of SCR

2 mark

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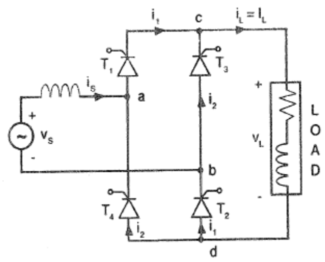
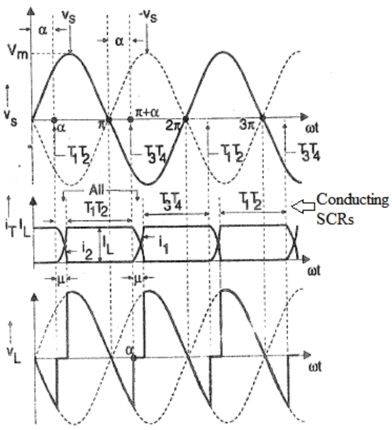
2 b) State the effect of source impedance on the performance of 1ϕ fully controlled converter.

**Ans:**

**Effect of source inductance on the performance of single phase fully controlled converter:**



(a) Circuit diagram



(b) Waveforms
Effect of Source Inductance on the performance of 1-ph full converter.

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

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

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

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

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

2 c) State differences between MOSFET and thyristor inverter.

Ans:

| **MOSFET based Inverter** | **Thyristor based inverter** |
|---|---|
| These are based on Power MOSFETs as switching devices | These are based on SCR as switching devices |
| Power MOSFETs are voltage controlled devices and trigger circuit operates at low power. | SCRs are current controlled devices and triggering circuit consumes more power. |
| Fast turn ON and OFF | Slow turn ON and OFF as compared to MOSFET |
| Inverters operate at higher switching | Inverters operate at lower switching |

1 mark for each of any four points

| | |
|---|---|
| frequency. | frequency. |
| Switching losses are less | Switching losses are more |
| Operate at small / medium power rating. | Can operate at higher power rating. |
| Quality of the inverter output waveform can be improved by increasing switching frequency. | Quality of the output waveform is less |

2 d) State the application of chopper and list the various control techniques of chopper.

**Ans:**

**Applications of Chopper:**

1. Choppers are used in DC voltage regulators.
2. Choppers are used in conjunction with an inductor to generate a DC current source for current source inverter (CSI).
3. Choppers are widely used for traction motor control in electric automobiles, trolley cars, marine hoists, forklift trucks and mine haulers.
4. Choppers are being in use in transport systems all over the world.
5. Since the choppers provide high efficiency, fast dynamic response and regenerative braking facility, the future electric automobiles are likely to use choppers for their speed control and braking.

**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)

1 mark for each of any two applications + 1mark for each of two techniques = 4 marks

Time Ratio Control:

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

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

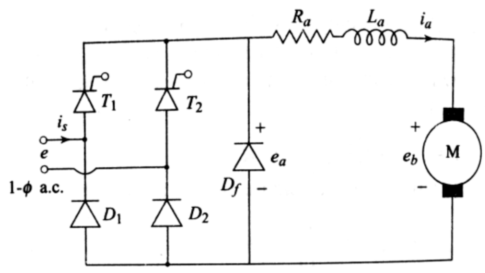
Current Limit Control:

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

2 e) Explain the technique for speed control of DC series motor using thyristor converter.

**Ans:**

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



(a) Power circuit

1 mark for circuit diagram

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.

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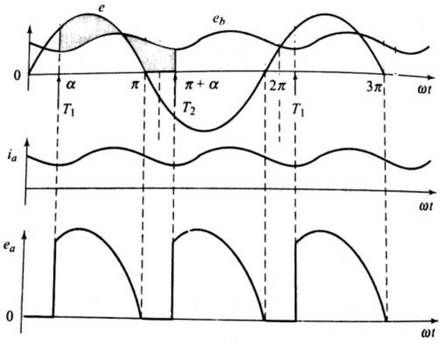


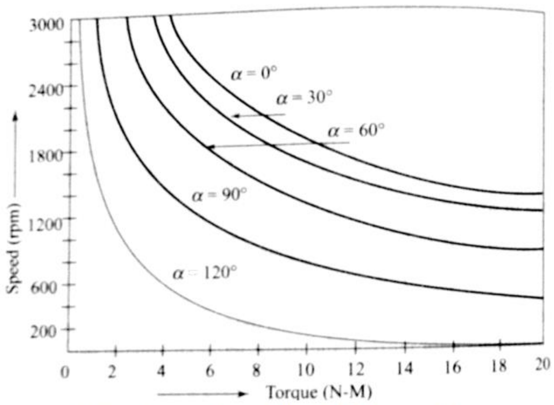
(b) Waveforms for continuous conduction

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. 2 marks for explanation 1 mark for waveform

$$E_b \alpha I_a N$$

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 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 $\alpha$ are shown in fig.(c)

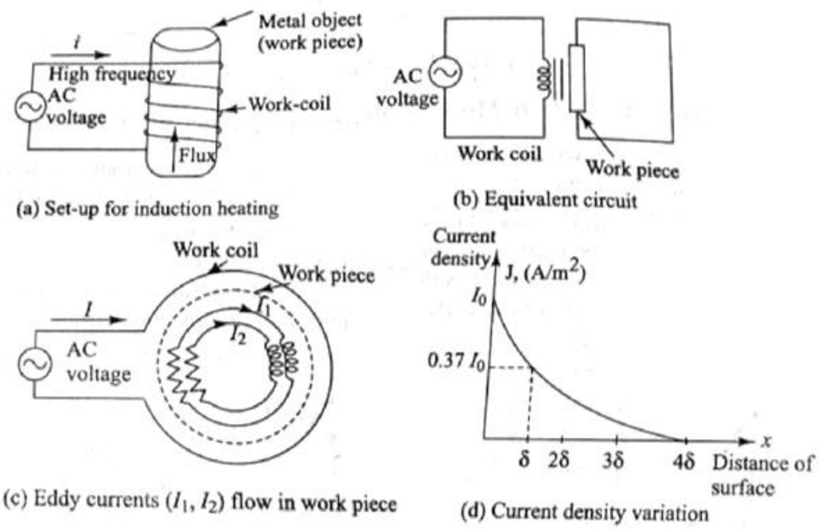
2 f) Describe thyristorised induction heating.

**Ans:**

**Thyristorised induction heating:**

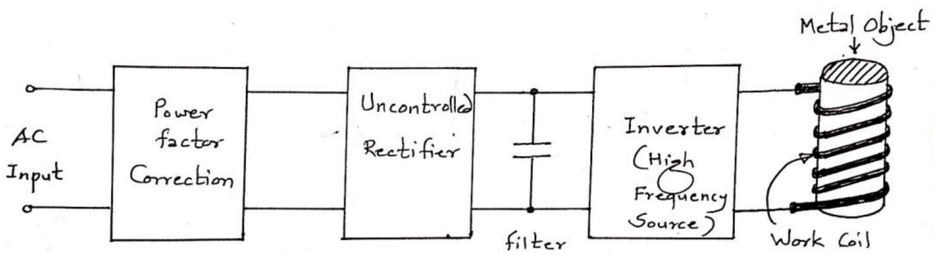
When a conducting object is subjected to a changing magnetic field, according to Faraday's laws of electromagnetic induction, emf is induced in the object. The object, being conductor, offers many short-circuited paths. So the circulating current flow through these paths. The currents are in the form 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". The material to be heated is known as the work piece and the coil around it is known as work coil, as shown in the figure. The coil acts as primary and work piece acts as short circuited secondary. When primary is excited by high frequency ac supply, eddy currents are set up in the work piece and electrical power loss heats up the object. 1 mark for principle of induction heating

For induction heating, high frequency AC supply is obtained using thyristorised converter circuits. The block diagram of one of such arrangements is shown in the figure. The available AC supply is first converted to DC using uncontrolled rectifier 1 mark for thyristorised induction heating explanation and filter arrangement. Then the DC is converted to AC with required high frequency using thyristorised inverter. Since the load is highly inductive, the power factor of load is too low. So to improve it, power factor correction circuit is employed at the input stage.



(a) Set-up for induction heating
(b) Equivalent circuit
(c) Eddy currents ($I_1$, $I_2$) flow in work piece
(d) Current density variation

1 mark for diagrams



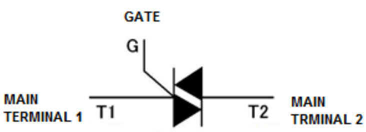

1 mark for block diagram

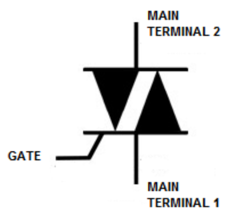
**3** **Attempt any FOUR of the following:** **16**

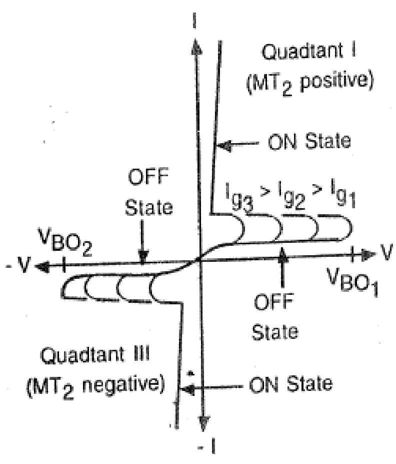
3 a) Draw symbols and V-I characteristics for:
(i) TRIAC, (ii) GTO, (iii) DIAC, (iv) IGBT

**Ans:**

**1) TRIAC**:



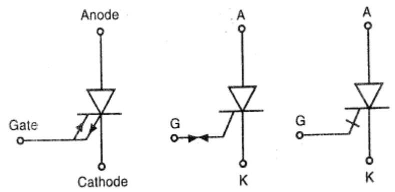



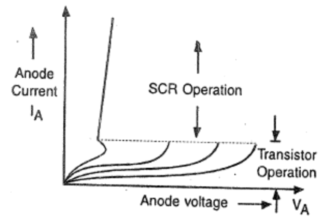
V-I Characteristics

½ mark for symbol + ½ mark for characteristic = 1 mark for each bit

**2) GTO:**

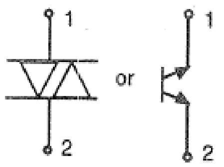



GTO Symbols

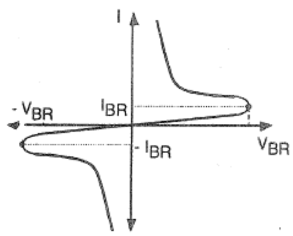



V-I characteristics of GTO

**3) DIAC:**

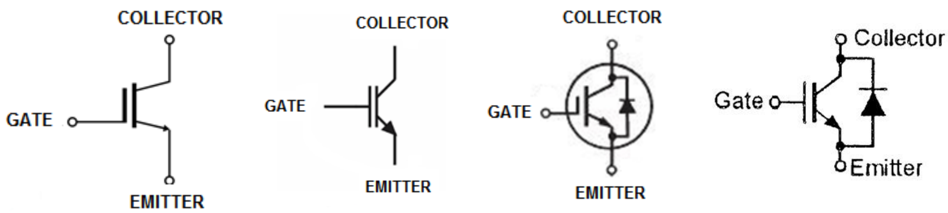


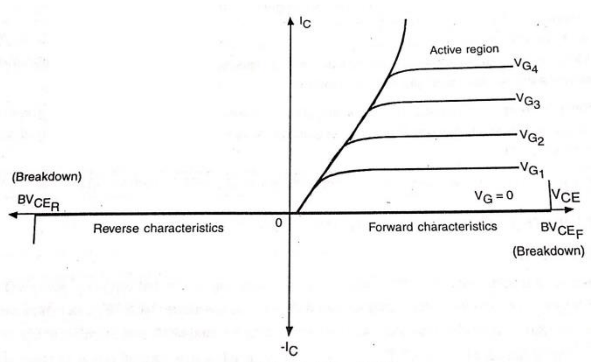

Symbol




V-I Characteristics

**4) IGBT**:




V-I characteristics of IGBT

3 b) Explain the operation of cyclo-converter with a neat diagram.

**Ans:**

**Single phase cycloconverter:**

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

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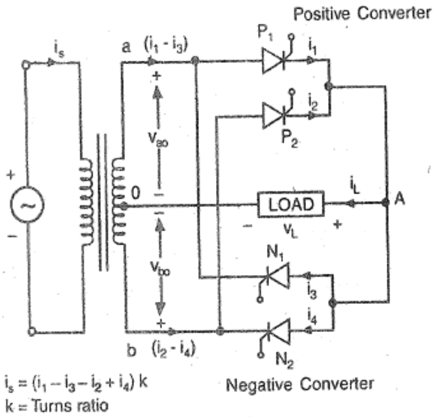
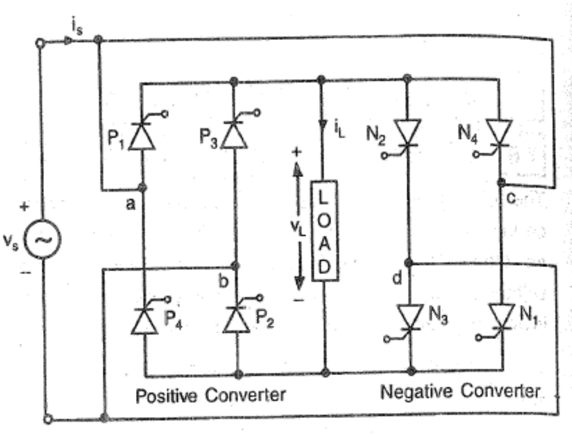
across load for longer duration (half-cycle) i.e output frequency is reduced.



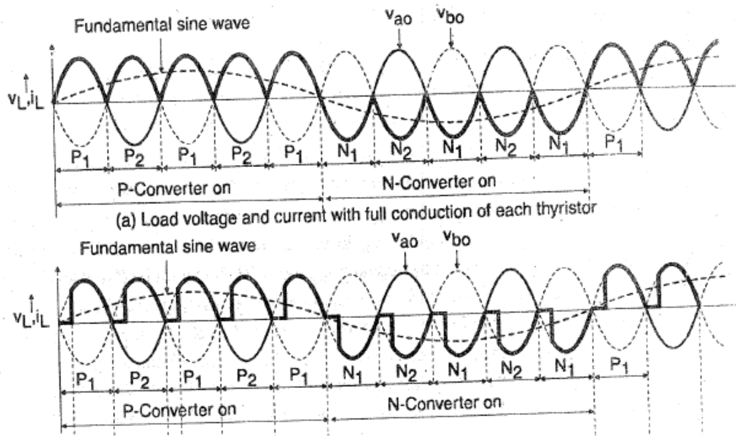

(a) Single-phase Mid-point cycloconverter




(b) Single-phase Bridge type cycloconverter

1 mark for any one circuit diagram + 2 marks for explanation + 1 mark for waveform = 4 marks

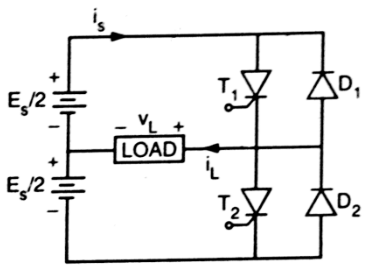
The basic operation is reflected in waveforms. In waveform diagram it is seen that the positive half cycle of output voltage is fabricated from five half cycles of input AC, so the output frequency is 1/5th of input supply frequency.




3 c) Draw and explain the circuit diagram of single-phase half bridge inverter.

**Ans:**

**Single-phase half-bridge inverter:**




(a) Circuit arrangement

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

1 mark for circuit diagram

(a) Purely Resistive Load:

Referring to waveforms in fig.(b), at t=0, the SCR $T_1$ is fired by gate pulse train. Once $T_1$ conducts, the upper source voltage ($E_s/2$) appears across the load. Thus constant voltage $+E_s/2$ appears across load when $T_1$ is on and $T_2$ is off. The load current is positive. At instant $t = t_1$, the gate pulses of $T_1$ are removed and gate pulses are provided to $T_2$. Thus at $t = t_1$, $T_1$ is turned off and upper source voltage appears across $T_1$ whereas, $T_2$ is turned on and lower source voltage appears across load. Therefore load voltage is reversed and reversed current flows. During the period when $T_2$ is on, constant voltage $–E_s/2$ appears across load. Thus alternate switching of $T_1$ and $T_2$ causes alternating voltage across load and the load current follows the load voltage variations. The load voltage and load current both have rectangular waveforms as shown in fig.(b).

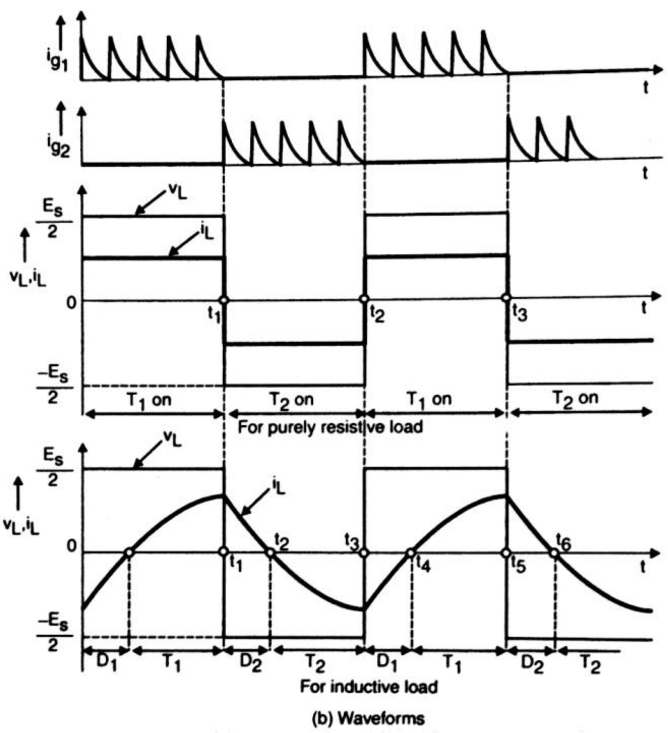
2 marks for explanation (Inductive load optional)

(b) Inductive Load:

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

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

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



(b) Waveforms

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

1 mark for waveforms (inductive load waveforms optional)

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

3 d) Describe how control of firing angle can control speed of DC shunt motor controlled by thyristor converter.

**Ans:**

**Speed Control of DC shunt motor by thyristor converter:**

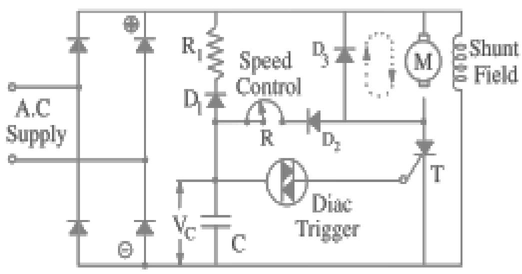
(i) The voltage equation of DC shunt motor is,
$V = R_a I_a + E_b$
$E_b = V - R_a I_a$

(ii) Back emf is proportional to magnetic flux and speed, $E_b \propto \emptyset\omega$

(iii) For DC shunt motor, flux can be assumed constant, so $E_b \propto \omega$ or $\omega \propto E_b$
The speed equation becomes, $\omega \propto (V - R_a I_a)$

(iv) Thus speed can be controlled by controlling the voltage supplied to armature

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



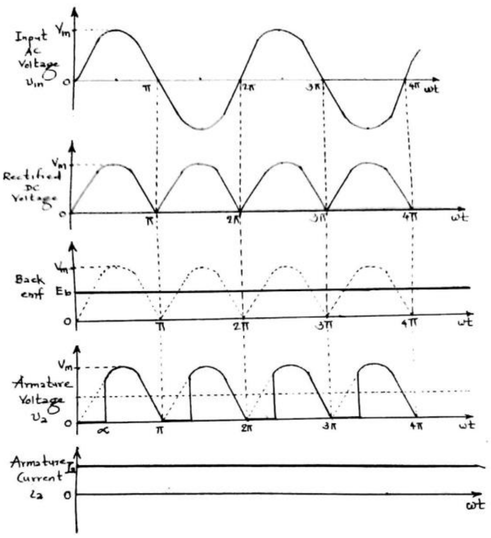



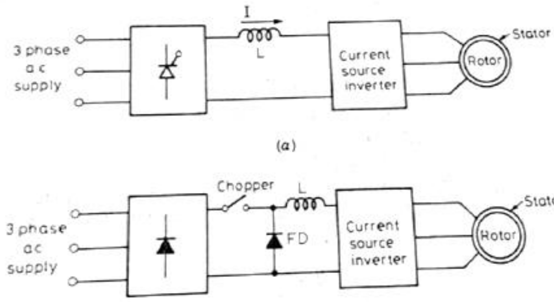

Figure shows a circuit which provides a wide range of speed control for a fractional kW shunt d.c. motor. The circuit uses a bridge circuit for full-wave rectification of the a.c. supply. The shunt field winding is permanently connected across the output of the bridge circuit. The armature voltage is supplied through thyristor *T*. The magnitude of this voltage (and hence, the motor speed) can be changed by turning ON the thyristor T at different points in each half- cycle with the help of *R*. The thyristor turns OFF only at the end of each half-cycle. Free-wheeling diode $D_3$ provides a circulating current path (shown dotted) for the energy stored in the armature winding at the time T turns OFF. Without $D_3$, this current would circulate through T and the bridge rectifier thereby prohibiting T from turning OFF. At the beginning of each half-cycle, T is in the OFF state and *C* starts charging up via motor armature, diode $D_2$ and speed-control variable resistor *R* (it cannot charge through $R_1$ because of reverse- biased diode $D_1$). When voltage across *C i.e.,* $V_C$ builds up to the breakover voltage of diac, diac conducts and applies a sudden pulse to T thereby turning it ON. Hence, power is supplied to the motor armature for the remainder of that half-cycle. At the end of each half-cycle, *C* is discharged through $D_1$, $R_1$ and shunt field winding. The delay angle $\propto$ depends on the time it takes $V_C$ to become equal to the breakover voltage of the diac. This time, in turn, depends on the time-constant of the *R*- *C* circuit and the voltage available at point *A*. By changing *R*, $V_C$ can be made to build-up either slowly or quickly and thus change the angle $\propto$ at will. In this way, the average value of the d.c. voltage across the motor armature can be controlled. It further helps to control the motor speed because it is directly proportional to the armature voltage. Now, when load is increased, motor tends to slow down. Hence, $E_b$ is reduced. The voltage of point *A* is increased because it is equal to the d.c. output voltage of the bridge rectifier ***minus*** back e.m.f. $E_b$. Since $V_A$ increases *i.e.*, voltage across the *R-C* charging circuit increases, it builds up *VC* more quickly thereby decreasing the time of charging, which leads to early switching ON of T in each half-cycle. As a result, power supplied to the armature is increased which increases motor speed thereby compensating for the motor loading. The waveforms of input voltage, rectified DC voltage, back-emf, armature voltage are also shown in the figure.

3 e) Describe working of basic current source inverter (CSI) based induction motor speed control.

**Ans:**

**Current source inverter (CSI) based induction motor speed control:**

In current-source-inverter, the input current is constant but adjustable. The output current is alternating and its amplitude is independent of the nature of the load. However, the magnitude and waveform of output voltage depends upon the nature of the load. The input DC supply is obtained from controlled bridge rectifier or diode bridge and chopper, as shown in the figure. The input current of inverter is maintained ripple-free and constant using inductor. The constant current is switched through the thyristors to create 3phase 6-step symmetrical line current waves. The thyristors are arranged in bridge and the current is switched sequentially into one of the motor phases by the top half of the inverter and this current return to the dc link from other phases via the bottom half of the inverter. By switching every $2\pi/3$ radians, a 6-step current waveform can be applied to the motor.




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

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

4 a) i) Draw equivalent circuit of thyristor mounted on heat sink. Indicate thermal resistances.

**Ans:**

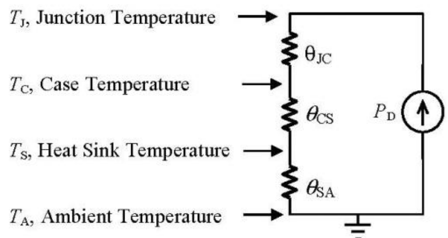
**Equivalent circuit of thyristor mounted on heat sink:**

$P_D$ is the average power dissipation in the device.

$\theta_{JC}$ is the junction-to-case thermal resistance.

$\theta_{CS}$ is the case-to-heat sink thermal resistance.

$\theta_{SA}$ is the heat sink-to-ambient thermal resistance.




2 marks for labeled circuit diagram + 2 marks for thermal resistances

4 a) ii) What is converter? List the types of converter. State the function of freewheeling

diode in converters.

**Ans:**

**Converter:**

The converter is a circuit configuration whose output is controlled DC supply. 1 mark

The controlled rectifiers, which convert AC into controlled DC, are usually called converters.

**Types of Converters:**

Converters are classified into two types according to the input AC supply as:

1) Single phase converter
2) Three phase converter

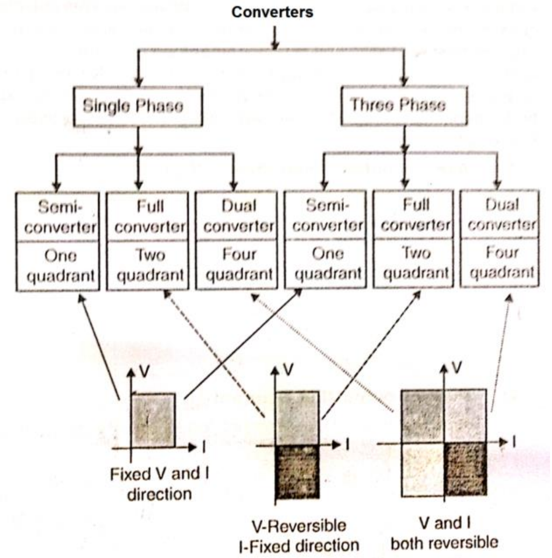
Each type is further subdivided into:

i) Semi converter 1 mark
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.



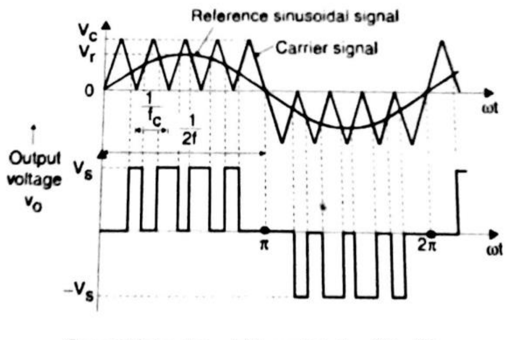

**Function of freewheeling diode in converters:**

The freewheeling diode is connected across output or load with its cathode to positive terminal and anode to negative terminal. When the load is highly inductive, the load inductance voltage gets reversed during the fall of load current. The output or load voltage then attempts to reverse but as soon as the reversed voltage becomes more than threshold voltage, the freewheeling diode conducts and provides path for inductive load current. Since diode conducts, it maintains the load voltage nearly equal to zero and prevents from becoming negative. It improves the average load voltage and helps to dissipate the power stored in load inductance. 2 marks

4 a) iii) With the help of neat circuit diagram explain working of sinusoidal pulse width modulation.

**Ans:**

**Sinusoidal pulse width modulation:**



Sinusoidal-pulse-width modulation (Sin M)

2 marks for diagram

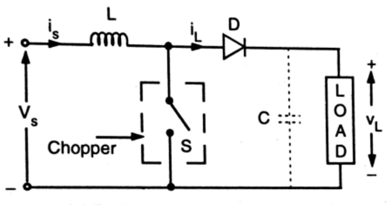
2 marks for explanation

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.

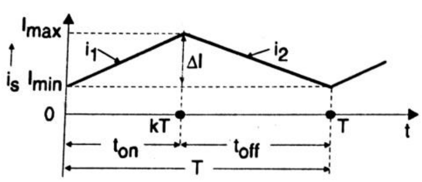
4 a) iv) Draw a schematic of step up chopper and explain it.

**Ans:**

**<u>Step-up Chopper</u>:**



(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:

1 mark for circuit diagram

1 mark for waveforms

2 marks for explanation

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

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

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) Draw waveforms of the following power electronic circuit for gate pulses shown in Fig. No. 2 indicate load voltage, current, capacitor voltage.

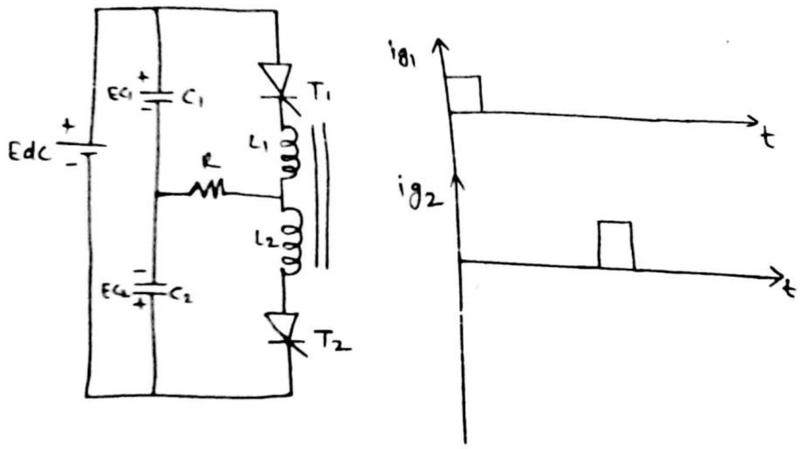



**Fig. No. 2**

**Ans:**

The circuit shown in Fig. No. 2 is **Half-bridge, Series Resonant Inverter**.

The waveforms of gate pulses, Capacitor voltages ($E_{c1}$, $E_{c2}$), Load Voltage $V_L$, Load Current $I_L$ are shown below.

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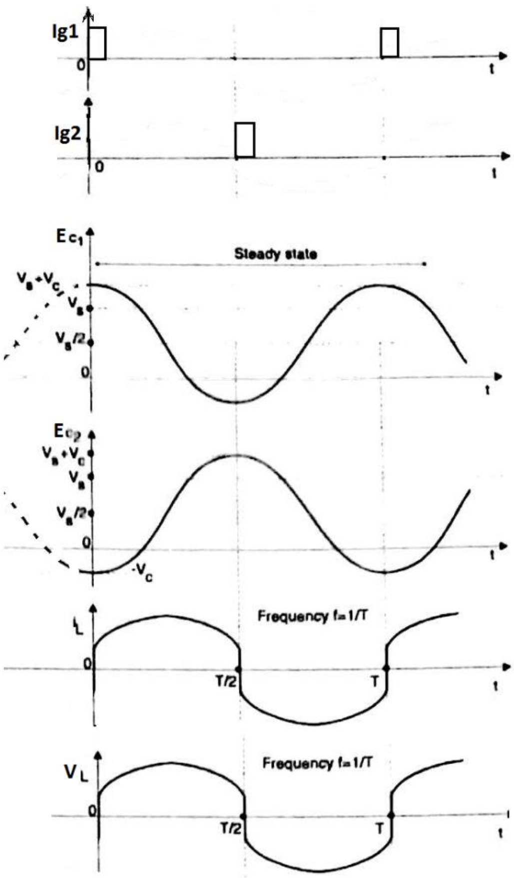
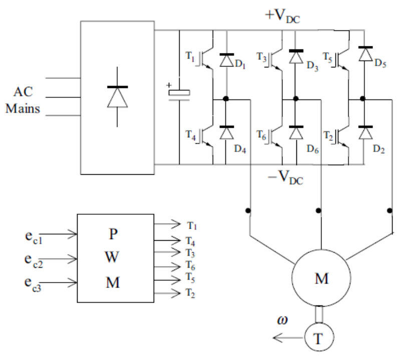


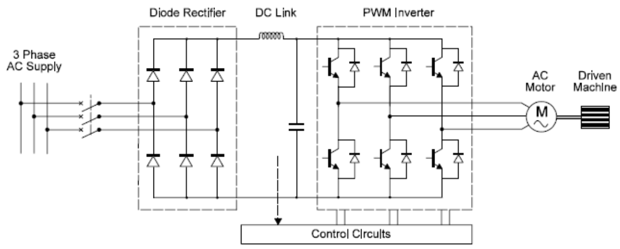

1½ mark for each waveform of
$V_L$
$I_L$
$E_{c1}$
$E_{c2}$
=
6 marks

4 b) ii) Describe speed control of 3 ϕ IM using voltage source inverter. What is the need of controlling V/F ratio.

**Ans:**

**Speed control of 3 ϕ IM using voltage source inverter:**




2 marks for circuit diagram (any one)
+
2 mark for description
+
2 mark for need of V/f control
=
6 marks

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.

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. 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 airgap flux is maintained.

**Need of controlling V/f ratio:**

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 Attempt any FOUR of the following: 16**

5 a) State the meaning of commutation. Explain class B method of commutation.

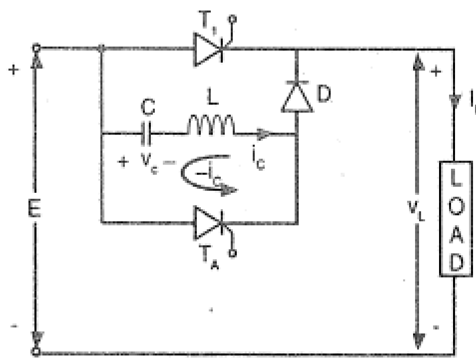
**Ans:**

**Commutation:**

The process of turning off a conducting thyristor is called “Commutation”. During commutation, the forward current is reduced, the reverse voltage is maintained across the conducting device and in some cases, the current through the device is shifted to some other device or component in the circuit. 1 mark for commutation

**Class B: Resonant Pulse Commutation:**

The circuit arrangement for class B resonant pulse commutation is shown in the fig.(a). In this technique, a resonating LC circuit commutates the SCR by providing a current pulse in the reverse direction. The $T_1$ is the main SCR and $T_A$ is the auxiliary SCR. When DC supply voltage E is applied to the circuit, with both $T_1$ and $T_A$ off, the current flows from supply through C, L, D and load $R_L$. This current charges capacitor C to voltage in the range E to 2E depending upon the parameters L, C and $R_L$. For $R_L$ = 0, the capacitor can charge to 2E. Let us assume that the value of $R_L$ is such that the capacitor charges to E. At the end of charging, the charging current falls to zero. With this initial condition, if a gate pulse is applied to

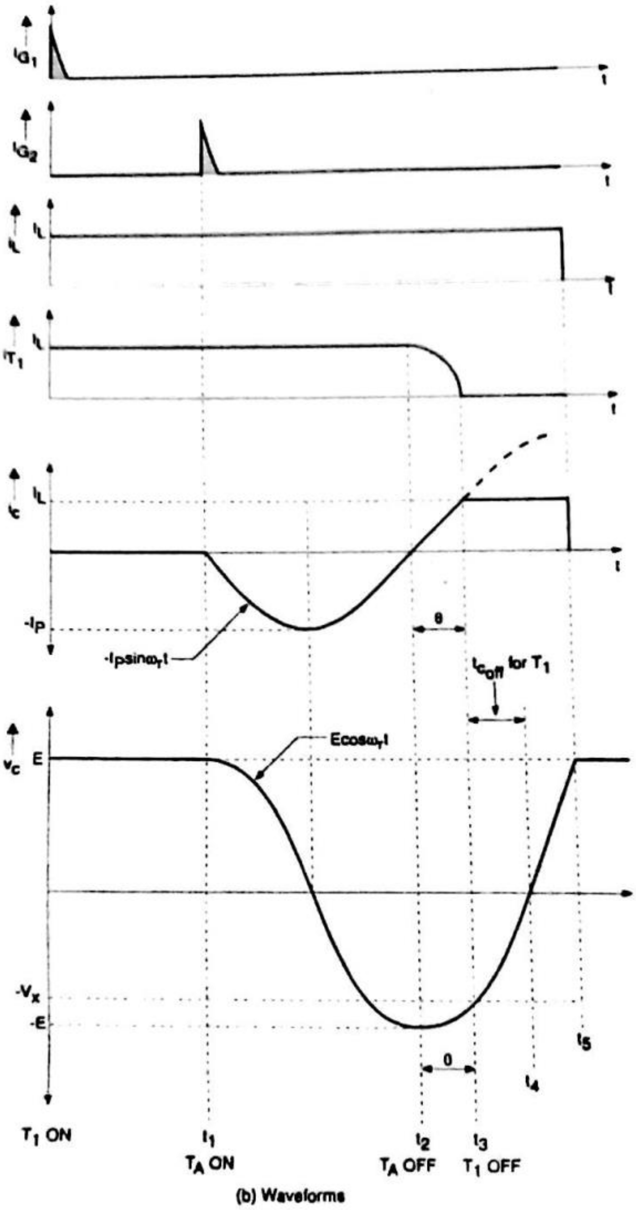


(a) Circuit diagram

1 mark for circuit

2 marks for explanation

$T_1$, it conducts and carries the load current. The charge on the capacitor is held as it cannot discharge through the $T_1$ due to diode D. However, when gate pulse is applied to $T_A$ at instant $t = t_1$, it conducts and allows the capacitor to discharge. The capacitor not only discharges completely but further charges with reversed polarity due to series inductor. When reversed capacitor voltage reaches to peak value this discharge current falls to zero. Now the oppositely charged capacitor forces current through L and $T_A$. This current makes the forward current of $T_A$ to fall to zero and $T_A$ is turned off. Then the capacitor forces current through L, D and $T_1$. This current is opposite to the load current through $T_1$. When the capacitor current becomes equal to load current, the current in $T_1$ becomes zero and it is turned off. Thus turning on of $T_A$ causes ultimately a resonant current pulse in the reverse direction through $T_1$ and turns off $T_1$.




Class B - Resonant Pulse Commutation

**WINTER – 2016 Examinations**
**Model Answer**
**Subject Code: 17638: Power Electronics**

5 b) Write the specifications / rating of SCR.
(i) Voltage, (ii) current, (iii) power, (iv) temperature

**Ans:**

1. **Voltage Rating:**
   - i) Peak working forward-blocking voltage $V_{DWM}$
   - ii) Peak repetitive forward-blocking voltage $V_{DRM}$
   - iii) Peak surge or non-repetitive forward blocking voltage $V_{DSM}$ — 1 mark for any two
   - 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 $I_{Trms}$ — 1 mark for any two
   - 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) — 1 mark for any two
   - iv) Loss due to leakage current during forward and reverse blocking
   - v) Switching losses during turn-on and turn-off
4. **Temperature Rating:**
   - i) Maximum junction temperature — 1 mark

5 c) With a neat circuit diagram explain the working principle of 1 ϕ fully controlled half wave converter with resistive load. Draw the waveform across load for firing angle 90°.

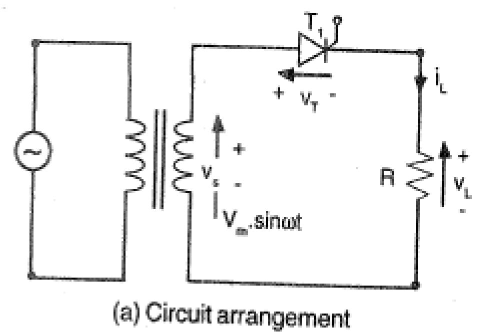
**Ans:**

**Single-phase Fully-controlled Half-wave converter:**

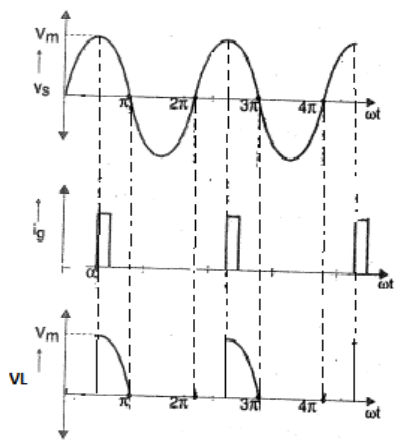
1 mark for circuit diagram

1 mark for waveforms

2 marks for explanation



(a) Circuit arrangement

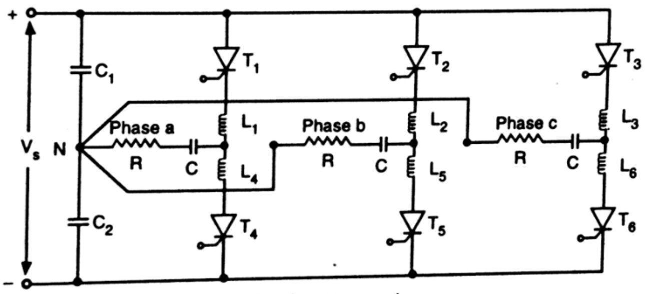



The circuit diagram of 1 ϕ fully controlled half wave converter with resistive load is as shown in the fig. (a). During positive half cycle of input voltage $v_s$, the thyristor anode is positive with respect to its cathode. Thus thyristor is forward biased. If a short pulse is applied to gate of the thyristor at $\omega t = \alpha$ (here 90°), it is turned on and conducts for rest of the positive half cycle. When the input voltage starts to reverse and become negative after $\omega t = \pi$, thyristor anode becomes negative with respect to its cathode, hence thyristor get reverse biased and it is turned off. During off-state of thyristor, the supply voltage $v_s$ appears across thyristor and load voltage remains zero. Thus during each positive half cycle, the supply voltage appears across load resistance from firing instant to end of that half cycle and during negative half cycle, load voltage remains zero. The waveforms of supply voltage $v_s$, gate pulses and load voltage $v_L$ are also shown in the figure.

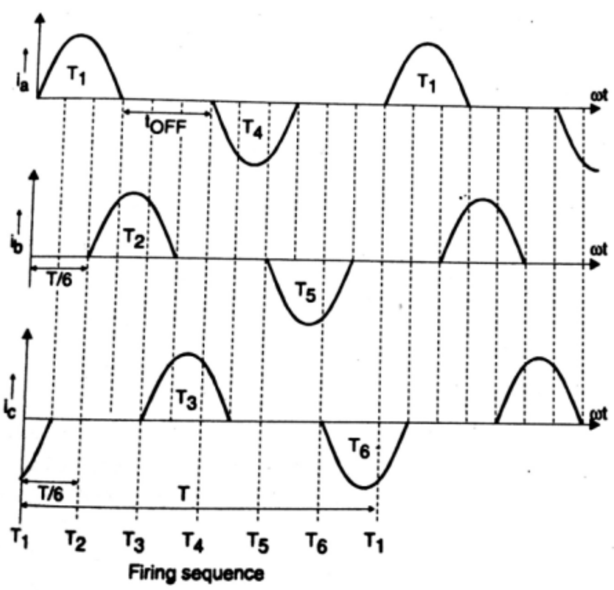
5 d) Draw circuit diagram of 3 $\phi$ series inverter and describe its operation.

**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 ($t_{off}$)

2 marks for circuit

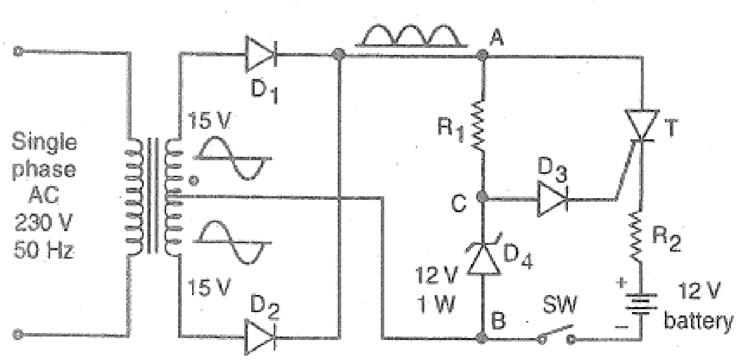
2 marks for explanation with waveforms

is the time gap between positive pulse and negative pulse.

5 e) Draw schematic circuit diagram of thyristorized battery charger.

**Ans:**

**Thyristorized battery charger:**



Automatic battery charger using SCR

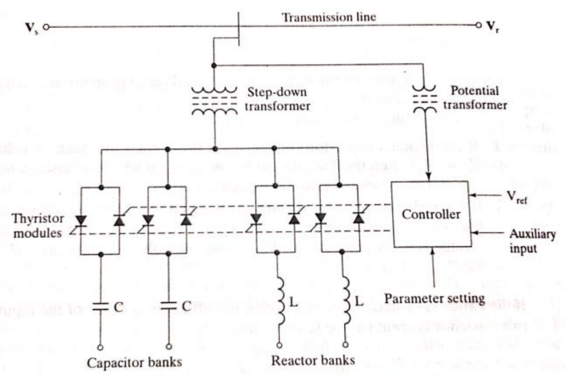
4 marks for labeled circuit diagram

(2 marks for unlabeled diagram)

5 f) Describe use of thyristor in static VAR compensation.

**Ans:**

**<u>Static VAR compensator:</u>**



General arrangement of static VAR compensator

2 marks for diagram

2 marks for explanation

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

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

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

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

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

**WINTER – 2016 Examinations**
**Model Answer**
**Subject Code: 17638: Power Electronics**

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

6 a) What are different turn-on methods of SCR? Explain any one method.

Ans:

SCR Turn-on or Triggering Methods:

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

½ mark for each of any four methods (= 2 marks)

dv/dt turn-on or 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:

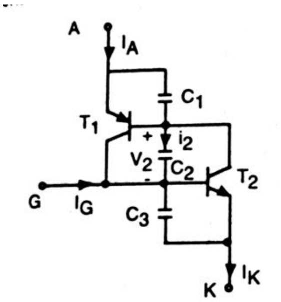
2 marks for any one method explanation

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

where, $C_2$ = capacitance of junction $J_2$

$V_2$ = voltage across junction $J_2$

$q_2$ = charge in the junction $J_2$




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.

6 b) Differentiate between single and three phase controlled converter on the basis of efficiency, ripple-factor, RMS values and average values.

**Ans:**

**Difference between Single-phase and Three-phase Converters:**

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

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

6 c) State different methods to control the output voltage of inverter. Explain PWM method.

**Ans:**

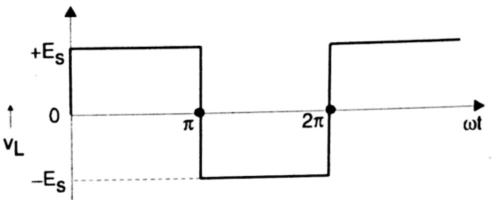
**Methods of Voltage Control in Inverters:**

1) External Control:
   a) Externally controlling the ac output voltage
      (i) AC voltage control: Using AC voltage controller between inverter & load — ½ mark
      (ii) Series inverter control: Connecting two or more inverters in series
   b) Externally controlling the dc input voltage
      (i) Obtaining controlled dc supply for inverter from fully controlled rectifier & filter arrangement.
      (ii) Obtaining controlled dc supply for inverter from uncontrolled rectifier, chopper & filter arrangement. — 1 mark
      (iii) Obtaining controlled dc supply for inverter from AC voltage controller, uncontrolled rectifier, filter arrangement.
      (iv) Obtaining controlled dc supply for inverter from chopper & filter arrangement.
2) Internal Control: By controlling the operation of inverter itself – PWM technique — ½ mark

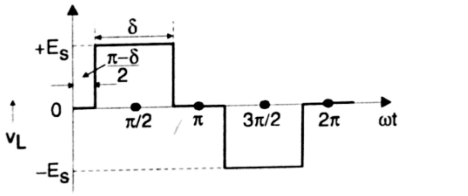
**Pulse-Width-Modulation (PWM) Control:**

The output voltage of single-phase bridge inverter is normally a square-wave as shown in fig.(a). The output voltage amplitude $E_s$ depends on the input DC supply voltage. Therefore, to control the output voltage, external control of input DC voltage is required. From Fourier analysis, it is seen that the square wave output contains odd harmonics. The amplitude of $n^{th}$ odd harmonic component in square wave is given by, ½ mark for waveforms

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



(a) Square wave output (without modulation)



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

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

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

1 ½ mark for explanation

= 4 marks

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

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

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

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

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

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

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

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

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

6 d) With a neat circuit diagram, explain the working principle of Jones Chopper.

**Ans:**

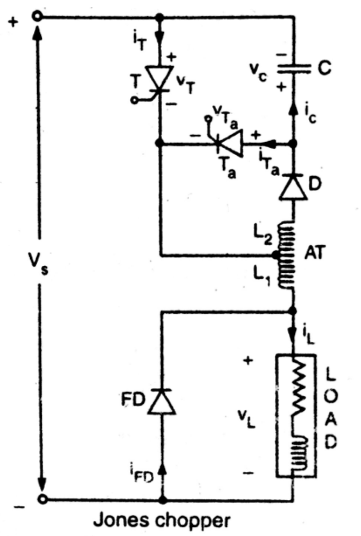
**Jones Chopper:**

The circuit diagram of Jones Chopper is shown in the fig. It employs class D commutation technique in which a charged capacitor is switched by an auxiliary SCR to commutate the main SCR. The circuit operation can be divided into various modes as follows: 2 marks for circuit

<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 $L_1$ 2 marks for

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. explanation

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.



Jones chopper

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.

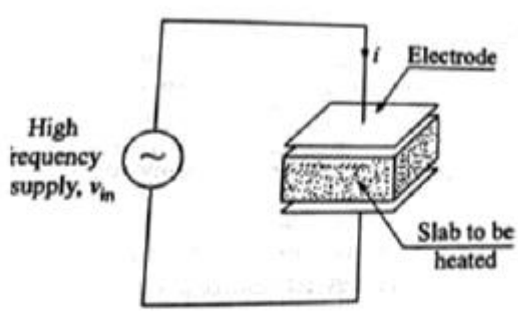
Jones chopper offers flexible control and effective use of trapped energy in coupled inductors. There is no starting problem and any SCR can be triggered at start.

6 e) Describe working principle of dielectric heating using thyristor.

**Ans:**

**Principle of Dielectric Heating using thyristor:**

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




2mark for principle

1 mark for diagram

1mark for use of thyristor

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

Thyristors are used inverter which converts DC into high frequency AC. This high-frequency supply is applied across the electrodes to heat up the work-piece dielectric material, as shown in the following diagram.