MAHARASHTRA STATE BOARD OF TECHNICAL EDUCATION
(Autonomous)
(ISO/IEC-27001-2013 Certified)

Summer – 2019 Examinations

Model Answers

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 to assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling errors should not be given more importance (Not applicable for subject English and Communication Skills).
4) While assessing figures, examiner may give credit for principal components indicated in the figure. The figures drawn by candidate and model answer may vary. The examiner may give credit for any equivalent figure drawn.
5) Credits may be given step wise for numerical problems. In some cases, the assumed constant values may vary and there may be some difference in the candidate's answers and model answer.
6) In case of some questions credit may be given by judgement on part of examiner of relevant answer based on candidate's understanding.
7) For programming language papers, credit may be given to any other program based on equivalent concept.

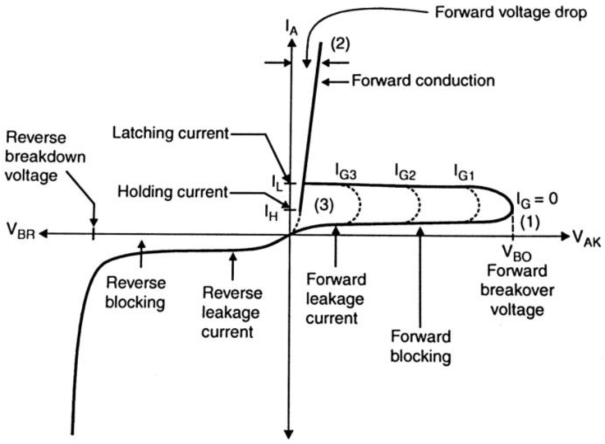
Summer – 2019 Examinations
<u>Model Answers</u>
Subject Code: 17638: POWER ELECTRONICS

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

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

Ans:

V-I characteristics of SCR:



V-I Characteristics of SCR

Correct diagram 2 marks + 2 marks Explanation = 4 marks

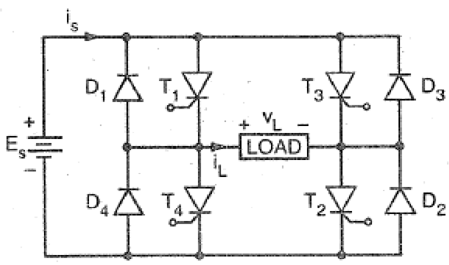
(i) Latching Current:
Latching current is defined as the minimum anode current required to maintain the SCR in the on-state immediately after the SCR has been turned on and the gate signal has been removed.

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

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

Ans:

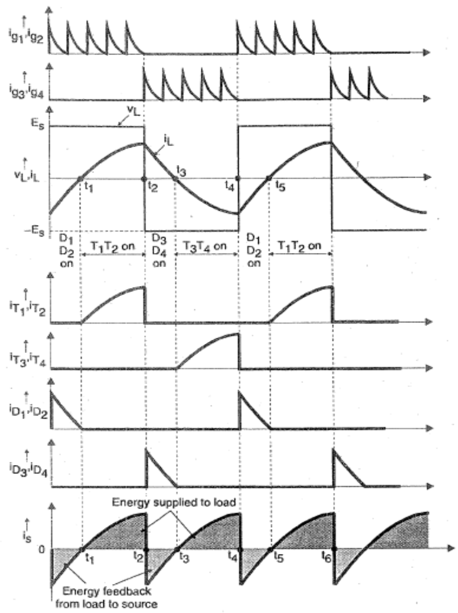
Circuit Diagram:



(a) Circuit arrangement

2 marks for circuit diagram

Waveforms:



Single-phase, full-bridge inverter waveforms

2 marks for waveforms

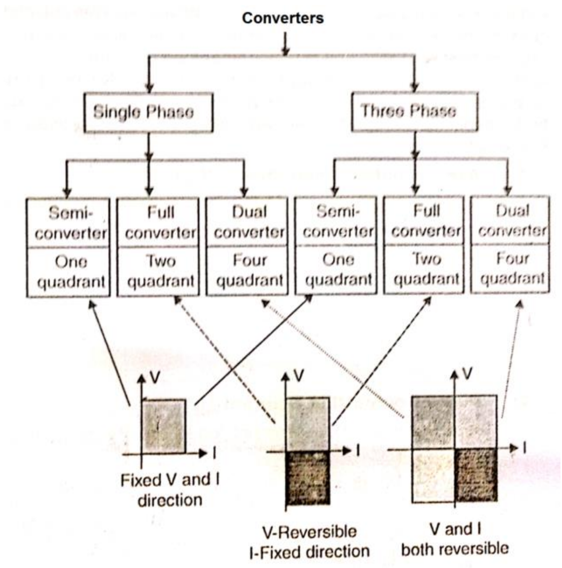
1 a) iii) State the necessity of converter and give the classifications of controlled converter.

Ans:

Necessity of Converters:

The converters are the circuit configurations whose output is controlled DC supply. There are many applications which require DC supply. A well-known DC source is battery, in which chemical energy is converted into electrical energy. The battery sources have limited energy capacity and discharge during their use. The discharged battery needs recharging for further use. To recharge the battery, it should be connected to another DC supply. Thus there is requirement of alternative DC source for charging the batteries. In present days, the AC supply is used in all stages of power system. It is possible to convert AC supply into DC supply. It eliminates the need of energy storage. The DC load can be fed from such DC supply, which is available as & when AC supply is there. Large DC loads, which are difficult to handle using batteries, can be effectively and continuously supplied from such DC supply. Thus whether small or large, the DC load can be supplied from the DC supply, which is obtained after converting AC into DC. Thus the converters are necessary to convert available AC supply into DC supply and to make power available for battery charging, light DC loads, large DC loads and even for transferring bulk amount of power over long distance transmission lines (High voltage DC transmission).

2 marks for necessity



2 marks for classification

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
ii) Full converter
iii) Dual converter

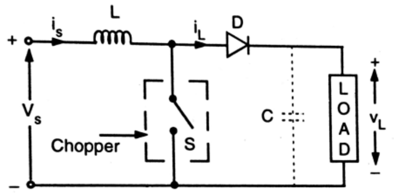
A "Semi converter" is a one-quadrant converter in the sense that it gives output voltage with fixed polarity and output current with fixed direction.

A "Full converter" is a two-quadrant converter in the sense that it gives output voltage of either polarity (i.e voltage can be reversed), however the output current has fixed direction. A "Dual converter" is a four-quadrant converter in the sense that its output voltage polarity and output current direction can be reversed so as to operate the converter in all four quadrants.

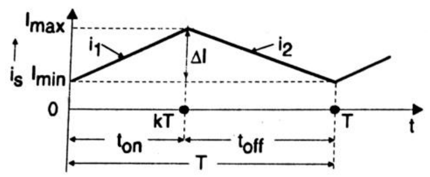
1 a) iv) Draw a schematic of step up chopper and explain it.

Ans:

Step-up Chopper:



(a) Basic circuit arrangement



(b) Current waveform

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

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.

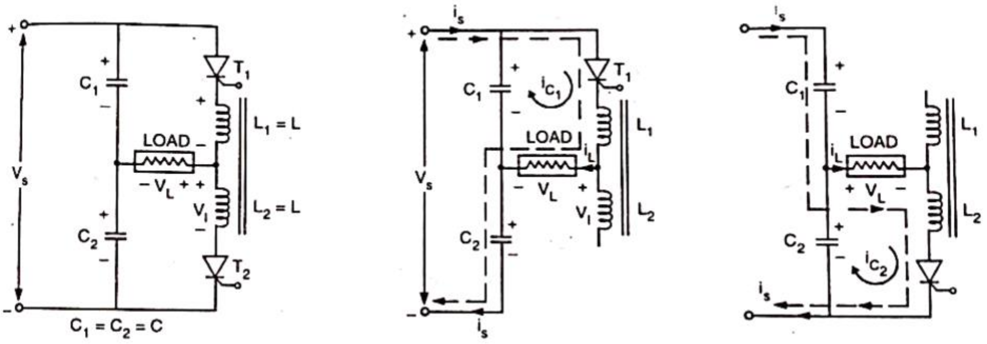
If a large capacitor C connected across the load, the output voltage will be continuously available. During t_{on} capacitor will charge and during t_{off} it will discharge and provide output voltage.

1 b) Attempt any ONE of the following: **06**

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

Ans:

Method of overcoming the intermittent power flow in a basic series inverter (Using Half-Bridge Series-Resonant Inverter):



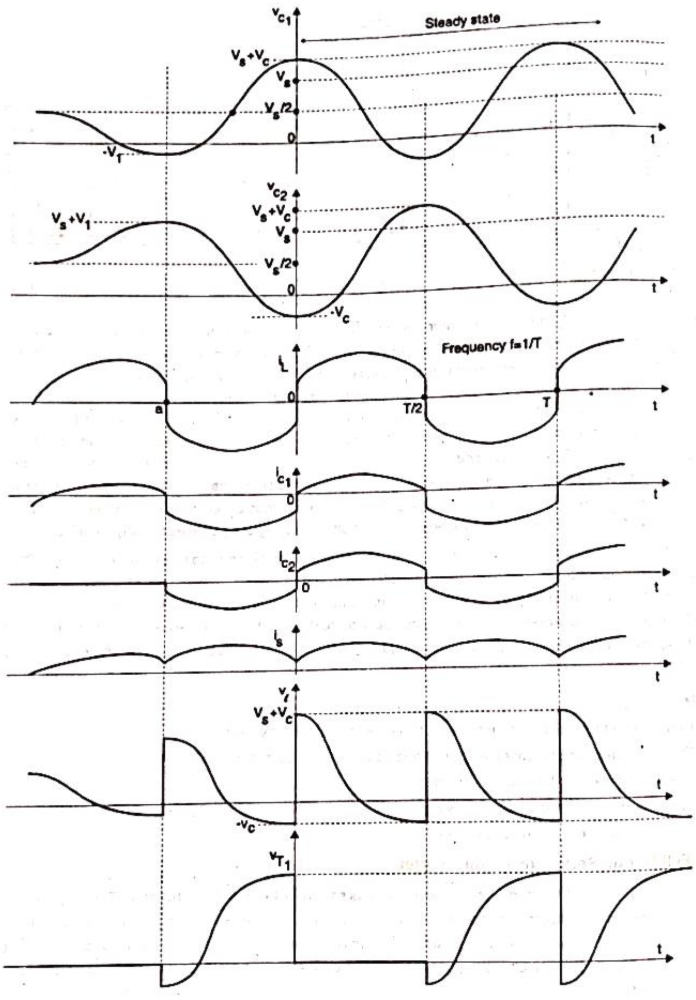
(a) Circuit diagram (b) T_1 conducting (c) T_2 conducting

2 marks for circuit diagram

To overcome the intermittent power flow in a basic series inverter, a modified circuit configuration, called half-bridge series resonant inverter as shown in Fig. (a), can be used. It employs two coupled inductors and two capacitors. Initially when both the SCRs T_1 and T_2 are off, both capacitors C_1 and C_2 get charged to voltage (V_S / 2) as $C_1 = C_2 = C$. If T_1 is fired, two currents flow through it, one is due to source i.e i_s and other is due to discharging of the capacitor C_1 i.e i_{c1} as shown in Fig. (b). Thus the load current i_L is the sum of i_s and i_{c1}. Due to discharging, the voltage across c_1 falls but due to i_s the voltage across C_2 rises. At any instant $v_{c1} + v_{c2} = V_S$. The parameters r, L C are such that, the circuit is underdamped and a current pulse is observed. All currents i_s, i_{c1} and i_L rise, attain peak value and then fall. At the peak value instant, the di/dt = 0, hence inductor voltage v_ℓ ($v_{\ell 1} = v_{\ell 2} = v_\ell$) becomes zero. Then v_ℓ changes its polarity and try to maintain currents i_s and i_{c1}. In later part of current pulse, the capacitor C_1 is fully discharged ($v_{c1} = 0$, $v_{c2} = V_S$) and further charged with reverse polarity (lower plate positive) causing negative voltage across it. Therefore, C_2 is charged to voltage greater than V_S. Due to underdamping, the currents can become zero naturally. However prior to the currents fall to zero, if T_2 is fired (it is forward biased by both v_{c2} and $v_{\ell 2}$), at the instant of turn-on, thus ($v_{c2} - v_\ell$) appears across L_2. Two currents flow through T_2, one is i_s due to source and other is i_{c2} which is the discharging current of C_2 as shown in Fig. (c). The voltage ($v_{c2} - v_\ell$) appearing across L_2 causes equal emf in L_1 with upper terminal positive. Due to this emf, the SCR T_1 is reverse biased & turned-off. Thus turning on of T_2 causes turning off of T_1. When T_2 conducts, we get negative half-cycle of load current. In the later part of negative half-cycle of load current, the SCR T_1 is forward biased by capacitor voltage v_{c1} and inductor voltage $v_{\ell 1}$. If T_1 is fired, prior to (i_{c2} and i_s) fall to zero naturally, ($v_{c1} - v_\ell$) appears across L_1, causing equal voltage across L_2 with upper terminal positive. So T_2 is reverse biased and turned off. Thus firing of T_1 causes turning off of T_2.

2 marks for explanation

It is to be noted that load current i_L is constituted by source current i_s and capacitor current i_{c1} or i_{c2}. Thus input DC source continuously supply current to the load. The waveforms are shown in the following figure.



Waveforms
Half-bridge, series resonant inverter

2 marks for waveforms

1 b) ii) For a single phase full controlled half wave converter system and sketch waveforms for load voltage and load current for:

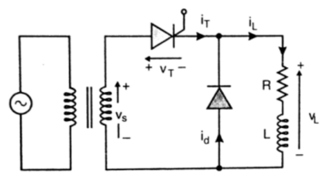
1) RL load
2) RL load with freewheeling diode.

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

Ans:

Single phase fully controlled half wave converter:

On comparing the waveforms of output load voltage with and without freewheeling diode, it is seen that when the freewheeling diode is not used, the output voltage get reversed after positive half cycle. This is because the load inductance maintains the load current and keeps SCR on even if the supply voltage is



(a) Circuit diagram

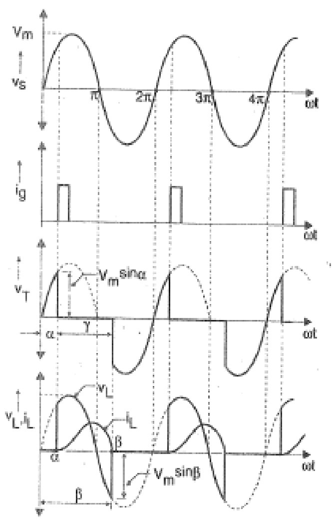
2 marks for circuit diagram + 2 marks for

reversed. Thus every positive half cycle of load voltage is followed by some negative voltage till the current drops to zero. When the freewheeling diode is used, the load inductance forces current through it after every positive half cycle. When diode conducts, the load voltage is maintained at approximately zero. Thus load voltage is prevented from becoming negative.The negative voltage appearing across load reduces the average load voltage. Thus the use of freewheeling diode helps to increase the average load voltage. For some sensitive loads, the negative voltage is undesirable. In such cases also the use of freewheeling diode is advantageous.

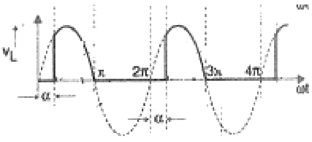
explanation + 1 mark for waveform + 1 mark for advantages

Advantages of Freewheeling Diode (FWD):

1) Freewheeling diode prevents negative voltage from appearing across the load.
2) It reduces reactive power flow.
3) It improves power factor of input.
4) Improves load performance.



Without freewheeling diode



With freewheeling diode

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

2 a) Describe thyristorised induction heating.

Ans:

Thyristorised Induction Heating:

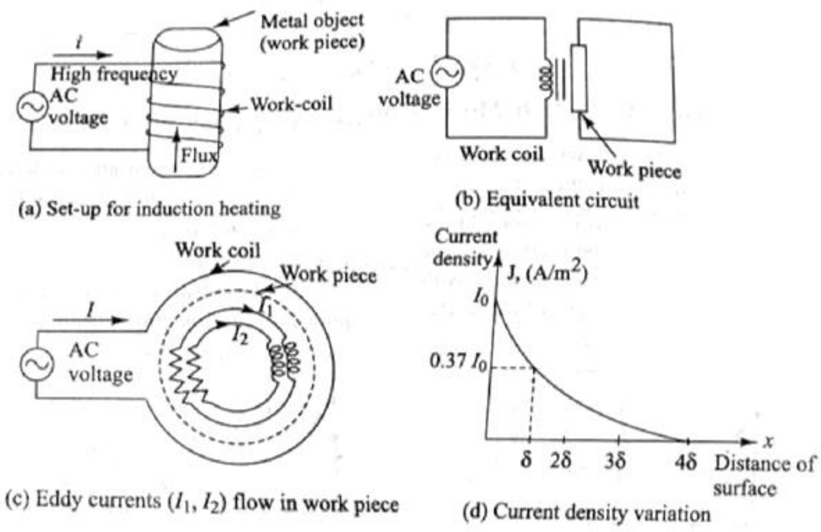
When a conducting object is subjected to a changing magnetic field, according to Faraday's laws of electromagnetic induction, emf is induced in the object. The object, being conductor, offers many short-circuited paths. So the circulating currents flow through these paths. The currents are in the form 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". 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 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

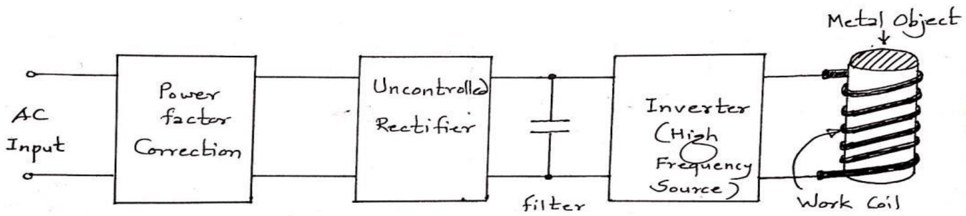
1 mark for thyristorised induction heating explanation

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

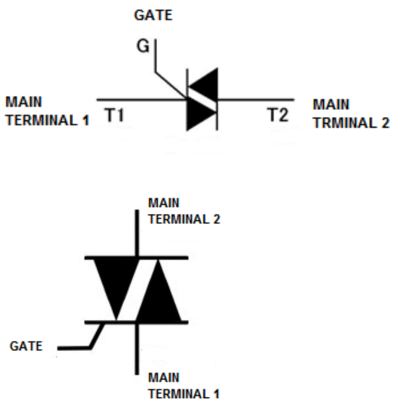


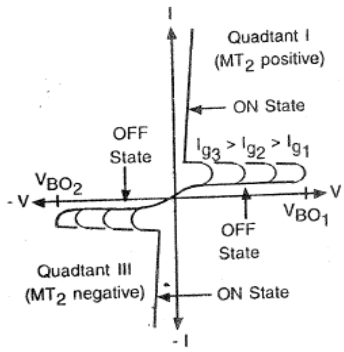
1 mark for block diagram

2 b) Draw symbol and V-I characteristics for:
i)TRIAC
ii)IGBT

Ans:

i) TRIAC:





V-I Characteristics

1 mark for one symbol of each = 2 marks

1 mark for characteristic of each = 2 marks

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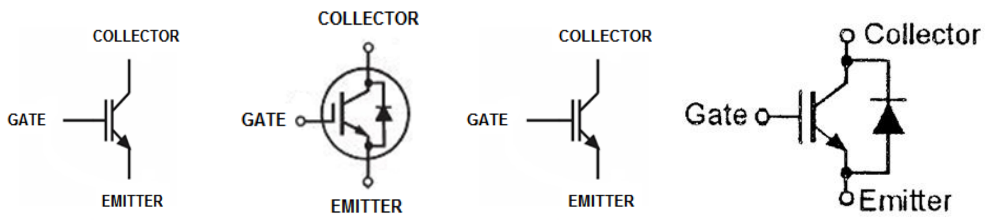
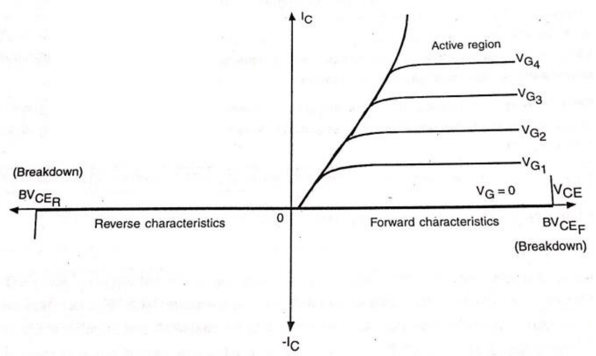
ii) IGBT:





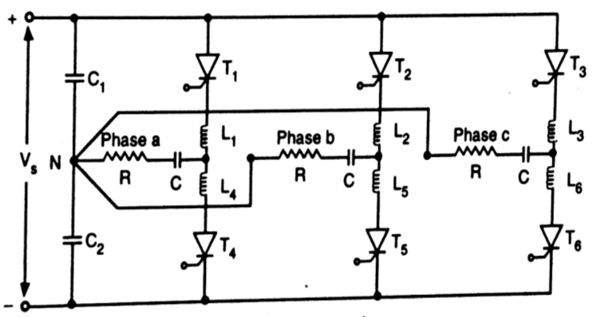
V-I characteristics of IGBT

2 c) Draw circuit diagram of 3-phase series inverter and describe its operation.

Ans:

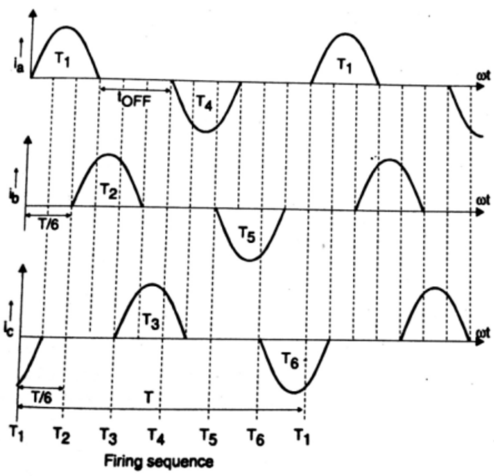
Three-phase Series Inverter:

1 mark for circuit diagram



(a) Circuit arrangement

1 mark for waveforms



(b) Waveforms

Explanation:

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 C1 and C2 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 T1 is fired, current flows through T1, L1, C and R of phase a.

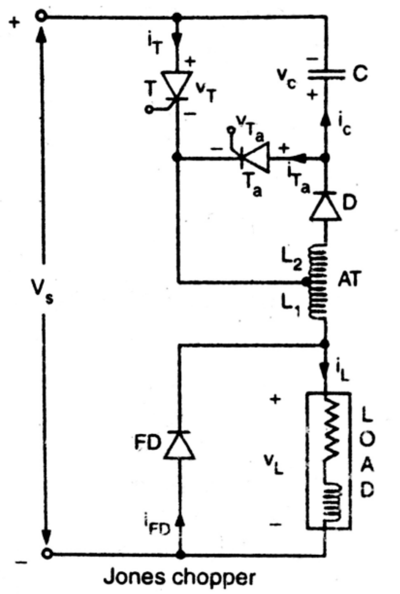
2 marks for explanation

The underdamped combination R-C-L1 causes a current pulse as shown in waveform of ia in fig.(b). At the end of this pulse, current falls to zero and T1 is commutated. At the end of this pulse, the capacitor C get charged to a voltage (with right plate positive) higher than that across C1 and therefore a reverse bias is maintained across T1. As independent operation of each phase is possible, the thyristor T2 can be fired prior to the turning off of T1. 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 (toff) is the time gap between positive pulse and negative pulse.

2 d) With a neat circuit diagram, explain the working principle of Jones chopper.

Ans:

Jones Chopper:



Jones chopper

Diagram 2 Marks + 2 marks Explanation

Explanation:

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

Mode 1: In this mode, the main SCR T is triggered at start and then it conducts the load current. Since L1 and L2 are coupled inductors, the applied voltage across L1 results in emf induced in L2. This emf charges the capacitor C with shown polarity through diode D and conducting T. When capacitor is fully charged, the charging current falls to zero and cannot reverse due to diode.

Mode 2: In this mode, the auxiliary SCR Ta is triggered. Once Ta 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 Ta to the load current, the main SCR is turned off. The load current now flowing through C and Ta causes capacitor to discharge fully.

Mode 3: The inductance L1 and load inductance try to maintain the load current through C and Ta. 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 L1 and load changes their polarity. The reversal of load voltage VL forward biases the free-wheeling diode and it conducts. The capacitor gets overcharged due to the energy supplied by Vs and L1. The load current falls below holding current level of Ta , hence Ta is turned off.

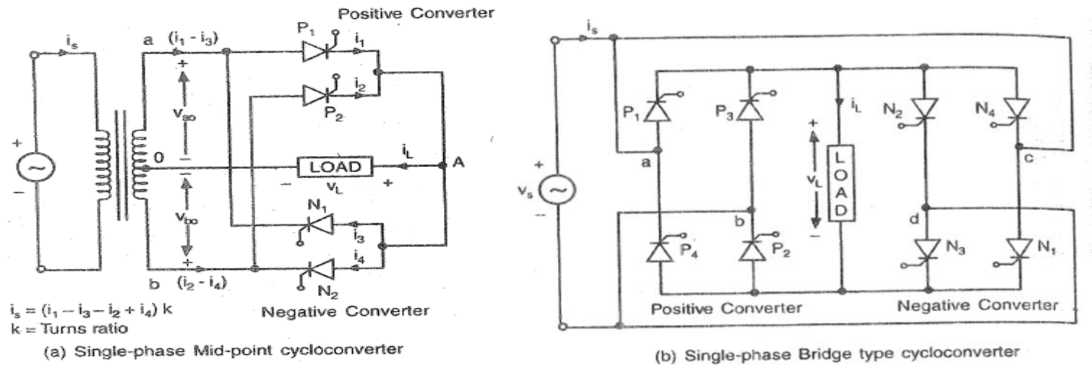
Mode 4: The overcharged capacitor C, with upper plate positive, then starts discharging through Vs, FD, L1, L2 and D. The discharging current is in the form of a pulse. At the end of this mode, the capacitor voltage falls to a level less that Vs and therefore current falls to zero and attempts to reverse 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 the operation of cyclo converter with a neat diagram.

Ans:

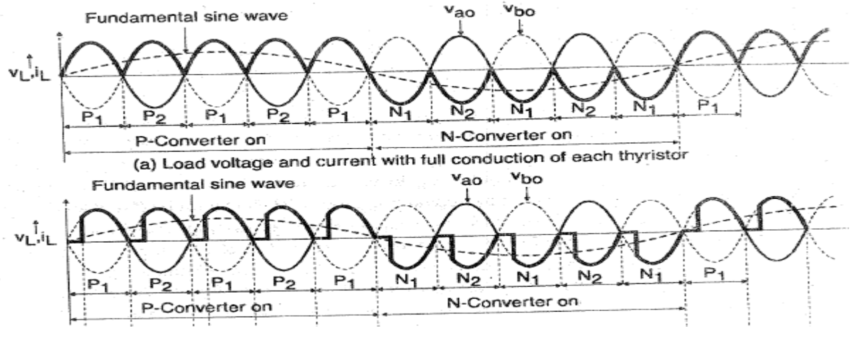
Cyclo-Converter:



(a) Single-phase Mid-point cycloconverter (b) Single-phase Bridge type cycloconverter

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

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.



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

2 f) State the difference between MOSFET and thyristor inverter

Ans:

MOSFET Based Inverter	Thyristor Based inverter.
These are based on Power MOSFET as a switching devices.	These are based on SCR as a switching devices.
Power MOSFET are voltage controlled device and Triggering circuits consumes less power.	SCR are current controlled device and Triggering circuits consumes more power
Fast turn ON and OFF	Slow turn ON and OFF as compared to Power MOSFET.
Inverters operates at higher frequency	Inverters operates at lower frequency
Switching losses are more	Switching losses are less
Operate at small/medium power rating.	Operate at higher power rating.
Quality of the inverter output waveform can be improved by increasing switching frequency.	Quality of the inverter output waveform is less and can not be improved.

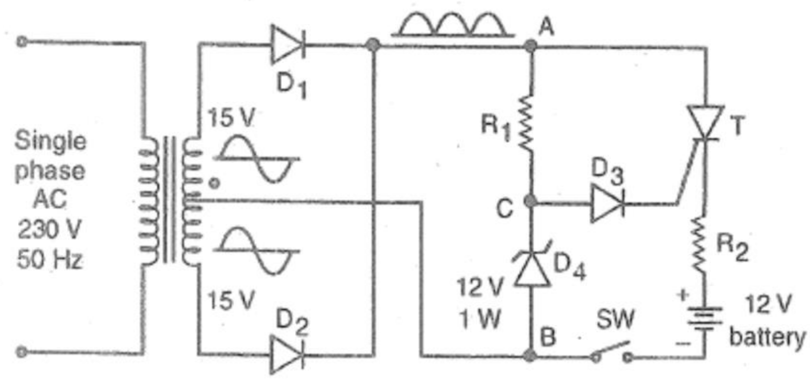
1 mark for each of any four points = 4 marks

3 Attempt any FOUR of the following: 16

3 a) Draw schematic circuit diagram of thyristorised battery charger

Ans:

<u>Thyristorised battery charger</u>



Automatic battery charger using SCR

4 marks for Correct labeled diagram

3 marks for partially labeled diagram

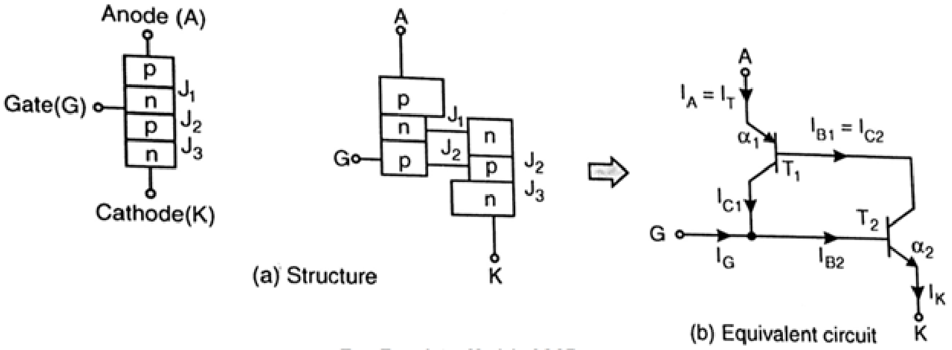
2 marks for unlabeled diagram

3 b) Draw construction of SCR using two transistor model. Explain its operation

Ans:

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 figures.



Two Transistor Model of SCR

2 marks for diagram

The collector current of transistor is related to emitter current and leakage current as:

$$I_C = \alpha I_E + I_{CBO}$$

where, α = common-base current gain

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

For transistors T_1 and T_2, we can write,

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

From KCL applied to T_1, we can write

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

2 marks for explanation

From KCL applied to entire equivalent circuit,

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

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

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

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

From this equation it is clear that the anode current depends on the gate current, leakage currents and current gains.

If $(\alpha_1 + \alpha_2)$ tends to be unity, the denominator $1 - [\alpha_1 + \alpha_2]$ approaches zero, resulting in a large value of anode current and SCR will turn on. The current gains vary with their respective emitter currents. When gate $I_G$current is applied, the anode current I_A is increased. The increased I_A, being emitter current of T_1, increases the current gain α_1. The gate current and anode current together form cathode current, which is emitter current of T_2. Thus increase in cathode current results in increase in current gain α_2. Increased current gains further increase the anode current and the anode current further increases the current gains. The cumulative action leads to the loop gain to approach unity and the anode current drastically rises which can be controlled by external circuit only.

3 c) State the application of chopper and list the various control techniques of Chopper.

Ans:

Applications of chopper

- Chopper is used for DC motor control
- Solar & wind energy conservation
- In electric cars
- Aeroplane & spaceship where onboard-regulated DC power supplies are required
- Chopper circuits are used as power supplies in computers, commercial

1 mark for

electronics, Electronics Instruments.
- In variable frequency drives
- In SMPS
- Switched capacitor filters.

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)

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

3 d) What is converter? List the types of converter. State the function of free-wheeling diode in converters.

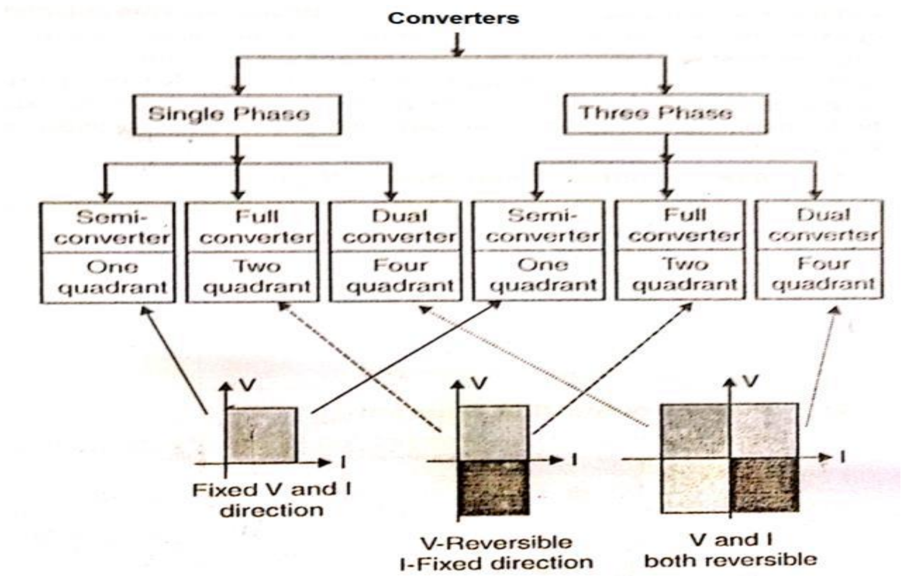
Ans:

Converter:
The converter is a circuit configuration whose output is controlled DC supply.
The controlled rectifiers, which convert AC into controlled DC, are usually called converters.

1 mark for definition

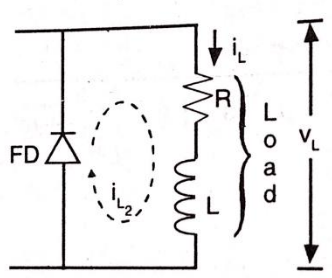
Types of Converters:
Converters are classified into two types according to the input AC supply as:
1) Single phase converter
2) Three phase converter

Each type is further subdivided into:
i) Semi converter
ii) Full converter
iii) Dual converter



1 mark for types

Function of freewheeling diode in converters:



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

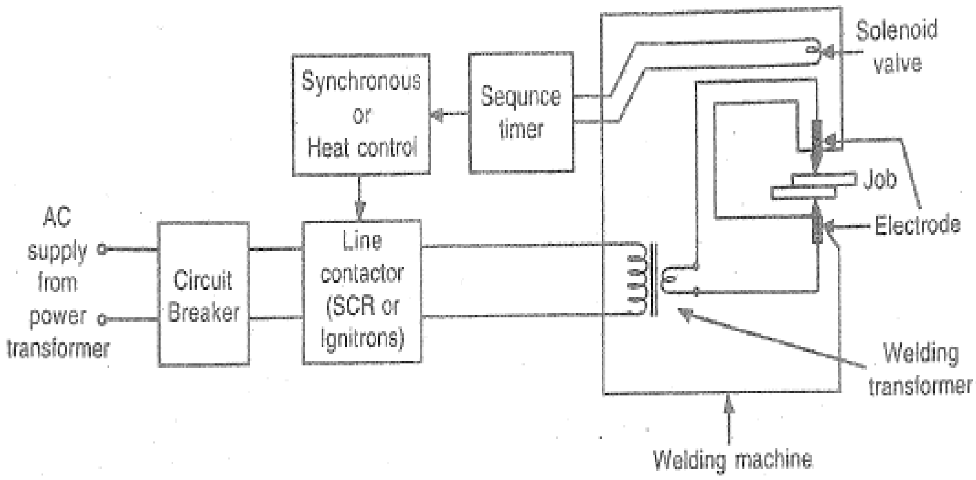
2 marks for function

3 e) Describe the working of resistance welding method with diagram.

Ans:

Resistance welding:

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



Resistance welding scheme

2 marks for diagram

1) **Line Contactor:** It is basically a switch which permits the welding current to flow to heat the metal pieces and make the weld. Since the welding current needs to flow for short duration, the contactor must close and then open quickly. For precise and noise free operation, it can be implemented by solid-state devices such as SCR.
2) **Synchronous or Heat Control:** An electronic circuit is used to control the firing of SCRs, which controls the voltage supplied to primary winding of welding transformer. By controlling the primary voltage, the welding current in the secondary is controlled to control the heat and weld.
3) **Sequence Timer:** It is an electronic timing circuit that provides timing signals to carry out the welding process in a particular sequence. The signals are provided in following sequence:

2 marks for explanation

i) The signal is provided to solenoid valve, which when opened, applies air pressure so that the electrodes come together and squeeze the metal pieces.
ii) The signal is then given to heat control unit to start the flow of welding current for welding.
iii) The signal is then given to heat control unit to stop the welding current.
iv) The signal is then given to solenoid valve to close it, so that the air pressure is reduced and electrodes are separated.
v) Finally signal is generated to recycle the operation.

In this way, the resistance welding scheme works.

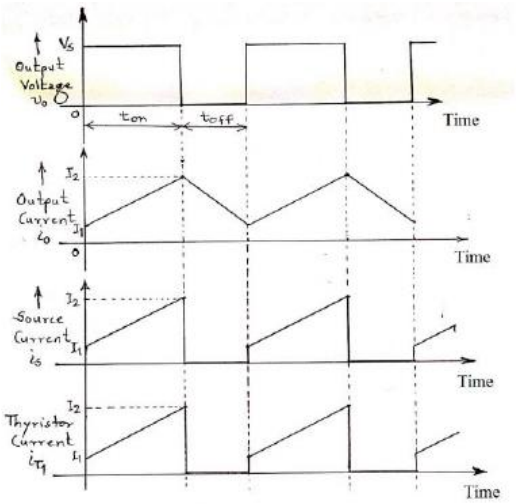
3 f) Sketch output voltage, output current, source current and thyristor current waveform for type C chopper indicate conduction of various devices.

Ans:

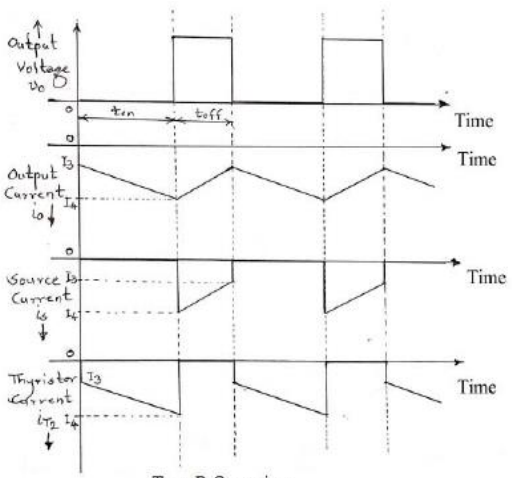
<u>Type C chopper :</u> Conducting devices

Type A operation: During ton: S1 (SCR T1) and during toff: D2
Type B operation: During ton: S2 (SCR T2) and during toff: D1

i)**<u>For Type-A operation:</u>** ii)**<u>For Type B operation</u>**



Type A Operation



Type B Operation

2 marks for waveforms of type-A operation

2 marks for waveforms of type-B operation

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

4 a) i) Describe the principle of dielectric heating. Give any two applications.

Ans:

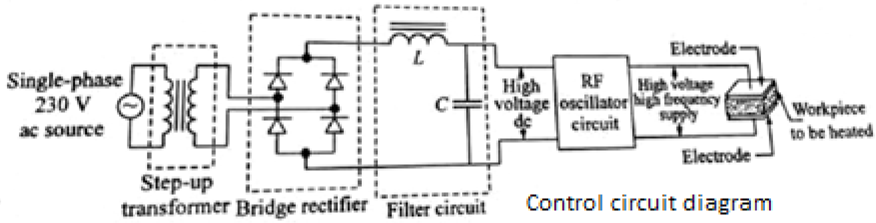
Principal of dielectric heating:

1) 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".
2) 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

2 marks for principle

internal molecular friction generates heat uniformly throughout allparts 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.

3) Thyristors are used in 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.



1 mark for circuit diagram

Applications of dielectric heating

- Preheating of plastic performs
- Gluing of wood
- Baking of foundary cores
- Diathermy
- Sterlization
- Textile industry
- Electronic Sewing
- Food Processing
- Pasteurising milk
- Dehydrating of fruits

1 mark for any two applications

4 a) ii) State different method to control output voltage of inverter. Explain PWM method.

Ans:

Different method to control output voltage of inverter:

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.

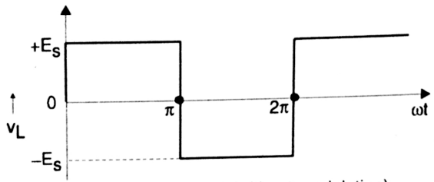
(iv) Obtaining controlled dc supply for inverter from chopper & filter arrangement.

2 marks for different methods

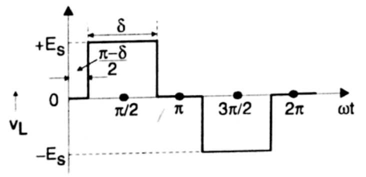
2) Internal Control: By controlling the operation of inverter itself – PWM technique

Pulse-Width-Modulation (PWM) Method:

The output voltage of single-phase bridge inverter is normally a square wave as shown in fig.(a). From Fourier analysis, it is seen that the square wave output contains odd



(a) Square wave output (without modulation)



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

harmonics. The amplitude of nth odd harmonic component in square wave is given by,

$$v_{Lnm\_sw} = \frac{4Es}{n\pi} \; for\ n = 1,3,5$$

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

2 marks for PWM method

$$v_{Lnm\_Qsw} = \frac{4Es \sin(\frac{n\delta}{2})}{n\pi} \; for\ n = 1,3,5$$

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

$$v_{Lnm\_sw} = \frac{4Es}{n\pi}$$

It is seen that if δ = 2 π/n, then $_{nm}\_Q_{sw}$ = 0. Thus by adjusting the pulse width δ equal to 2π/n rad particular nth harmonic can be eliminated.

e.g. if δ = 2 π/3, then $V_{L3m}\_Q_{sw}$ = 0, the third harmonic component is eliminated. Thus the harmonic reduction is possible using single-pulse-modulation.

(NOTE: Examiners are requested to award marks for explanation of any PWM method)

4 a) iii) Differentiate between three phase & single phase converter on the basis of efficiency, ripple factor, RMS values and average values.

Ans:

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 = $\sqrt{\left[\frac{\pi^2}{9cos^2\alpha}\left(\frac{1}{2} + \frac{3\sqrt{3}}{4\pi}cos2\alpha\right) - 1\right]}$ Less voltage ripple factor for same firing angle.	RF = $\sqrt{\left[\frac{\pi^2}{8cos^2\alpha} - 1\right]}$ More voltage ripple factor for same firing angle.
RMS Values	With continuous conduction and without free-wheeling	With continuous conduction and without free-wheeling

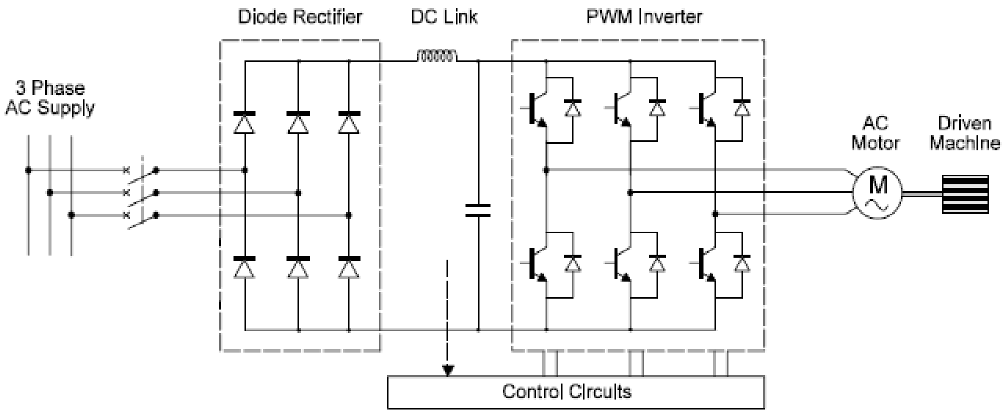
1 mark for each point = 4 marks

	diode, the output rms voltage depends on the firing delay angle α. $V_{rms} = \sqrt{3}V_m\left[\frac{1}{2}+\frac{3\sqrt{3}}{4\pi}cos2\alpha\right]^{\frac{1}{2}}$	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. $V_{dc} = \frac{2V_m}{\pi}cos\alpha$

4 a) iv) Draw the circuit diagram & explain the variable frequency control of induction motor.

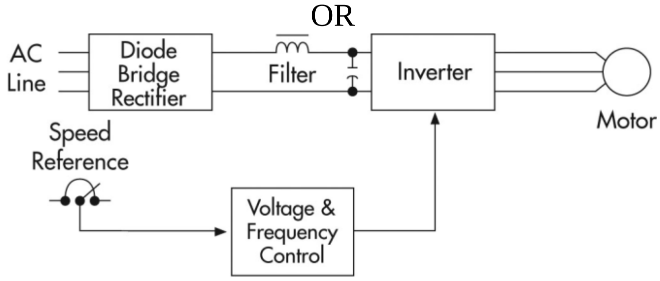
Ans:

Variable frequency control of induction motor



2 marks for circuit diagram

OR



Variable frequency control of induction motor:

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,

2 marks for explanation

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

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

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

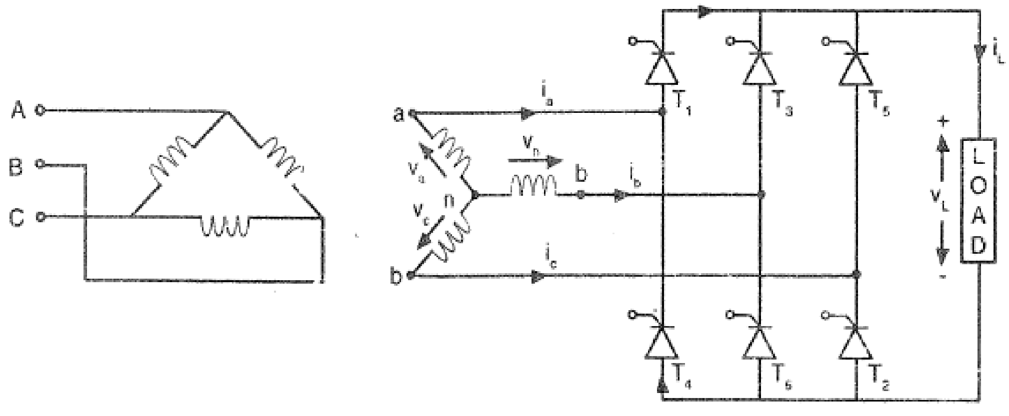
With a Square wave inverter indicated in figure, the supply frequency to the motor can be easily adjusted for variable speed. However, if rated airgap flux is to be maintained at its rated value at all speeds, the supply voltage to the motor should be varied in proportion to the frequency. In the figure, the dc voltage obtained from diode rectifier remains constant, however, properly firing the switching devices of inverter, the voltage and frequency can be controlled within the inverter. The firing pulses to switching devices are supplied according to the requirement of speed.

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

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

Ans:

Three Phase full controlled bridge converter with R Load:



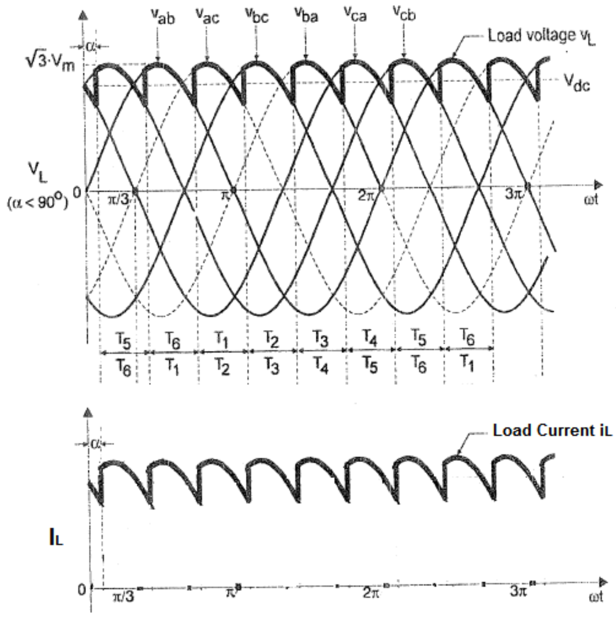
(a) Circuit arrangement

2 marks for circuit diagram

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 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 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).



(b) Waveforms

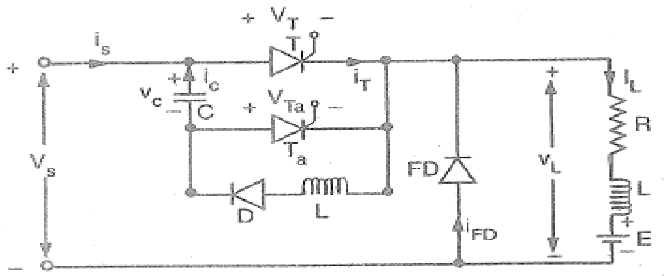
2 marks for waveform

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).

4 b) ii) Sketch circuit diagram of auxilary commutated chopper. Expain its operation using related waveform**.**

Ans:

<u>Auxillary commuted chopper:</u>

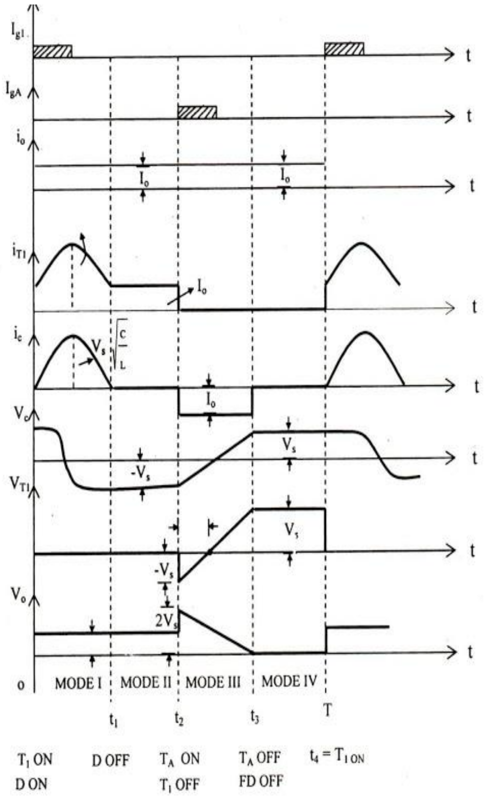


Voltage-commutated chopper

2 marks for circuit diagram

The fig. shows the circuit arrangement of voltage commutated chopper employing auxiliary commutation. At start, the Ta 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 Ta 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 Ta. Thus when Ta 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



2 marks for waveforms

5 Attempt any FOUR of the following: 16

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

Ans:

SCR Triggering Methods:

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

1 mark for classification

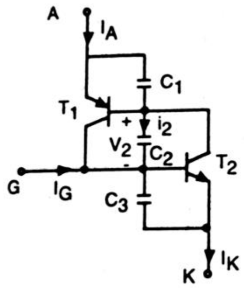
1) Forward Voltage Turn-on:

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

3 marks for explanation of any one method

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

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



Two-traisistor transient model of thyristor

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

where, C_2 = capacitance of junction J_2

V_2 = voltage across junction J_2

q_2 = charge in the junction J_2

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

3) Temperature:

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

4) Gate Turn-on:

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

5) Radiant Energy (Light) Turn-on:

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

5 b) State the criteria for selection of single phase and three phase inverter for required application.

Ans:

Selection criterion of Single-phase & Three-phase Inverter for required application:

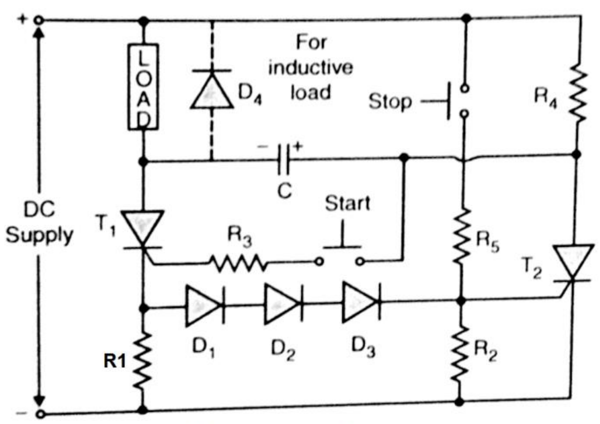
Criteria	Single phase inverter	Three phase inverter
Load terminals	Only one pair of load terminals.	Three phase load terminals. (3 or 4 terminals)
Pole voltages	The pole voltages of the single phase inverter are phase apart by 180° each	The pole voltages of the 3-phase inverter are phase apart by 120° each
Application	Single-phase inverter is used for low-range power applications VSIs cover the medium- to high power applications	Three-phase inverter is used for medium- to high-power applications
Output	Produces a square shape single phase AC output with a DC input.	Produces three phase stepped AC output with a DC input.
No. of switches	There are two or four valid Switches.	There are the six valid switches.

1 mark for each of any four points = 4 marks

5 c) Describe the circuit diagram and 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

2 marks for explanation

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

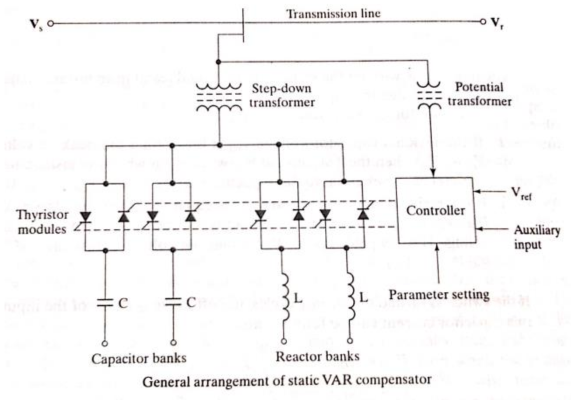
The load current can be automatically interrupted under overload condition. With T_1 on and carrying load current, if overload occurs, the voltage drop across R_1 exceeds the forward voltage drop of string of diodes D_1, D_2, D_3 and gate-cathode junction of T_2. Therefore, gate current is provided to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

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

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.



General arrangement of static VAR compensator

2 marks diagram

- 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.

2 marks description

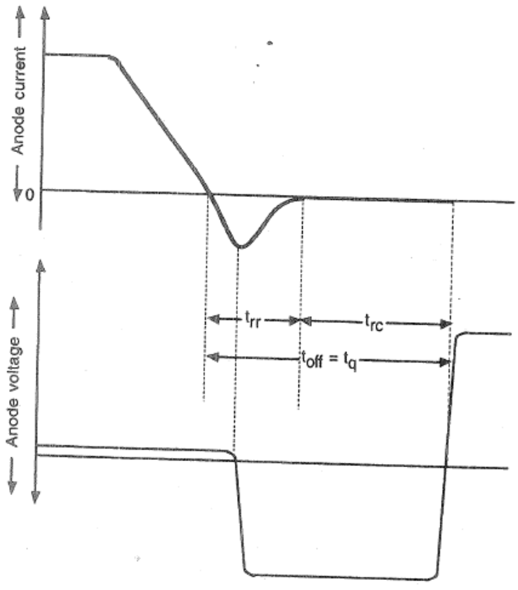
- During peak load condition, most of the loads are inductive and they demand the reactive power. In this situation, TSC is used to insert capacitors in power system to generate the reactive power.
- In fact, SVC comprises combinations like (TCR+TSC), (TCR+FC) as per the need.
- In TCR, phase control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

5 e) Explain the SCR turn off preocess with waveforms of voltage and current.

Ans:

SCR Turn-off Process:

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



Dynamic turn-off characteristics

1 mark for diagram

3 marks for explanation

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

Reverse Recovery Time (t_{rr}): It is the time required to recover (remove) the stored charge (extra carriers) from the vicinity of junctions J_1 and J_3.
At the end of reverse recovery time, the junction J_1 and J_3 are recovered, but junction J_2 still has trapped charges. The SCR can block forward voltage only when this excess carriers at junction J_2 recombine.

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

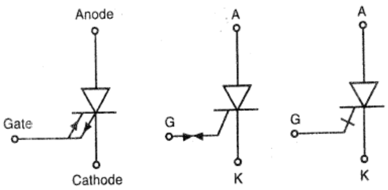
Turn-off Time (t_q): It is the minimum value of time interval between the instant when the on-state current has reduced to zero to the instant when the SCR is capable of withstanding forward voltage.i.e $t_q = t_{rr} + t_{rc}$

5 f) Draw symbol and characteristics of GTO, LASCR, Power semiconductor and its application.

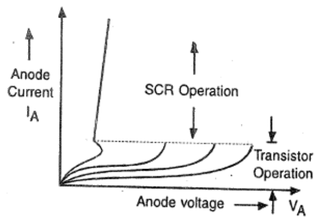
Ans:

1) GTO:

2 marks



GTO Symbols

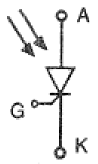


V-I characteristics of GTO

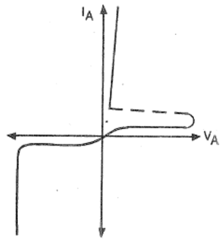
Application: AC/DC machine drives, UPS, Static VAR compensators, induction heating, Photo-voltaic and fuel cell converters.

2) LASCR:

2 marks



LASCR symbol



v-i characteristic of LASCR

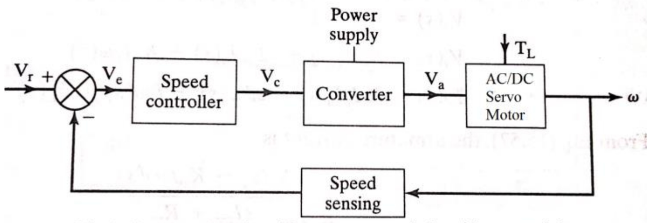
Applications: Static VAR compensators, HVDC

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

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

Ans:

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.

1 mark for block diagram

3 marks for explanation

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

6 b) Write the specifications/rating of SCR.

i) Voltage iii) Power

ii) Current iv) Temperature

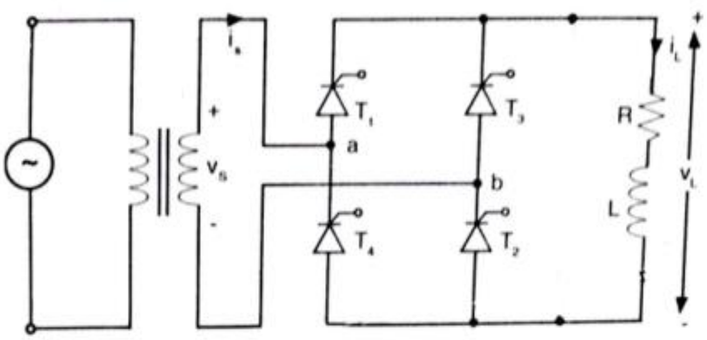
Ans:

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}
   - iv) Peak working reverse voltage V_{RWM} 1 mark for each bit = 4 marks
   - 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

6 c) Draw circuit for single phase full wave converter with RL load and draw its load voltage and current waveform.

Ans:

Single phase fully controlled bridge converter with RL load:



(a) Circuit arrangement

1 mark for circuit diagram

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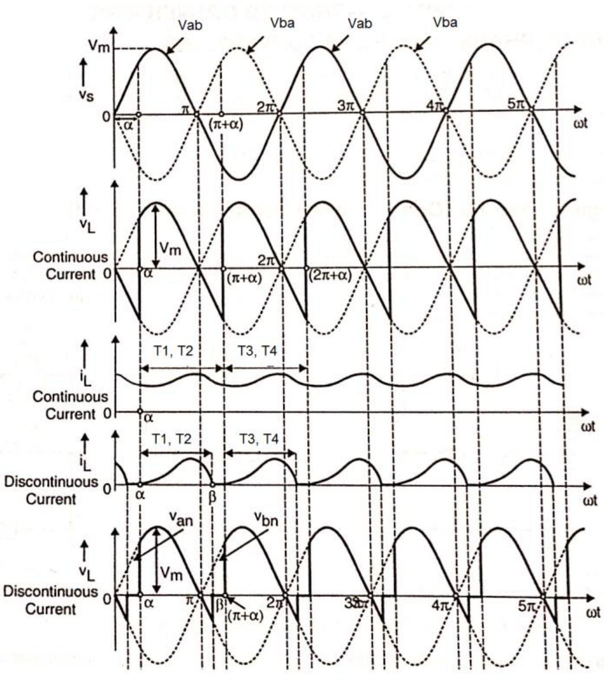


(b) Waveforms

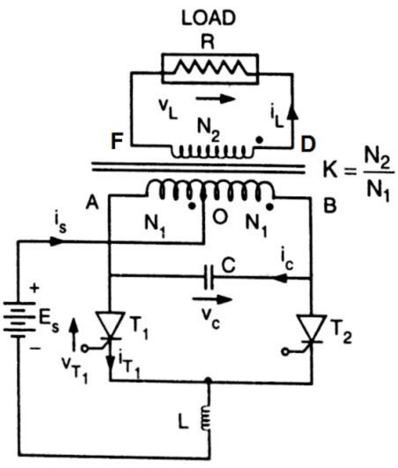
3 marks for waveforms

6 d) Draw and describe the operation of parallel inverter.

Ans:

Basic 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.



(a) Circuit arrangement

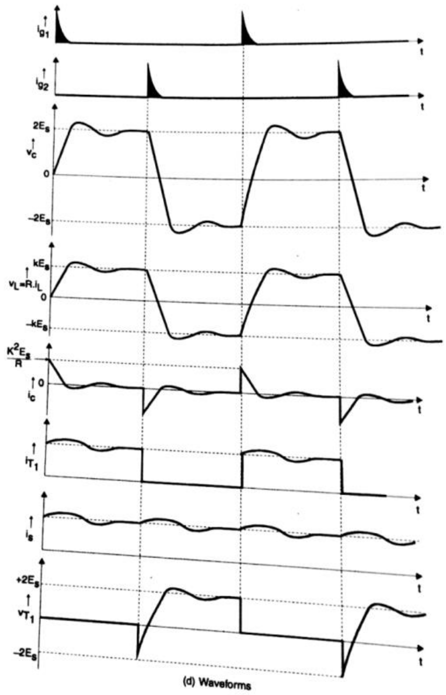
2 marks for circuit diagram

2 marks for operation = 4 marks

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

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

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



(d) Waveforms

6 e) State the meaning of commutation. Explain class B method of commutation.

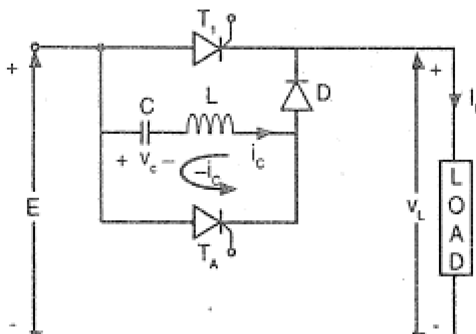
Ans:

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

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 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

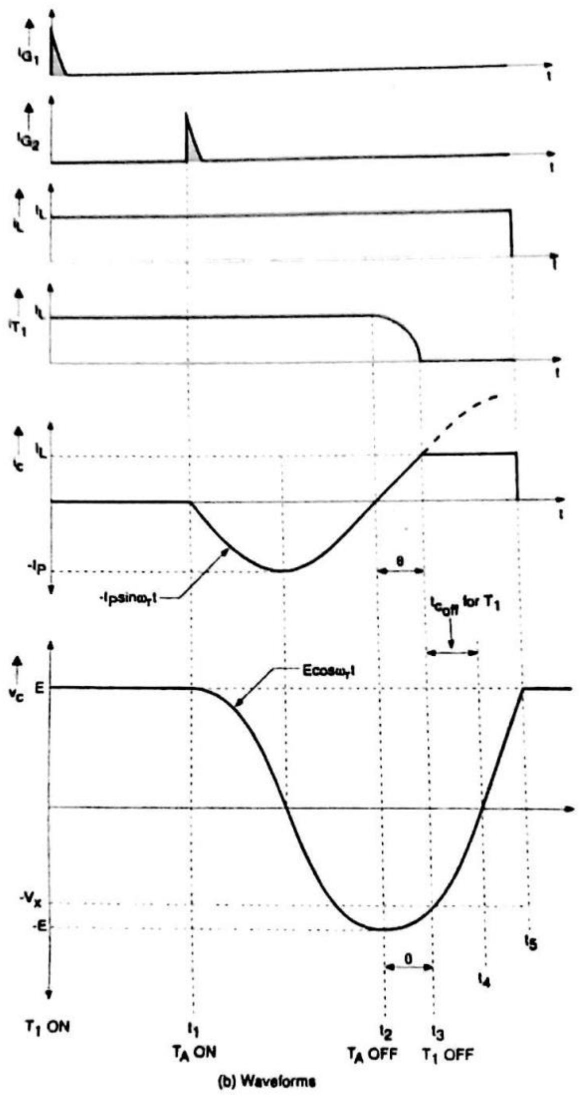


(a) Circuit diagram

1 mark for circuit diagram

2 marks for Description = 4 marks

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.



(b) Waveforms

Class B - Resonant Pulse Commutation

Waveforms are optional

6 f) Discuss the working of a load commutated chopper with relevant voltage and current waveform.

Ans:

Load-commutated chopper:

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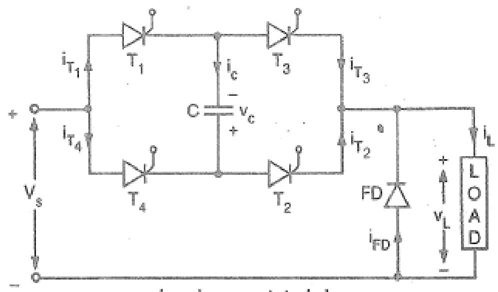


Load commutated chopper

1 mark for circuit diagram

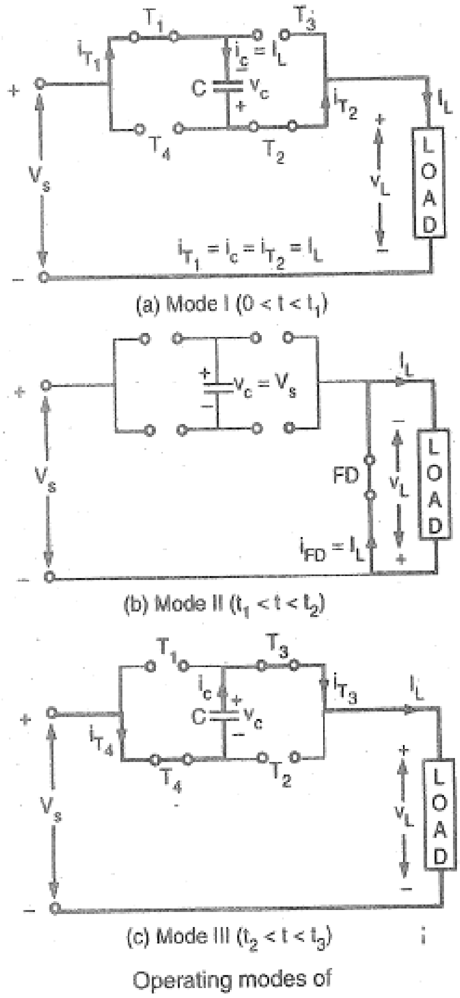
The circuit diagram, operating modes and waveforms of Chopper employing load commutation are shown in the figure. When T_1 T_2 are on, the capacitor charges with upper plate positive and when T_3 T_4 are on, the capacitor charges with lower plate positive to supply voltage V_s by the load current. Prior 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.

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 Description

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.



Operating modes of load commutated chopper

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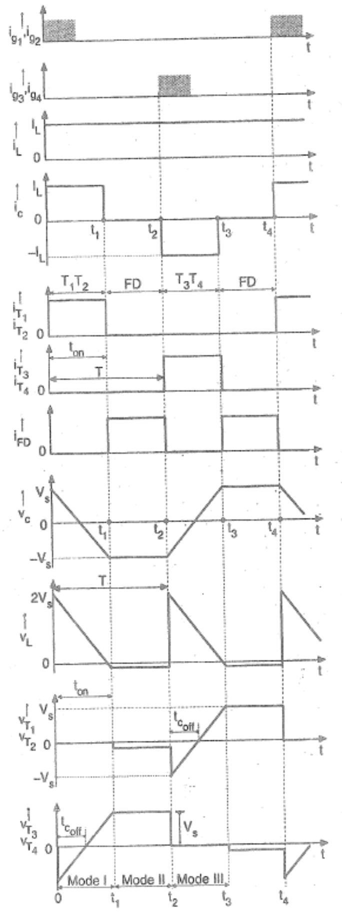
Waveforms of load commutated chopper

1 mark for waveforms

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