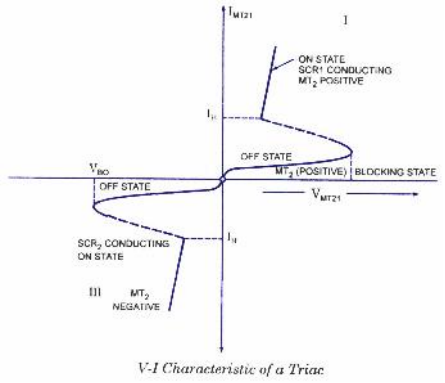
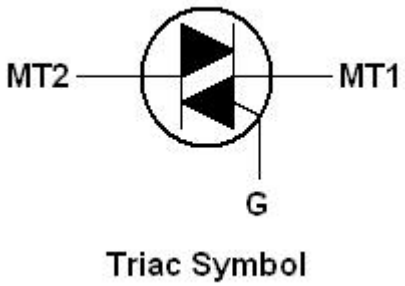
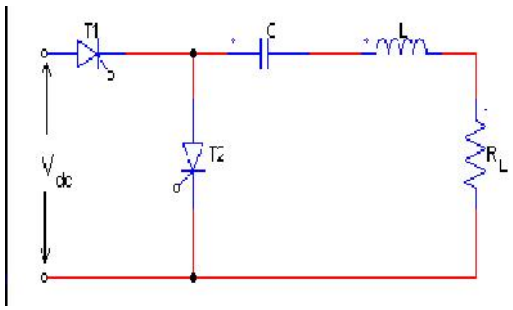
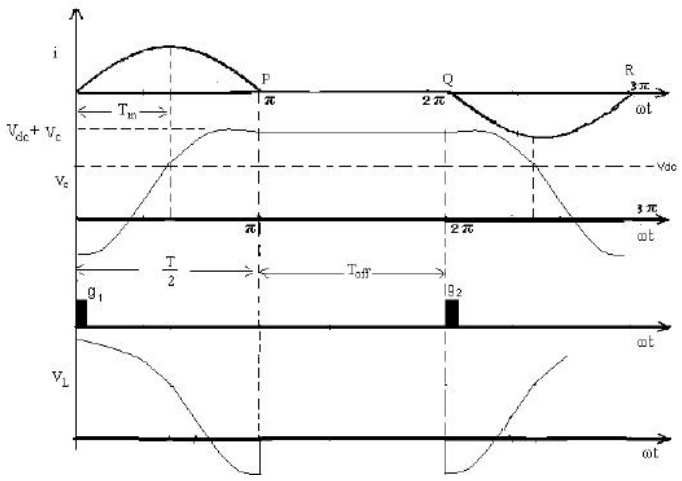
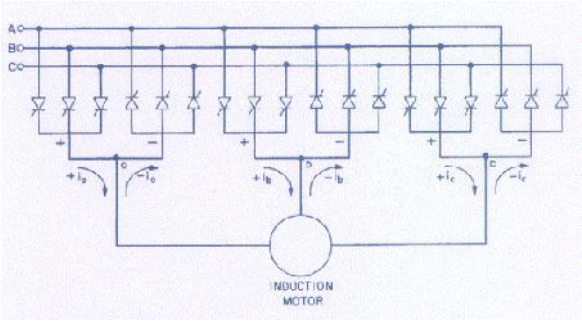
Important suggestions to examiners:

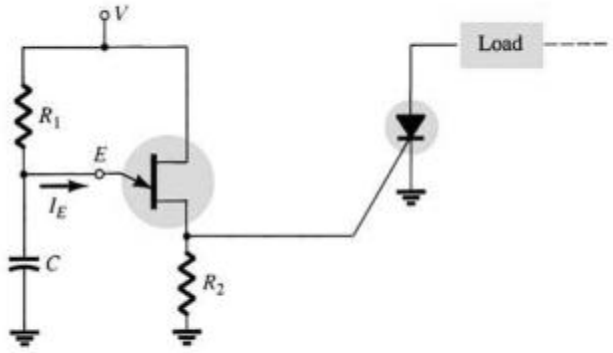
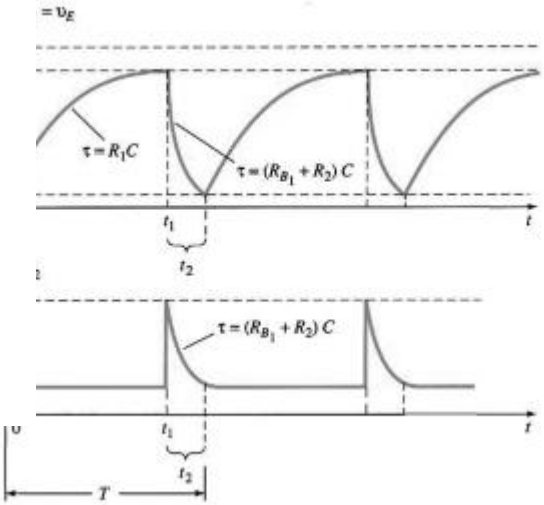
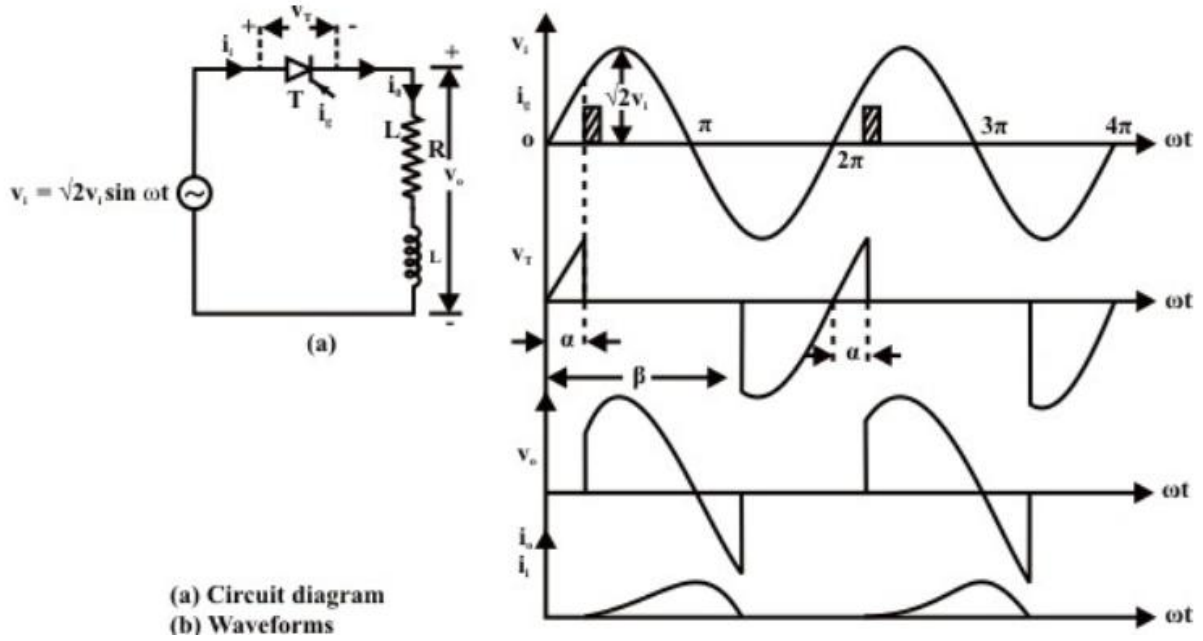
1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner may try to assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling errors should not be given more importance.
4) While assessing figures, examiner may give credit for principle components indicated in a 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) Some of the questions are not clearly indicative of the exact answer expected. In such cases, credit may be given by judgment of relevant answer based on candidate's understanding.

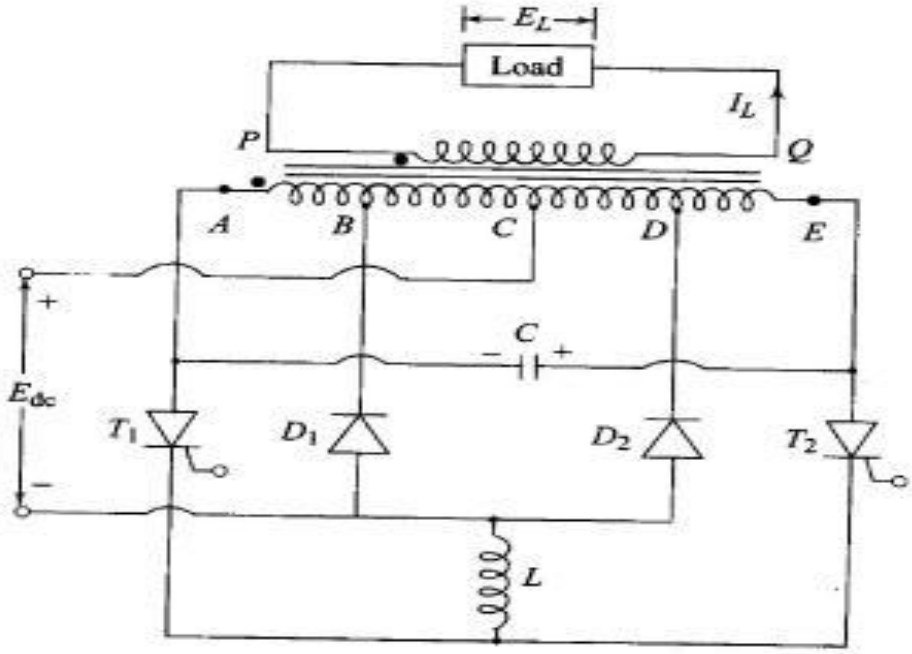
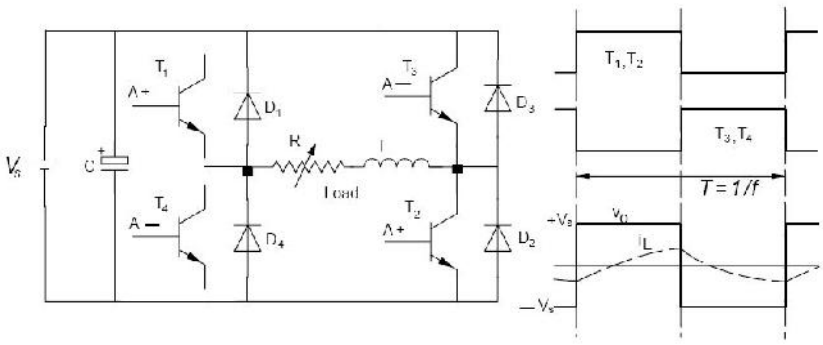
Q1. A) a) Draw a symbol and V-I characteristics of TRIAC. Label various points on the characteristics	4
 V-I Characteristic of a Triac  Triac Symbol	1+3
Q1. A) b) List the turn-on methods of thyristor and explain any three of them	4
Different turn-on methods: Turn-on by exceeding the breakover Voltage Turn-on by leakage current(thermal triggering) Turn-on by dV/dt Turn-on by gate triggering Any one explanation may be given credit	2 2
Q1. A) c) What is converter ? List the types of converter. State the function of freewheeling diode in converters.	4
Converter is a power electronic circuit which converts AC into DC. Different types of converters 1) 1ph 3ph. Uncontrolled converter 2) 1ph/3ph semiconverter	1 2

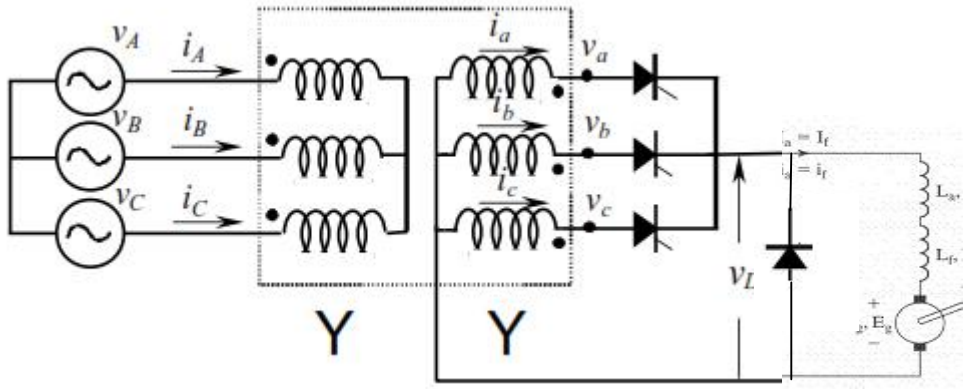
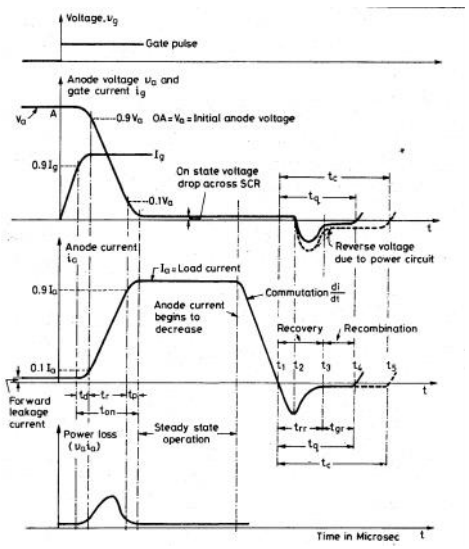
3) 1ph/3ph fully controlled converter Function of freewheeling diode: Freewheel diodes are used across inductive components such as coils to prevent voltage spikes when the power is turned off to the devices. It is used to bypass the stored energy in inductive elements when the switching device is turned off. When power to inductive loads such as coils and inductors is turned off, there is a sharp voltage spike. The direction of this voltage is opposite to the applied voltage in accordance with Lenz's Law. This places the FWD in forward bias.	1
Q1 A) d) With the help of a neat circuit diagram, explain the working principle of basic series inverter.	4
Mode - 1 • Due to under-damped circuit, load current is of alternate in nature. • T1 triggered – C charges to Vc • After some time vc returns to zero • Current decreases but capacitor voltage retains its voltage. (Vdc+Vc) • At "P", SCR T1 turned OFF since current though it is zero Mode - 2 • Load current remains at zero – T1 and T2 are OFF • During this period (PQ) Vc remains constant.   	1 1+2

Q1 B) a) State the methods of speed control of three phase induction motor. Explain how the speed of three phase induction motor is controlled using cycloconverter ?	6
Different methods of speed control of three phase induction motor: Changing applied voltage Rotor resistance control Pole changing schemes Stator frequency control	2
	2
The control of speed is achieved by v/F control(relevant explanation)	2
Q1 B) b) Give classification of single phase and three phase inverter. State the necessity of control of output voltage of an inverter.	6
Nature of source 1) Voltage Source Inverter 2) Current Source Inverter Inverter configuration 1) Series Inverter 2) Parallel Inverter 3) Bridge Inverter Nature of output waveform 1) Square wave 2) Quasi square 3) PWM Inverter 4) Pure sine wave inverter Commutation Circuit 1) Auxiliary commutated 2) Complimentary commutated (credit may be given for any three classifications)	3

Necessity of control of output voltage of an inverter. 1) To compensate for the input voltage variations 2) To compensate for the regulation of the inverter 3) To supply such loads which needs controlled voltage supply (Any other relevant information)	3
Q2 a) List and explain any four specifications and ratings of thyristor	4
CURRENT RATINGS OF SCR • Surge Current Rating (I_{FM})—The surge current rating (IFM) of an SCR is the peak anode current an SCR can handle for a short duration. • Latching Current (I_L)—A minimum anode current must flow through the SCR in order for it to stay ON initially after the gate signal is removed. This current is called the latching current (I_L). • Holding Current (I_H)—After the SCR is latched on, a certain minimum value of anode current is needed to maintain conduction. If the anode current is reduced below this minimum value, the SCR will turn OFF. VOLTAGE RATINGS OF SCR • Peak Repetitive Reverse Voltage (V_{RRM})—The maximum instantaneous voltage that an SCR can withstand, without breakdown, in the reverse direction. • Peak Repetitive Forward Blocking Voltage (V_{DRM})—The maximum instantaneous voltage that the SCR can block in the forward direction. If the VDRM rating is exceeded, the SCR will conduct without a gate voltage. • Nonrepetitive Peak Reverse Voltage (V_{RSM})—The maximum transient reverse voltage that the SCR can withstand. • Maximum Gate Trigger Current (I_{GTM})—The maximum DC gate current allowed to turn the SCR ON. • Minimum Gate Trigger Voltage (V_{GT})—The minimum DC gate-to-cathode voltage required to trigger the SCR. **(Any four specifications be given credit)**	1X4

Q2 b) With the help of a neat circuit, explain UJT triggering method.	4
The UJT is commonly used as a triggering SCR. The SCR shown is triggered when the UJT emitter circuit conducts. As the capacitor charges, V_E increases. When it reaches V_P, the UJT fires. The voltage developed across R_2 triggers the SCR.  	1 1+2
Q2 c) Draw a neat circuit and associated waveforms of a single phase fully controlled half wave converter with RL load.	4
 (a) Circuit diagram (b) Waveforms	2+2

Q2 d) What is meant by series inverter and parallel inverter ? Draw a neat circuit of basic parallel inverter.	4
In series inverter, position of commutating components is connected in series with load. In parallel inverter, commutating capacitor is placed in parallel with load. Parallel inverter  	1 3
Q2 e) With a neat circuit, explain the working of single phase full bridge inverter.	4
 In full bridge inverter, four switches are connected to form H-bridge. When T1 T2 are ON , the output voltage is $+v_{dc}$ and when T3 T4 are ON, the output voltage is $-V_{dc}$. DC side is constant voltage, low impedance (voltage source, or bulk cap) AC side voltage is square wave or quasi-square wave. AC side current is determined by the load. Anti-parallel diodes are necessary to provide energy feedback path.	2+1 1

Q2 f) What is DC drive ? Draw a neat circuit diagram to control the speed of DC series motor with three phase half converter.	4
DC drive is a power electronic converter based circuit to control the a speed, tension and current on a Direct Current Motor (DC Motor)  	1 3
Q3. a) Explain, in detail the turn-off process of thyristor.	4
A conducting thyristor is turned off when the anode current goes below its holding current. The total turn off time is summation of reverse recovery and recombination time. If forward voltage is applied to the SCR at the moment its anode current falls to zero, the device will not be able to block this forward voltage as the carriers (holes and electrons) in the four layers are still favourable for conduction. The device will therefore go into conduction immediately even though gate signal is not applied. It is essential that the thyristor is reverse biased for a finite period after the anode current has reached zero. The turn-off time tq of a thyristor is defined as the time between the instant anode current becomes zero and the instant SCR regains forward blocking capability. The turn-off time is divided into two intervals ; reverse recovery time trr and the gate recovery time tg r ; i.e. $t_q = t_{rr} + t_{gr}$.  	2+2

Q3 b)Compare: three phase converter with single phase converter (any four points). 4

Single phase converter	Three phase converter	1x4
No. of phases -1	3	
No. of SCRs—4	6	
Load Power –upto 2KW	Above 2KW	
Ripple factor-low	Better than single phase	
PIV-lower	Higher than single phase	
Additional filter-required	Not required	
Quality of dc op-poor	better	

Q3 c) Explain the pulse width modulation method with respect to single phase inverter. 4

In this method a fixed d.c. voltage is supplied to inverter controlled a.c. output voltage is obtained by adjusting the ON-OFF periods of inverter devices.

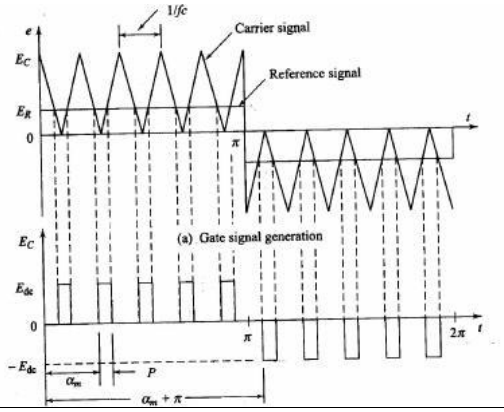
The reference signal is compared with the triangular carrier and the device switching signals are generated.

The commonly used PWM control techniques are.

1. Single pulse width modulation
2. Multiple pulse width modulation
3. Sinusoidal pulse width modulation

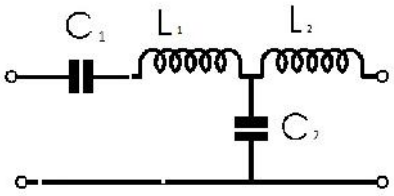
Advantages:-

1. Additional components are not required.
2. Lower order harmonics can be eliminated.

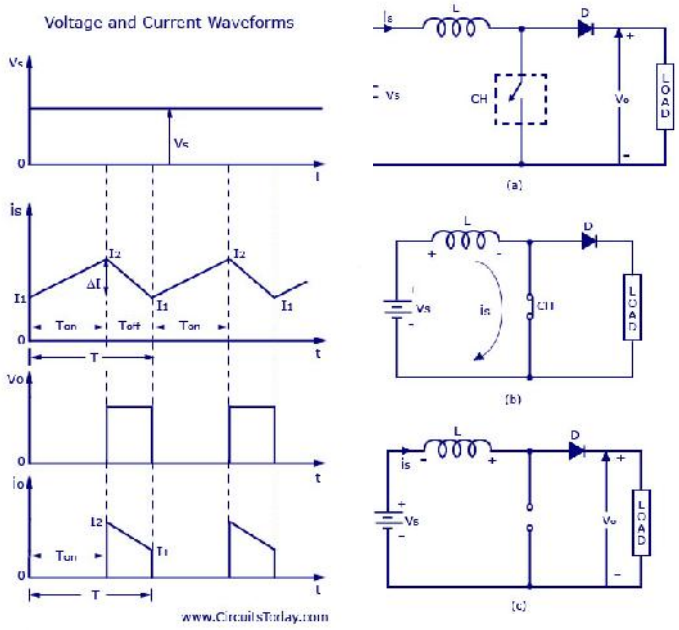
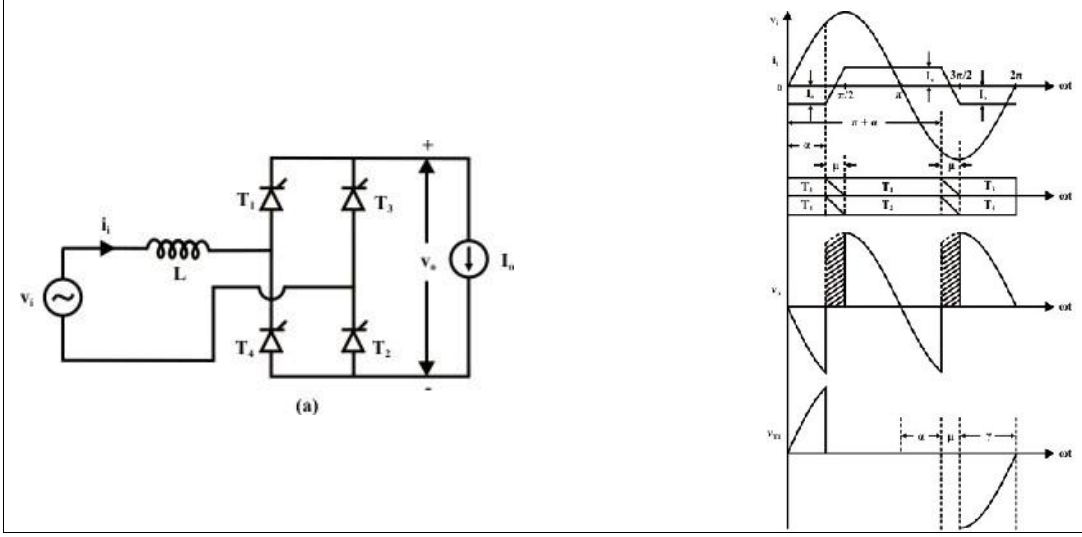


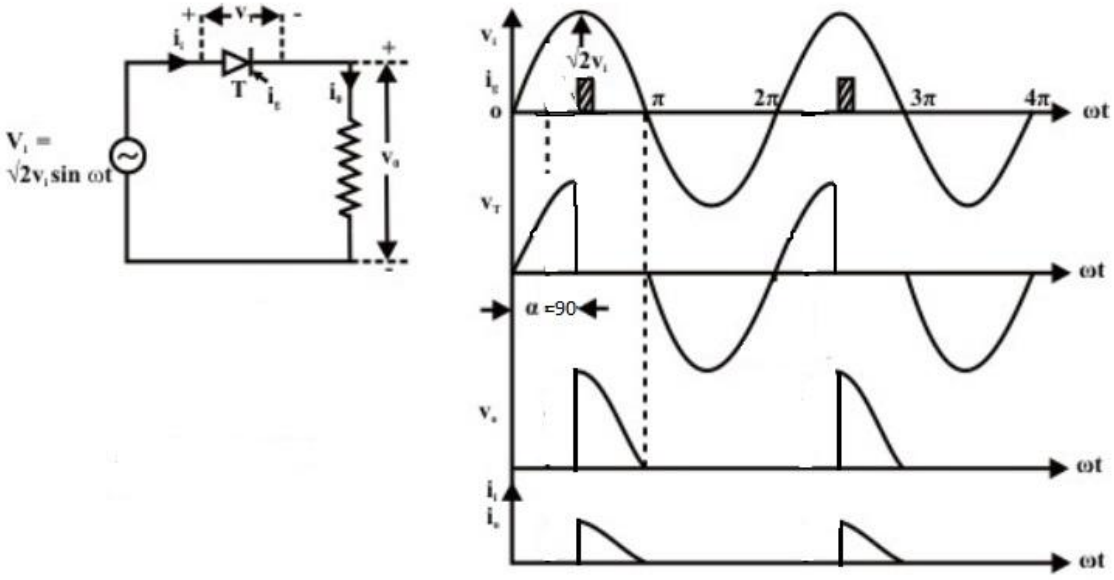
Q3 d) With a neat circuit, explain the working and use of OTT filter. 4

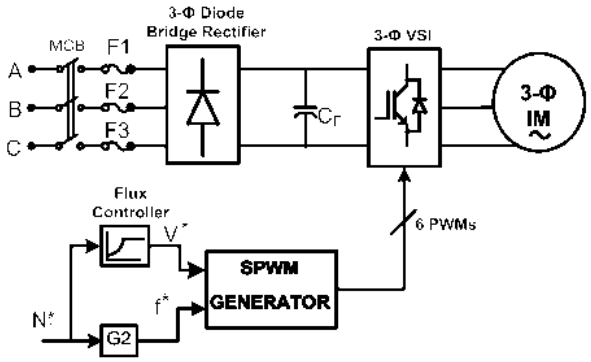
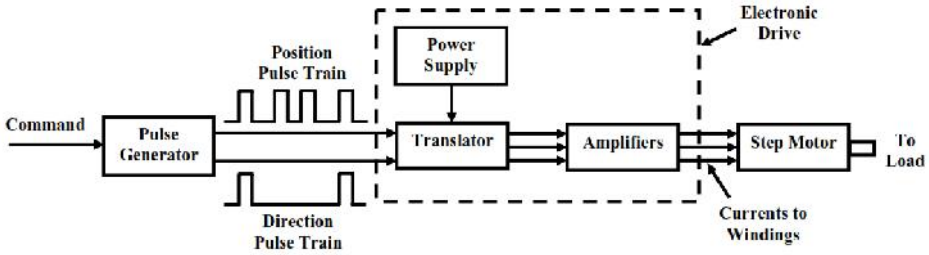
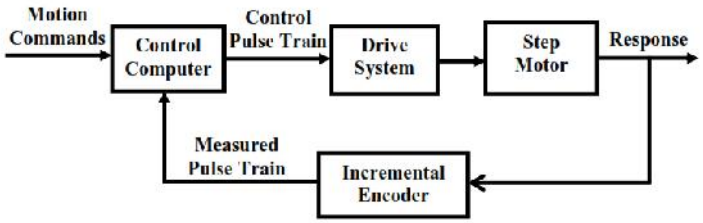
OTT filter provides a sinewave output by eliminating harmonic content of the inverter output. It provides good load regulation at the same time maintaining capacitive load to the inverter over a large range of load power factor. 2

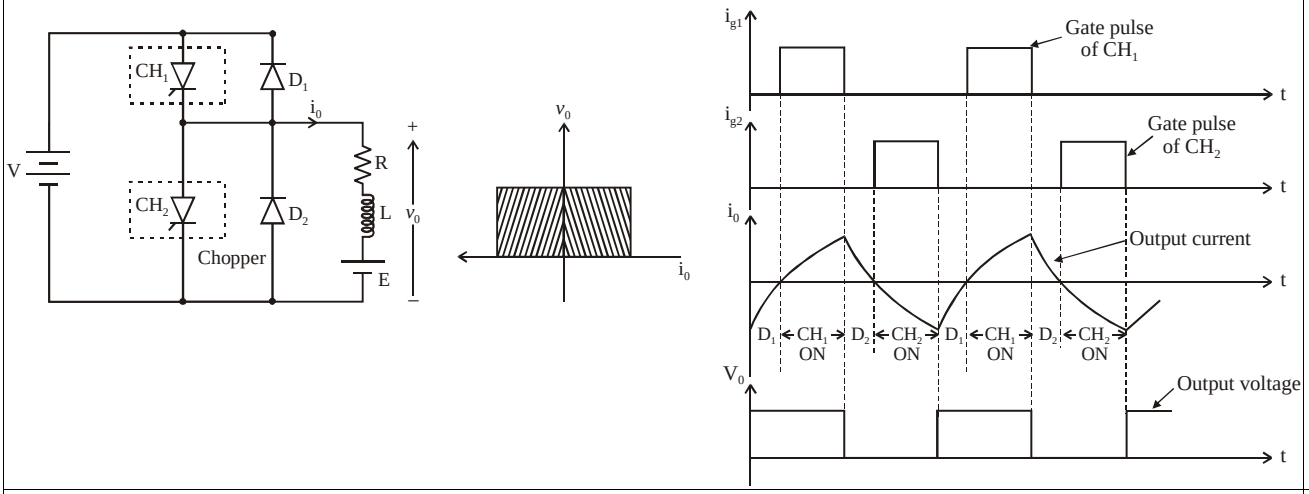
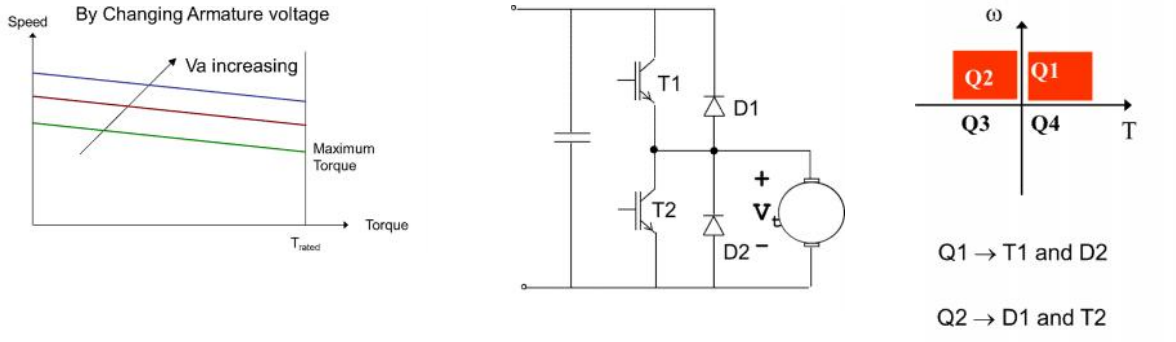


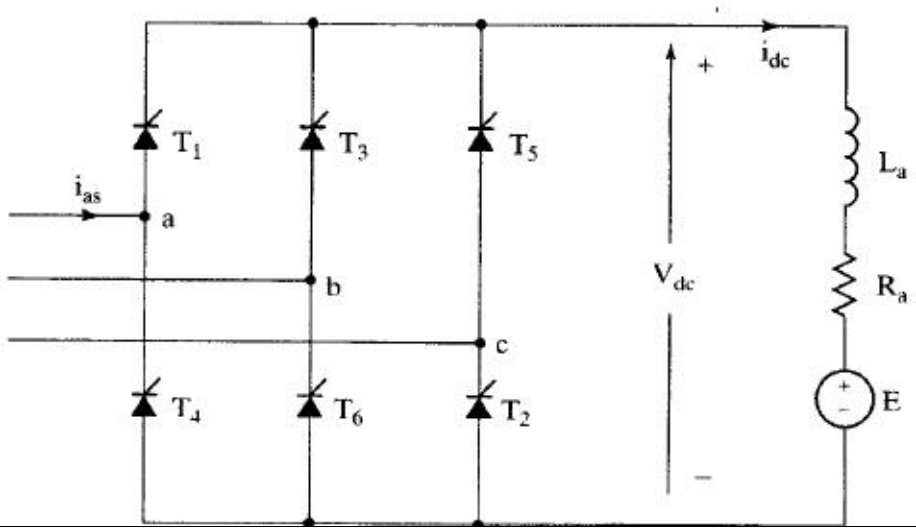
2

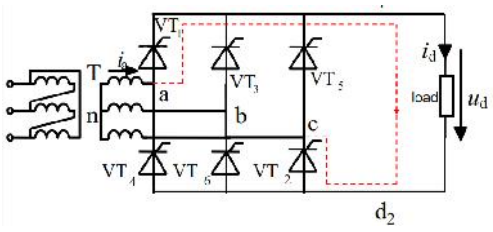
Q3 e) Draw a neat circuit and explain the working of step up chopper	4
Step –up chopper is used to step up the output dc voltage. Mode1: In step-up chopper a large inductor, L is in series with the source voltage V_s. This forms a closed path as shown in the figure (b). During the time period T_{on} the chopper is on. The inductor stores energy. When the chopper is turned off the current is forced to flow through the diode and load for a time T_{off} and as the inductor current cannot die suddenly. When the current decreases the polarity of the emf induced in L is reversed. Fig (c). As a result the total voltage available across the load is given by the equation $V_0 = V_s + L\ (di/dt)$. The voltage V_0 exceeds the source voltage and hence the circuit acts as a step-up chopper and the energy which is stored in L is released to the load. 	2+2
Q4 A) a) Explain the effect of source impedance on the working of converter.	4
Source inductance does have significant effect on the performance of the converter. With source inductance present the output voltage of a converter does not remain constant for a given firing angle. Instead it drops gradually with load current. The converter output voltage and input current waveforms also change significantly. Because of source impedance(inductance), thyristor commutation is delayed(overlap angle) which gives rise to drop in output voltage. 	2+2

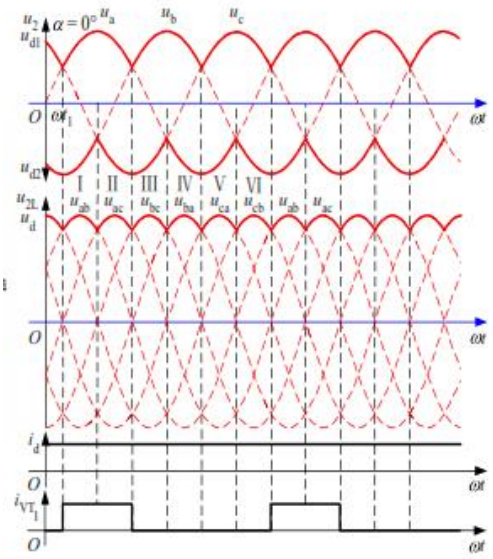
Q4 A) b) With a neat circuit diagram, explain the working principle of single phase fully controlled half wave converter with resistive load. Draw the waveform across load for firing angle 90°.	4
At ωt = 0 when the input supply voltage becomes positive the thyristor T becomes forward biased. It does not turn ON till a gate pulse is applied at ωt = α. During the period 0 < ωt ≤ α, the thyristor blocks the supply voltage and the load voltage remains zero. No load current flows during this interval. As soon as a gate pulse is applied to the thyristor at ωt = α, it turns ON. The voltage across the thyristor collapses to almost zero (forward voltage drop across thyristor) and the full supply voltage appears across the load. From this point onwards the load voltage follows the supply voltage. The load being purely resistive the load current I is proportional to the load voltage. At ωt = π as the supply voltage passes through the negative going zero crossing the load voltage and hence the load current becomes zero and tries to reverse direction. In the process the thyristor undergoes reverse recovery and starts blocking the negative supply voltage. Therefore, the load voltage and the load current remains clamped at zero till the thyristor is fired again at ωt = 2π + α.  	2+2
Q4 A) c) What is cycloinverter ? Explain the principle of operation of single phase cycloinverter.	4
A cyclo-converter converts ac input power at one frequency to ac output power at a lower frequency whereas a cyclo-inverter converts ac input power at one frequency to ac output power at a higher frequency. The operation of cyclo-inverter is same as that of cyclo-converter.	

Q4 A) d) Explain how the speed of three phase induction motor is controlled with variable frequency PWM, VSI	4
The reference speed input command (N_r^*) the reference frequency (f^*) and reference voltage (V^*) commands are calculated such that V/f ratio maintained to be constant. The reference commands V^* and f^* are given to the SPWM generator to generate 6-PWM pulses to the three-phase voltage source inverter which drives the three-phase induction motor.  	2+2
Q4 B) a) What is open loop control and closed loop control of stepper motor ? Explain in detail	6
The command to the pulse generator sets the number of steps for rotation and direction of rotation. The pulse generator correspondingly generates a train of pulse. The Translator is a simple logical device and distributes the position pulse train to the different phases. The amplifier block amplifies this signal and drives current in the corresponding winding. The direction of rotation can also be reversed by sending a direction pulse train to the translator. After receiving a directional pulse the step motor reverses the direction of rotation. The major disadvantage of the open loop scheme is that in case of a missed pulse, there is no way to detect it and correct the switching sequence.  	3
In closed loop control, it does not allow any pulse to be missed and a pulse is send to the driving circuit after making sure that the motor has rotated in the proper direction by the earlier pulse sent. In order to implement this, we need a feedback mechanism that will detect the rotation in every step and send the information back to the controller. The incremental encoder is used for measuring actual rotor angular position.  	3

Q4. B) b) With the help of neat circuit diagram and necessary waveforms, explain class C chopper.	4
Class C Chopper is a combination of Class A and Class B Choppers. For first quadrant operation, CH1 is ON or D_2 conducts. For second quadrant operation, CH_2 is ON or D_1 conducts. When CH_1 is ON, the load current is positive. The output voltage is equal to 'V' & the load receives power from the source. When CH_1 is turned OFF, energy stored in inductance L forces current to flow through the diode D_2 and the output voltage is zero.	1
	1+2
Q5 a) With the help of neat circuit diagram, explain how the speed of DC motor be controlled with: i) Step up chopper and ii) Three phase full controlled converter.	8
For DC motor, $E_b = Ke \times ¤ \times wm$ $V_{dc} = E_b + I_a \times R_a$ $T_e = K_e \times ¤ \times I_a$ Where E_b is back emf., I_a is armature current, ¤ is flux	2
The control of dc motor can be achieved by using a chopper 	2

For three phase full controlled converter drive, the armature voltage is $E_a = \frac{3\sqrt{3}}{®} E_m \cos\sim$ The average speed is $N = \frac{E_a - i_a R_a}{K_a ¤}$  	2 2
Q5. B) Draw neat circuit diagram and associated waveforms of three phase fully controlled bridge converter with RL load. Explain the working of the same. State advantages of three phase converter	8
In three phase fully controlled bridge converter, there are six thyristors resulting in 6-pulse operation.T_1, T_3, T_5 forms the positive group and T_4, T_6,T_2 form negative group. The positive group are turned on when supply voltages are positive. T_4,T_6,T_2 when negative. Each SCR can conduct for 120^0. The phase shift between two adjescent SCRs is 60^0. At any instant two SCRs can conduct and there are six such pairs. The firing angle is measured from wt =30^0 onwards. When the load inductance is large, then the load current is continuous. When the alpha is greater than 60, the load voltage is negative because of inductive nature of the load. Advantages of three phase full controlled converter 1) Higher output power 2) Lower ripple content 3) Higher ripple frequency 4) Low harmonics in the input supply	3





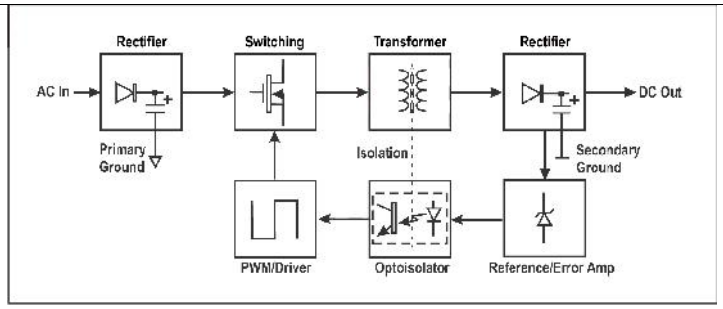
Note: The waveforms are tedious to draw.

Examiner is requested to assess understanding

level of the candidate

5

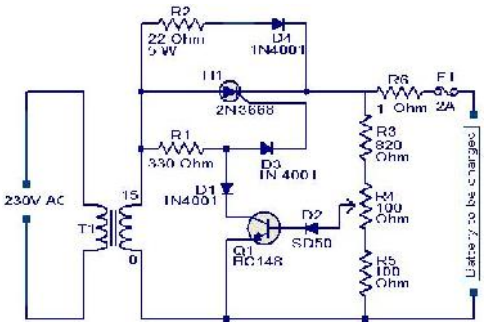
Q5 c. What are the various power electronic applications ? Explain in brief any two of them	4
Power electronics applications 1) Industrial Applications Such as AC DC drives, Converters Inverters for industrial application such as furnaces, rolling, textile mills, welding, Regulated DC power supplies, SMPS, battery chargers, Electric Vehicles 2) Electrical Transmission, Distribution systems STATIc VAr compensation, Active filters, Load balancing equipment, HVDC systems, FACTs devices 3) Domestic Applications Airconditioning, cooking appliances, UPS systems, Mobile chargers, Power supplies, LED lighting systems, light dimmers 4) Aerospace applications Satellite power supplies, aircraft power systems 5) Commercial application Advetising boards, Refirgeration, computers and office equipment. Switched mode power supply 1. A rectifier stage which produces a smoothed DV voltage directly from the incoming AC mains supply. 2. A regulator stage which uses a high voltage switch, usually a power FET to generate a variable AC voltage into the transformer primary, driven by a PWM oscillator. 3. The transformer to provide both power conversion and isolation between the primary AC mains input side of the power supply and the secondary side of the transformer. The secondary side is connected to the equipment. 4. A low voltage rectifier stage to convert the secondary AC voltage to the required secondary DC voltage.	4 2



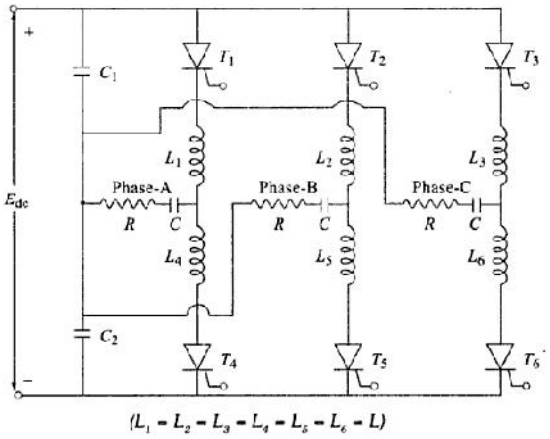
Battery charger circuit

A simple battery charger based on SCR is shown here.Here the SCR rectifies the AC mains voltage to charge the battery.When the battery connected to the charger gets discharged the battery voltage gets dropped.This inhibits the forward biasing voltage from reaching the base of the transistor Q1 through R4 and D2.This switches off the transistor.When the transistor is turned OFF,the gate of SCR (H1) gets the triggering voltage via R1 & D3.This makes the SCR to conduct and it starts to rectify the AC input voltage.The rectified voltage is given to the battery through the resistor R6(5W).This starts charging of the battery. 2

When the battery is completely charged the base of Q1 gets the forward bias signal through the voltage divider circuit made of R3,R4,R5 and D2.This turns the transistor ON.When the Q1 is turned ON the trigger voltage at the gate of SCR is cut off and the SCR is turned OFF.In this condition a very small amount of charge reaches the battery via R2 and D4 for trickle charging.Since the charging voltage is only half wave rectified ,this type of charger is suitable only for slow charging.For fast charging full wave rectified charging voltage is needed.

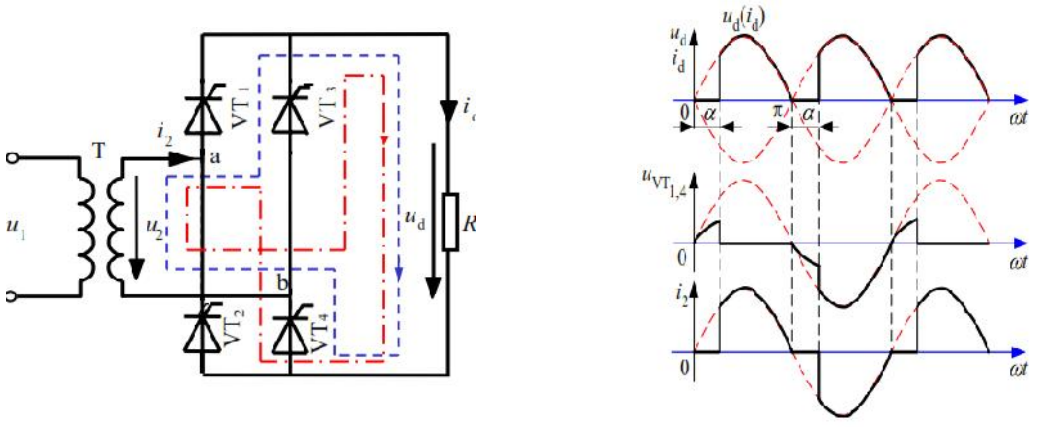


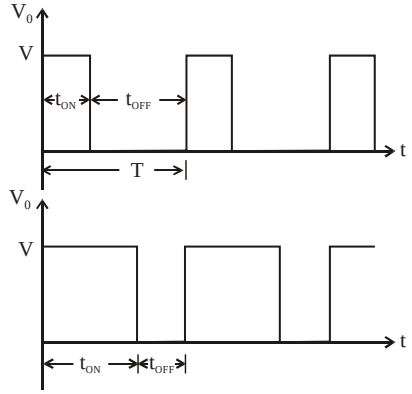
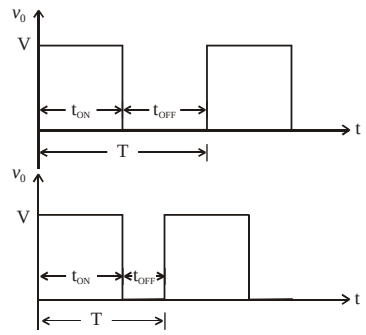
(Note : the above examples are just for example, any two applications with basic description may be given credit)

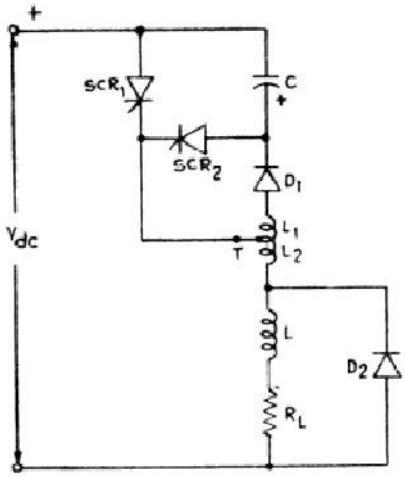
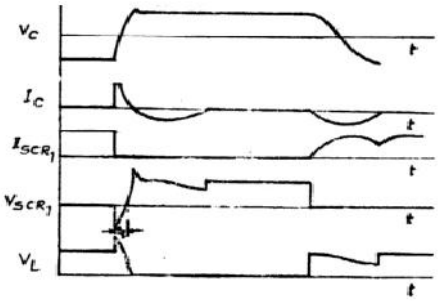
Q6 a) With the help of circuit diagram, explain the working of three phase series inverter	4
A three phase series inverter can be developed by using three single phase series inverters. Each phase functions as independent series inverter if capacitors across dc supply are large enough to maintain constant neutral voltage. The L, C, R elements are connected in series with each thyristor and they are selected for underdamped current response. The switching sequence of thyristors is T_1,T_6,T_2,T_4,T_3 T_5. The interval between successive firing is T/6 where T is the fundamental period.  $(L_1 = L_2 = L_3 = L_4 = L_5 = L_6 = L)$	2+2
Q6 b) Compare: Series inverter and Parallel inverter (four points).	4

Series Inverter	Parallel Inverter
Commutating components are in series	Commutating components are in parallel
Class A commutation	Class D commutation
Self commutated Inverter	Forced Commutated
Resonant circuit necessary	Not necessary
Output transformer not required	Output transformer required
Output wave form depends on load	Square wave
High distortion in output	Low as compared to series
Output frequency not adjustable	Output freq. adjustable

1x4

Q6 c) With the help of circuit diagram and associated waveforms, explain the working principle of single phase fully controlled full wave converter with resistive load	4
	2+2

In fully controlled fullwave converter, during each half of supply cycle, diagonally opposite pairs of thyristors are made to conduct and commutate simultaneously. During positive half cycle, T1 and T 4 are forward biased and when they are triggered, the current flowis through path L-T1-R-T4-N. During negative half cycle, T3,T2 are forward biased. When they are triggered, the current flows through L-T3-R-T2-N. As the load is resitive the load current follows the load voltage.	
Q6 d) List the various control techniques used in chopper and explain any one technique in detail	4
Chopper control techniques The output dc voltage can be varied by the following methods. 1 Pulse width modulation control or constant frequency operation. 2 Variable frequency control 1) Constant frequency operation t_{ON} is varied keeping chopping frequency 'f' & chopping period 'T' constant. Output voltage is varied by varying the ON time t_{ON}  2) Variable frequency control Chopping frequency 'f' is varied keeping either t_{ON} or t_{OFF} constant. To obtain full output voltage range, frequency has to be varied over a wide range. This method produces harmonics in the output and for large t_{OFF} load current may become discontinuous  	2 2

Q6 e) With a neat circuit diagram, explain the working principle of Jones chopper	4
When SCR1 is turned on, the capacitor C discharges resonantly through SCR1, L1, and D1 This discharge current does not flow through L2 and back to the battery because of the transformer action of T. This discharge current does not flow through L2 and back to the battery because of the transformer action of T. The load current is picked up by SCR1, and the flywheel diode D1 is reverse-biased and its current reduced to zero. As the capacitor voltage swings negative, the reverse bias on diode D2 decreases. This continues up to a time and capacitor voltage assumes a polarity as shown in figure. When SCR2 is turned ON, the negative voltage on capacitor C is applied across SCR1 which is turned OFF after its recovery current becomes zero. The load current which is nominally constant starts to flow in SCR2 and capacitor C. The capacitor C is charged positively at first up to a voltage equal to the supply voltage Vdc. The flywheel diode becomes forward biased and begins to pick up the load current and capacitor current starts to reduce.   	2+2