K.S. SCHOOL OF ENGINEERING AND MANAGEMENT, BANGALORE - 560109
DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING
I SESSIONAL TEST QUESTION PAPER 2018 – 19 ODD SEMESTER
SET-B

USN										

Degree : **B.E**
Branch : **ECE**
Course Title : **Power Electronics**
Duration : **90 Minutes**

Semester : **VII 'A'&'B'**
Date : **4-9-2019**
Course Code : **15EC73**
Max Marks : **30**

Note: Answer ONE full question from each part

Q. No.	Question	Marks	K Level	CO mapping
	PART-A			
1 (a)	Define power electronics. **Identify** its industrial applications.	5	K2 Understand	CO1
(b)	**Identify** the merits and demerits of power electronics as compared to conventional methods of power processing.	5	K2 Understand	CO1
(c)	**Explain** class B commutation.	5	K2 Understand	CO2
	OR			
2 (a)	**Explain** Two Transistor Analogy of SCR. Using Two Transistor analogy derive an expression for anode current in terms of gate current.	5	K2 Understand	CO1
(b)	**Explain** the static characteristics of SCR.	5	K2 Understand	CO1
(c)	**Discuss** the different methods to turn ON Thyristor.	5	K2 Understand	CO2
	PART-B			
3 (a)	With neat diagram, **discuss** the control characteristics of various power semiconductor devices.	5	K2 Understand	CO1
(b)	**Discuss** the Gate Characteristics of SCR with neat diagram.	5	K2 Understand	CO1
(c)	**Explain** Dynamic Turn OFF characteristics of SCR.	5	K2 Understand	CO2
	OR			
4 (a)	**Explain** the peripheral effects caused by power electronics converters.	5	K2 Understand	CO1
(b)	**Identify** the components of total average power loss occurring in practical semiconductors switches? **Discuss** the need to compute these losses?	5	K2 Understand	CO1
(c)	A thyristor with latching current of 100mA is connected in series with a resistance of 10 ohms and inductance of 1 H. DC source voltage is 207 volt. **Compute** the minimum gate pulse width to turn on thyristor.	5	K2 Understand	CO2

Course In charge **Head - Dept** **Principal**

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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

I SESSIONAL TEST SCHEME & SOLUTION 2019 – 20 ODD SEMESTER

SET-B

Degree	:	**B.E**	**Semester**	:	**VII 'A'&'B'**
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Course Title	:	**Power Electronics**	**Course Code**	:	**15EC73**
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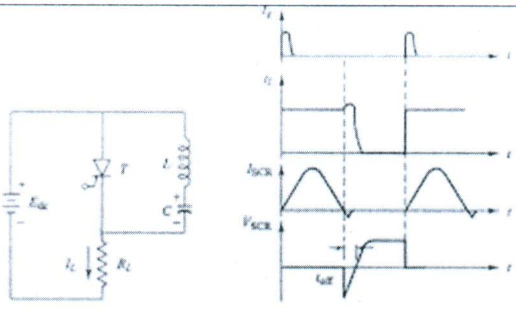
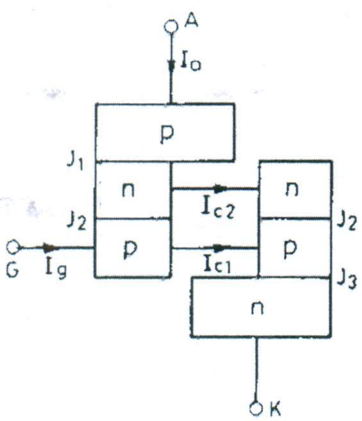
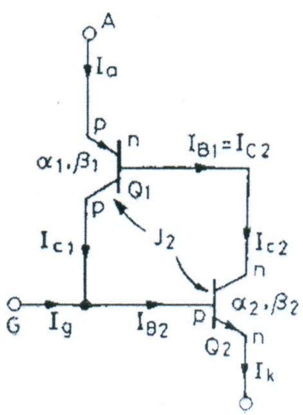
Note: Answer ONE full question from each part

Q. No.	Questions with Scheme & Solution	Marks	K Level	CO map ping
	PART-A			
1(a)	Define power electronics. **Identify** its industrial applications.	5	K2 Understand	CO1
Sol	Power Electronics is a branch of solid state Electronics which deals with control and conversion of electric power. **Automotives and Traction**: Subways, hybrid electric vehicles, trolley, fork-lifts, and many more. A modern car itself has so many components where power electronic is used such as ignition switch, windshield wiper control, adaptive front lighting, interior lighting, electric power steering and so on. Besides power electronics are extensively used in modern traction systems and ships. **Industries:** Almost all the motors employed in the industries are controlled by power electronic drives, for eg. Rolling mills, textile mills, cement mills, compressors, pumps, fans, blowers, elevators, rotary kilns etc. Other applications include welding, arc furnace, cranes, heating applications, emergency power systems, construction machinery, excavators etc. **Defense and Aerospace:** Power supplies in aircraft, satellites, space shuttles, advance control in missiles, unmanned vehicles and other defense equipments. **Renewable Energy:** Generation systems such as solar, wind etc. needs power conditioning systems, storage systems and conversion systems in order to become usable. For example solar cells generate DC power and for general application we need AC power and hence power electronic converter is used. **Utility System:** HVDC transmission, VAR compensation (SVC), static circuit breakers, generator excitation systems, FACTS, smart grids, etc.	Any five application (1 x 5 = 5)		
(b)	**Identify** the merits and demerits of power electronics as compared to conventional methods of power processing.	5	K2 Understand	CO1
Sol	**Merits:** **Mass Production :** Due to huge development in the production techniques of semiconductor devices, these semiconductor based power	Merits Any		

	electronic devices are now produced in huge bulk and hence have resulted into very low price. **Highly Reliable :** Since these devices have no mechanical moving parts, there are very less failure chances and hence has a very rugged performance and long life, provided it is operated under rated conditions. **Highly Efficient :** In most of the applications these devices acts as a switch and we know that in both the modes of the switch, i.e. ON and OFF the power loss in it is very less, and the switching losses are also very low. **Negligible Maintenance :** Again due to absence of mechanical moving parts, the power electronic systems require almost nil maintenance. **Fast :** In comparison to mechanical or electro-mechanical devices the power electronic systems have way faster dynamic response. **Size :** These power electronic systems are very small in size when compared to mechanical systems for similar power ratings and hence less weight, less floor space, less handling issues, less installation cost, less packing and transportation prices and many more. **Demerits:** **Harmonics :** This is the only serious disadvantages of power electronic systems that it injects considerable harmonics both the sides, to the connected load side and to the power source side. **Low Power Factor :** Certain power electronic converters operate at very low input power factor and hence it might be required to install reactive power compensation equipments. **Low Overload Capacity :** Power electronic devices work on rated voltage and current provided proper heat evacuation system is provided. Excess current causes hot spots at junctions and burning of devices.	three (1x3 = 3) Demerits any two (1x2=2) 3+2=5		
(c)	**Explain** class B commutation.	**5**	**K2 Understand**	**CO2**
Sol	 Fig.1 Class B commutation circuit Fig.2 Associated waveforms Initially, as soon as the supply voltage Edc is applied, the capacitor *C* starts getting charged with its upper plate positive and the lower plate negative, and it charges up to the voltage Edc. When thyristor *T* is triggered, the circuit current flows in two directions: (1) The load current ILIL flows through the path Edc+−T−RL−Edc−Edc+−T−RL−Edc−	Characteristic figure (2) Expalnation (3) 2+3=5		

	(2) Commutating current Ic . The moment thyristor *T* is turned ON, capacitor *C* starts discharging through the path C+−L−T−C−C+−L−T−C−.When the capacitor *C* becomes completely discharged, it starts getting charged with reverse polarity. Due to the reverse voltage, a commutating current ICIC starts flowing which opposes the load current IL.IL. When the commutating current ICIC is greater than the load current ILIL , thyristor *T* becomes turned OFF. When the thyristor *T* is turned OFF, capacitor *C* starts getting charged to its original polarity through *L* and the load. Thus, when it is fully charged, the thyristor will be ON again. Hence, from the above discussion it becomes clear that the thyristor after getting ON for sometime automatically gets OFF and after remaining in OFF state for sometime, it again gets turned ON. This process of switching ON and OFF is a continuous process. The desired frequency of ON and OFF states can be obtained by designing the commutating components as per the requirement.			
	OR			
2(a)	**Explain** Two Transistor Analogy of SCR. Using Two Transistor analogy derive an expression for anode current in terms of gate current.	**5**	**K2 Understand**	**CO1**
Sol		Two Transistor Model (1) Derivation (2) Explanation (2) 1+2+2 = 5		

$$\therefore \qquad I_{c1} = I_{b2} \quad \text{and} \quad I_{b1} = I_{c2}$$

Also, $$I_k = I_a + I_g \qquad (2.1)$$

Now, we have the relation from transistor analysis,

$$I_{b1} = I_{e1} - I_{c1} \qquad (2.2)$$

Also, $$I_{c1} = \alpha_1 I_{e1} + I_{co1} \qquad (2.3)$$

where I_{co1} is the reverse leakage current of the reverse biased junction J_2 when the two outer layers are not present.

Substituting Eq. (2.3) in Eq. (2.2) we get

$$I_{b1} = I_{e1} - \alpha_1 I_{e1} - I_{co1}.$$

$$I_{b1} = (1 - \alpha_1) I_{e1} - I_{co1}$$

$$I_a = I_{e1}$$

$$\therefore \qquad I_{b1} = (1 - \alpha_1) I_a - I_{co1} \qquad (2.4)$$

Also, $$I_{c2} = \alpha_2 I_{e2} + I_{co2}$$

$$\therefore \qquad I_k = I_{e2}$$

$$\therefore \qquad I_{c2} = \alpha_2 I_k + I_{co2} \qquad (2.5)$$

But $$I_{b1} = I_{c2} \qquad (2.6)$$

Substituting Eqs (2.4 and (2.5) in Eq. (2.6), we get

$$(1 - \alpha_1) I_a - I_{co1} = \alpha_2 I_k + I_{co2} \qquad (2.7)$$

Substituting Eq. (2.1) in Eq. (2.7), we get

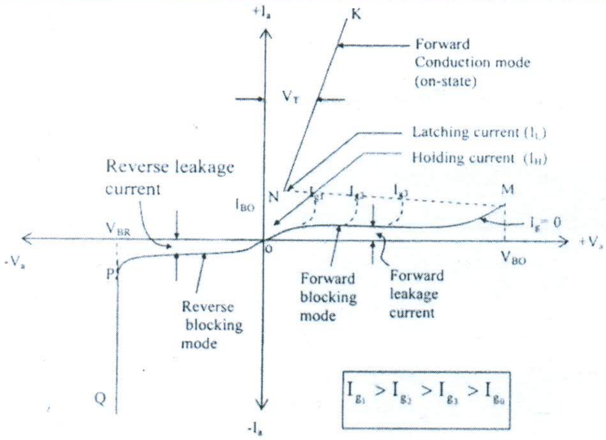
$$(1 - \alpha_1) I_a - I_{co1} = \alpha_2 (I_a + I_g) + I_{co2}$$

$$(1 - \alpha_1 - \alpha_2) I_a = \alpha_2 I_g + I_{co2} + I_{co1}.$$

$$[1 - (\alpha_1 + \alpha_2)] I_a = \alpha_2 I_g + I_{co1} + I_{co2}$$

$$\therefore \qquad I_a = \frac{\alpha_2 I_g + I_{co_1} + I_{co_2}}{[1 - (\alpha_1 + \alpha_2)]} \qquad (2.8)$$

(b)	**Explain** the static characteristics of SCR.	5	K2 Understand	CO1

<table>
<tr>
<td>Sol</td>
<td>


As the applied anode to cathode voltage is increased above zero, very small current flows through the device, under this condition the SCR is off. It will be continued until; the applied voltage reaches the forward Break over voltage. If the anode-cathode (applied) voltage exceeds the Break over voltage it conducts heavily the SCR turns ON and anode to cathode voltage decreases quickly because, under this condition the SCR offers very low resistance hence it drops very low voltage across it. At this stage the SCR allows more current to low through it. The amplitude of the current is depending upon the supply voltage and load resistance connected in the circuit. The current below which SCR turns OFF is called the "holding current (IH)" It can be defined as the minimum value of anode current required to keep the SCR in ON State. If the 5CR falls below this holding current the SCR turns OFF. If the value of the gate current I is increased above zero, ('G > O) the SCR turns ON even at lower Break over voltage. The region lying between origin and forward break over voltage is called forward blocking region. In this region SCR is OFF'. In forward conduction region SCR is ON. Once the SCR is switched ON then the gate looses all the control. So SCR cannot be turned OFF by varying the gate voltage.
</td>
<td>VI Characteristic (2)

Explanation (3)

2+3=5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(c)</td>
<td>Discuss the different methods to turn ON of Thyristor.</td>
<td>5</td>
<td>K2
Understand</td>
<td>CO2</td>
</tr>
<tr>
<td>Sol</td>
<td>Forward Voltage Triggering :
One of the commonly used SCR Turn On methods is by increasing the forward anode to cathode voltage. By doing this, the depletion layer width is also increasing at junction J2. This also causes to increase the minority charge carriers accelerating voltage at junction J2. This further leads to an avalanche breakdown of the junction J2 at a forward break over voltage VBO.
Temperature Triggering:
The reverse leakage current depends on the temperature. If the temperature is increased to a certain value, the number of hole-pairs also increases. This causes to increase the leakage current and further it increases the current gains of the SCR. This starts the regenerative action inside the SCR since the ($\alpha 1 + \alpha 2$) value approaches to unity.</td>
<td></td>
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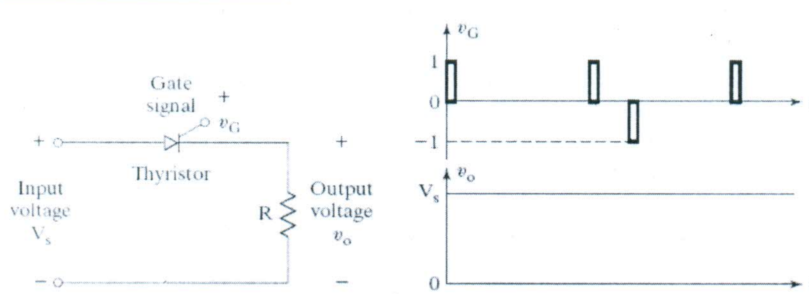
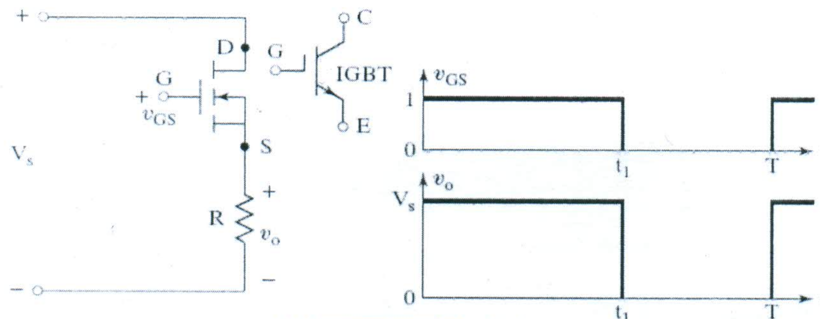
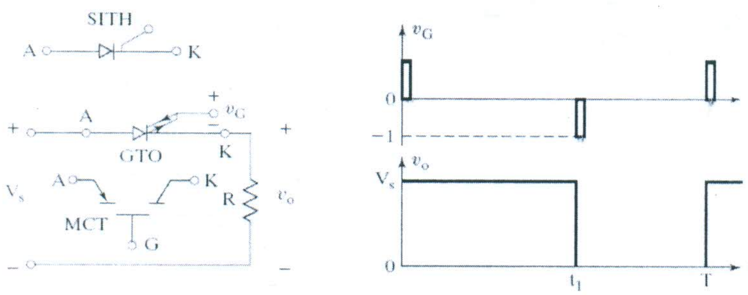
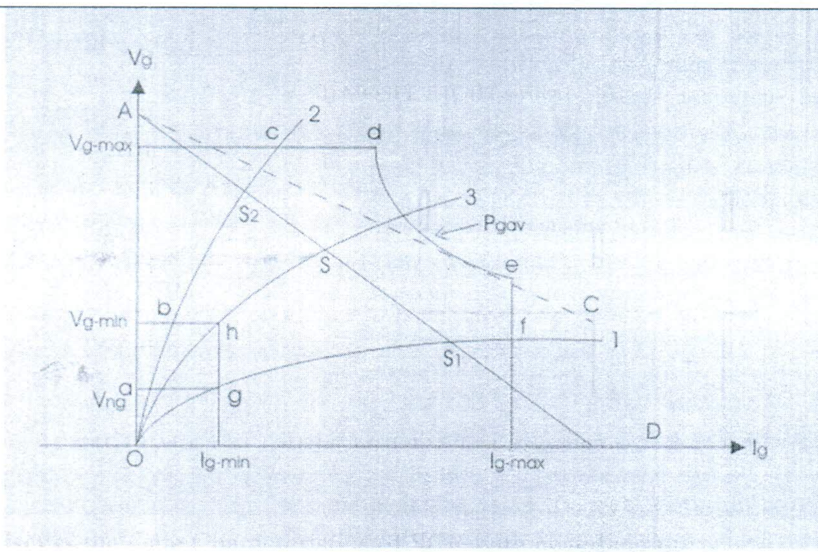
</table>

	dv/dt Triggering: In forward blocking state junctions J1 and J3 are forward biased and J2 is reverse biased. So the junction J2 behaves as a capacitor (of two conducting plates J1 and J3 with a dielectric J2) due to the space charges in the depletion region. If the rate of change of the applied voltage is large that leads to increase the charging current which is enough to increase the value of alpha. **Light Triggering:** In this method, light rays with appropriate wavelength and intensity are allowed to strike the junction J2. These types of SCRs are consisting a niche in the inner p-layer. Therefore, when the light struck on this niche, electron-hole pairs is generated at the junction J2 which provides additional charge carriers at the junction leads to turn ON the SCR. **Gate Triggering:** **DC Gate Triggering:** In this triggering, a sufficient DC voltage is applied between the gate and cathode terminals in such a way that the gate is made positive with respect to the cathode. The gate current drives the SCR into conduction mode. **AC Triggering:** This is the most commonly used method for AC applications where the SCR is employed for such applications as a switching device. With the proper isolation between the power and control circuit, the SCR is triggered by the phase-shift AC voltage derived from the main supply. **Pulse Triggering:** The most popular method of triggering the SCR is the pulse triggering. In this method, gate is supplied with single pulse or a train of pulses. The main advantage of this method is that gate drive is discontinuous or doesn't need continuous pulses to turn the SCR and hence gate losses are reduced in greater amount by applying single or periodically appearing pulses. For isolating the gate drive from the main supply, a pulse transformer is used.	5 Methods of Triggering (1x5=5)		
	PART-B			
3(a)	With neat diagram, **discuss** the control characteristics of various power semiconductor devices.	**5**	**K2 Understand**	**CO1**
Sol	<ins>**Contol Characteristics**</ins>  (a) Thyristor switch	Characteristic (2) Explanation (3) 2+3=5		

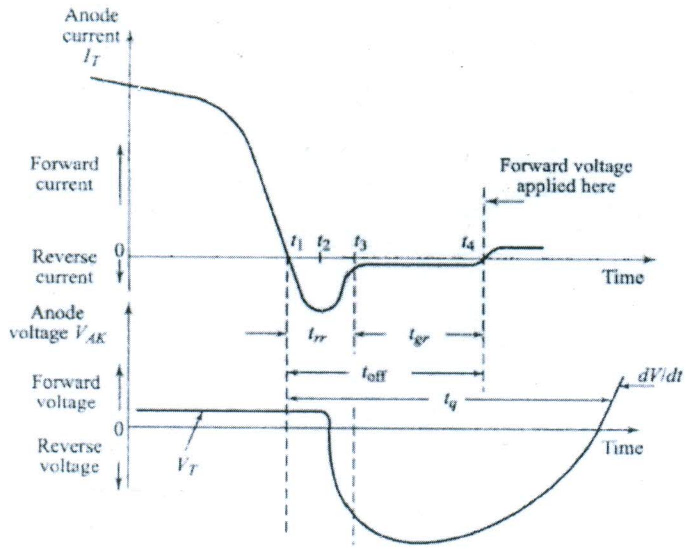
<table>
<tr><td></td><td>

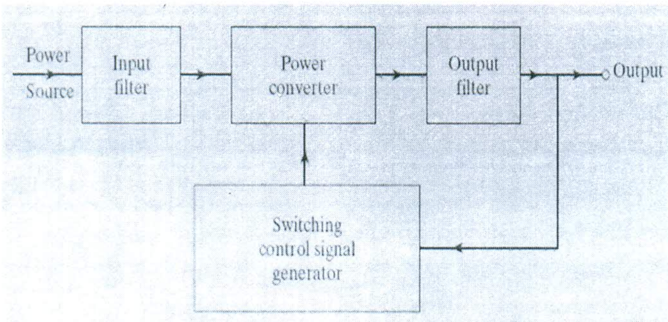
(d) MOSFET/IGBT switch


(b) GTO/MTO/ETO/IGCT/MCT/SITH switch (For MCT, the polarity of V_G is reversed as shown)</td><td></td><td></td><td></td></tr>
<tr><td>(b)</td><td>Discuss the Gate Characteristics of SCR with neat diagram.</td><td>5</td><td>K2 Understand</td><td>CO1</td></tr>
<tr><td>Sol</td><td>

The first region near the origin is defined by the maximum gate voltage that will not trigger any device. The gate must be operated in this region whenever forward bias is applied across the thyristor and triggering is not necessary.
The second region is further defined by the minimum value of gate voltage to trigger all devices at minimum rated junction temperature.
The third region is the largest region shows the limits on the gate signal for reliable firing. Normally, a signal in the lower left part of this region is adequate for firing. For applications where fast turn ON is required, a hard firing signal in the upper part of the region may be needed.</td><td>Gate Characteristic figure (2)
Explanation (3)

2+3=5</td><td></td><td></td></tr>
</table>

(c)	**Explain** Dynamic Turn OFF characteristics of SCR.	5	K2 Understand	CO2
Sol	 Turn-OFF time of thyristor is defined as the minimum time interval between the instant at which the anode current becomes zero, and the instant at which the device is capable of blocking the forward voltage. At instant t_1 the anode forward current becomes zero. During the reverse recovery time t_1 to t_3 the anode current flows in the reverse direction. At the instant t_2, a reverse anode voltage is developed and the reverse recovery current continuous to decrease. At t_3, junction J_1 and J_3 are able to block a reverse voltage. However, the thyristor is not yet able to block a reverse voltage. However, the thyristor is not yet able to block a forward voltage because carriers, called trapped charges, are still present at the junction J_2. During the interval t_3 to t_4, these carriers recombine. At t_4, the recombination is complete and therefore, a forward voltage can be re-applied at this instant. The SCR turn-OFF time is the interval between t_4 and t_1. In a SCR, this time varies in the range 10 to 100 micro second. Thus, the total turn-off time t_q required for the device is the sum of the duration, which the reverse recovery current flows after the application of reverse voltage, and the time required for the recombination of all excess carriers in the inner two layers of the device. This may be noted that in case of highly inductive load circuit, the current cannot change abruptly at t_1. In addition, the fast change in current at t_2 may give rise to high voltage surges in the inductance, which will then appears across the terminals of the thyristor.	Dynamic turn off characteristic figure (2) Explanation (3) 2+3=5		
	OR			
4(a)	**Explain** the peripheral effects caused by power electronics converters.	5	K2 Understand	CO1

Sol	 The power converter operations are based mainly on the switching of power semiconductor devices and as a result the power converters introduce current and voltage harmonics (unwanted AC signal components) into the supply system and on the output of the converters. These induced harmonics can cause problems of distortion of the output voltage, harmonic generation into the supply system, and interference with the communication and signaling circuits. It is normally necessary to introduce filters on the input side and output side of a power converter system so as to reduce the harmonic level to an acceptable magnitude. The figure below shows the block diagram of a generalized power converter with filters added. The power converters can cause radio frequency interference due to electromagnetic radiation and the gating circuits may generate erroneous signals. This interference can be avoided by proper grounding and shielding.	Block Diagram (2) Explanation (3) 2+3=5		
(b)	**Identify** the components of total average power loss occurring in practical semiconductors switches? **Discuss** the need to compute these losses?	**5**	**K2 Understand**	**CO1**
Sol	P_{ON}: This is on the ON-state power loss. It is a function of the forward voltage drop and forward current. This is major component of total power loss in the switch at low frequency operations. This loss is given by the product of the voltage drop across the device with the current it is carrying, averaged over the repetition period. P_{OFF}: This is the OFF-state power loss. It is a function of blocking voltage and leakage current of the switch. Since the leakage current in most of the modern switches is typically of the order of few microamperes, this loss is very small. So, it can be assumed to be zero. P_G: This is the gate power loss. It is the power input to the control terminals of the switch from the control circuit. In practice, with pulse triggering, this loss is negligible when compared to continuous triggering. P_{SW}: This is the switching loss. It is the energy dissipated in the device during turn-ON and turn-OFF. This can be significant when switch operates at a high frequency. The switching loss occurs as a result of non-zero current through, and voltage across the switch during state transition. Total power loss $P_D = P_{ON}+P_{OFF}+P_G+P_{SW}$	Components of Average power loss (4) Reason for calculating (1) 4+1=5		

	Predetermination of total average power loss in a switch is necessary to select an appropriate heat sink.			
(c)	A thyristor with latching current of 100mA is connected in series with a resistance of 10 ohms and inductance of 1 H. DC source voltage is 207 volt. **Compute** the minimum gate pulse width to turn on thyristor.	**5**	**K2 Understand**	**CO2**
Sol	The instantaneous current through the conducting thyristor is given by, $$i = \frac{V}{R}\left[1 - e^{-\frac{tR}{L}}\right] \qquad (1)$$ Therefore the minimum time after which $i = I_{latch}$ is given by, $$I_{latch} = \frac{V}{R}[1 - e^{-tR/L}]$$ $$\therefore 100 \times 10^{-3} = \frac{207}{10}[1 - e^{-t\times 10/1}]$$ $$4.83 \times 10^{-3} = [1 - e^{-10t}]$$ $$\therefore e^{-10t} = 0.955$$ $$\therefore -10t = -4.84 \times 10^{-3}$$ $$t = 484.26\mu sec$$ Thus the minimum pulse width to turn on the thyristor is $484.26\mu sec$	Formulae (1) Steps (3) Final answer (1) 1+3+1=5		

Course In charge **Head - Dept** 5/9/19 **Principal**

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II SESSIONAL TEST QUESTION PAPER 2019 – 20 ODD SEMESTER
SET-A

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Note: Answer ONE full question from each part

Q. No.	Question	Marks	K Level	CO mapping
	PART-A			
1(a)	Draw the circuit diagram of RC Triggering circuit and **illustrate** its working with relevant waveforms.	5	Applying (K3)	CO2
(b)	With a neat circuit diagram and waveform, **explain** the working of sinlge phase dual converter.	5	Understanding (K2)	CO3
(c)	Explain the working of single phase half wave controller with R load. Also **derive** the expression for RMS output voltage.	5	Applying (K3)	CO3
	OR			
2(a)	Draw the circuit diagram of UJT Triggering circuit and **illustrate** its working with relevant waveforms.	5	Applying (K3)	CO2
(b)	**Explain** the working of semi converter (Half Bridge) with RL Load along with relevant circuit diagrams and waveforms.	5	Understanding (K2)	CO3
(c)	Explain the working of ON-OFF type AC voltage controller. **Derive** the expression for RMS output voltage.	5	Applying (K3)	CO3
	PART-B			
3(a)	A UJT is used to trigger the thyristor whose minimum gate triggering voltage is 6.2 V. The UJT ratings are $\eta = 0.66$, $I_P = 0.5$ mA, $I_V = 3$ mA, $R_{B1} + R_{B2} = 5$ KΩ, leakage current = 3.2 mA, $V_P = 14$ V, $V_V = 1$ V. Oscillator frequency is 2 KHz and the capacitor C = 0.04 μF. **Design** the circuit.	5	Applying (K3)	CO2
(b)	Explain the operation of single phase bidirectional AC voltage controller for resistive load with the help of neat circuit diagram and **derive** expression for rms output voltage.	5	Applying (K3)	CO3
(c)	An AC voltage controller has a resistive load of R = 10Ω and rms input voltage is 120 V, 50 Hz. The thyristor switch is ON for n = 25 cycles and OFF for M = 75 cycles. **Calculate**: rms output voltage, input power factor, average and rms thyristor current.	5	Applying (K3)	CO3
	OR			

4(a)	Explain the working of half wave converter with RL load. Also **derive** the expression for average output voltage.	5	Applying (K3)	CO2
(b)	A single phase half wave ac voltage controller has an input voltage of 120 V and a load resistance of 5Ω. The firing angle of thyristor is 60^0. **Calculate** average output voltage, rms output voltage, power factor.	5	Applying (K3)	CO3
(c)	With the help of circuit diagram, explain the operation of a single phase full converter with RL load. **Derive** expression for rms and average output voltages.	5	Applying (K3)	CO3

Course In charge **Head - Dept** **Principal**

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DEPARTMENT OF ELETRONICS AND COMMUNICATION ENGINEERING

II SESSIONAL TEST SCHEME & SOLUTION 2019 – 20 ODD SEMESTER

SET-A

Degree	: B.E		Semester	:	VII 'A'&'B'
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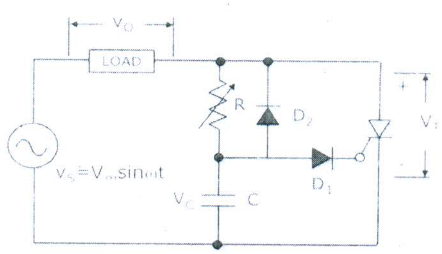
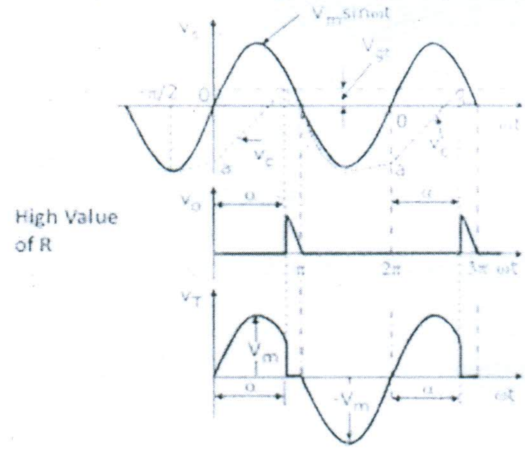
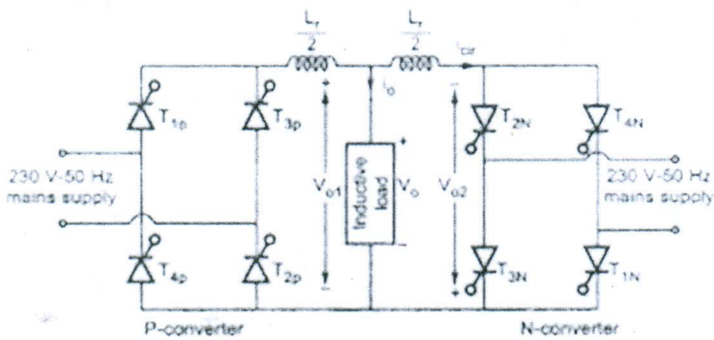
Duration	: 90 Minutes		Max Marks	:	30

Note: Answer ONE full question from each part

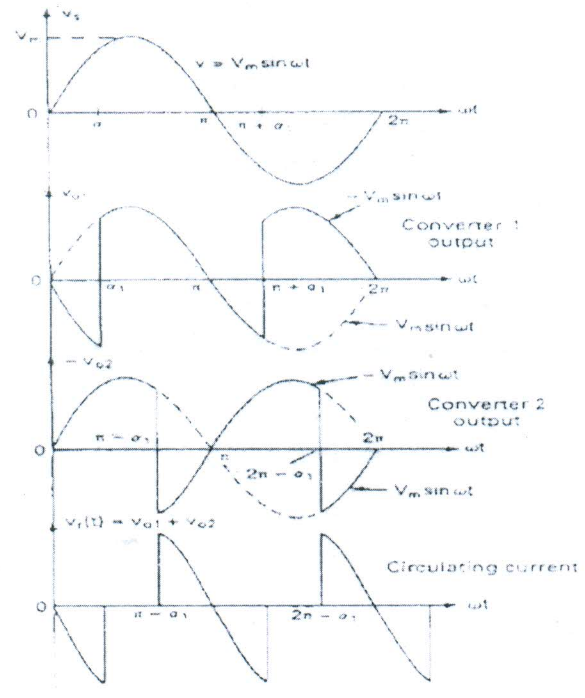
Q. No.	Questions with Scheme & Solution	Marks	K Level	CO mapping
	PART-A			
1(a)	Draw the circuit diagram of RC Triggering circuit and **Illustrate** its working with relevant waveforms.	5	K3	CO2
Sol	**RC Half Wave Circuit**  Capacitor 'C' in the circuit is connected to shift the phase of the gate voltage. D1 is used to prevent negative voltage from reaching the gate cathode of SCR. In the negative half cycle, the capacitor charges to the peak negative voltage of the supply ( ) −Vm through the diode D2 . The capacitor maintains this voltage across it, till the supply voltage crosses zero. As the supply becomes positive, the capacitor charges through resistor 'R' from initial voltage of −Vm , to a positive value. When the capacitor voltage is equal to the gate trigger voltage of the SCR, the SCR is fired and the capacitor voltage is clamped to a small positive value. Case 1: R → Large. When the resistor 'R' is large, the time taken for the capacitance to charge from −Vm to Vgt is large, resulting in larger firing angle and lower load voltage. Case 2: R → Small When 'R' is set to a smaller value, the capacitor	**Circuit – 2M Explanation – 2M Waveform – 1M**		

	charges at a faster rate towards Vgt resulting in early triggering of SCR and hence VL is more. When the SCR triggers, the voltage drop across it falls to 1 – 1.5V. This in turn lowers, the voltage across R & C. Low voltage across the SCR during conduction period keeps the capacitor discharge during the positive half cycle.  			
(b)	With a neat circuit diagram and waveform, **explain** the working of sinlge phase dual converter.	5	K2	CO3
Sol	 Dual converter, the name itself says two converters. It is really an electronic converter or circuit which comprises of two converters. One will perform as rectifier and the other will perform as inverter. Therefore, we can say that double processes will occur at a moment. Here, two full converters are arranged in anti-parallel pattern and linked to the same dc load. These converters can provide four quadrant operations. Modes of Operation of Dual Converter There are two functional modes: Non-circulating current mode and circulating mode. Non Circulating Current Mode • One converter will perform at a time. So there is no circulating current between the converters. • During the converter 1 operation, firing angle ($\alpha 1$) will be $0<\alpha 1< 90^{\circ}$; Vdc and Idc are positive.	**Circuit – 2M** **Explanatio n – 2M** **Waveform – 1M**		

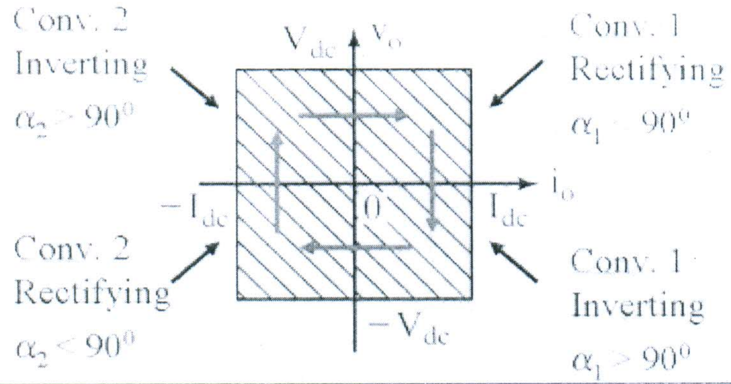
- During the converter 2 operation, firing angle ($\alpha 2$) will be $0<\alpha 2< 90^{\circ}$; Vdc and Idc are negative.

Circulating Current Mode

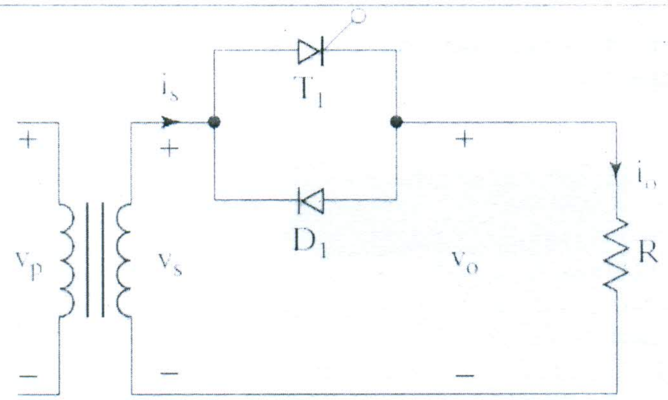
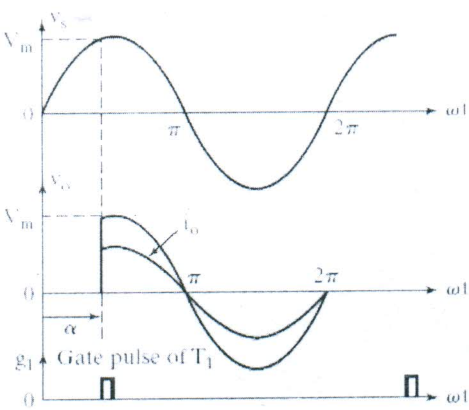
- Two converters will be in the ON condition at the same time. So circulating current is present.
- The firing angles are adjusted such that firing angle of converter 1 ($\alpha 1$) + firing angle of converter 2 ($\alpha 2$) = 180°.
- Converter 1 performs as a controlled rectifier when firing angle be $0<\alpha 1< 90^{\circ}$ and Converter 2 performs as an inverter when the firing angle be $90^{\circ}<\alpha 2< 180^{\circ}$. In this condition, Vdc and Idc are positive.
- Converter 1 performs as an inverter when firing angle be $90^{\circ}<\alpha 1< 180^{\circ}$ and Converter 2 performs as a controlled rectifier when the firing angle be $0<\alpha 2< 90^{\circ}$ In this condition, Vdc and Idc are negative.

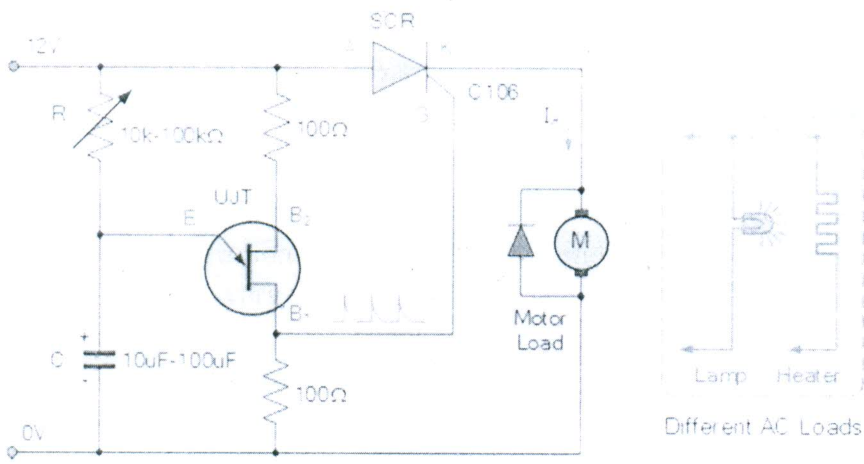
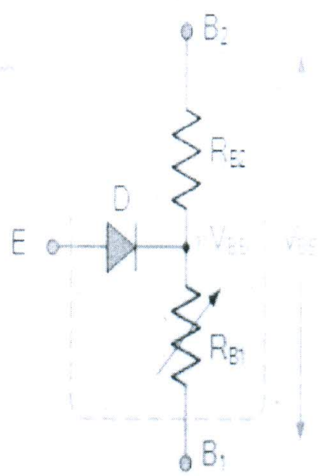


(b) Waveforms

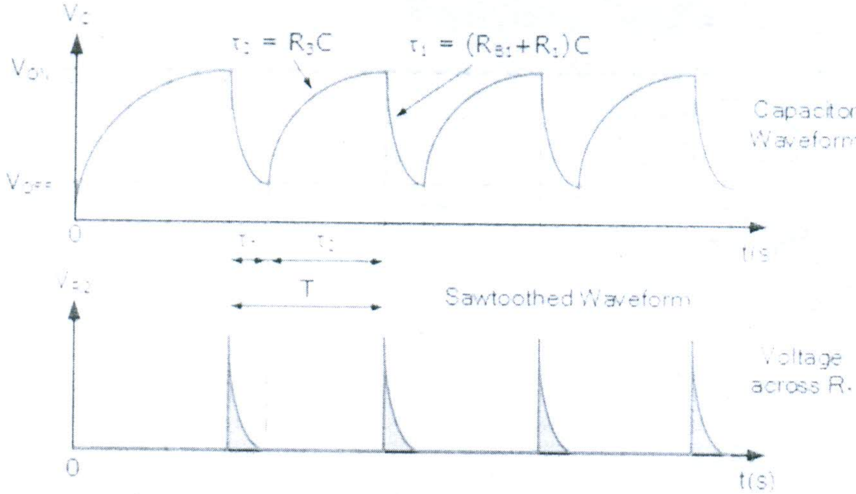


(c)	Explain the working of single phase half wave controller with R load. Also **derive** the expression for RMS output voltage.	5	K3	CO3

Sol	 The thyristor is forward biased during the positive half cycle of input ac supply. It can be triggered and made to conduct by applying a suitable gate trigger pulse only during the positive half cycle of input supply. When is triggered it conducts and the load current flows through the thyristor, the load and through the transformer secondary winding. By assuming as an ideal thyristor switch it can be considered as a closed switch when it is ON during the period to radians. The output voltage across the load follows the input supply voltage when the thyristor is turned-on and when it conducts from to radians. When the input supply voltage decreases to zero at , for a resistive load the load current also falls to zero at and hence the thyristor turns off at . Between the time period to , when the supply voltage reverses and becomes negative the diode becomes forward biased and hence turns ON and conducts. The load current flows in the opposite direction during to radians when is ON and the output voltage follows the negative half cycle of input supply.  The expression for rms output voltage is given by $$V_{0(rms)} = \frac{V_m}{2}\left(\frac{(2\pi-\alpha)+\frac{\sin 2\alpha}{2}}{\pi}\right)^{\frac{1}{2}}$$	**Circuit – 1M** **Explanation – 1M** **Waveform – 1M** **Derivation – 2M**		

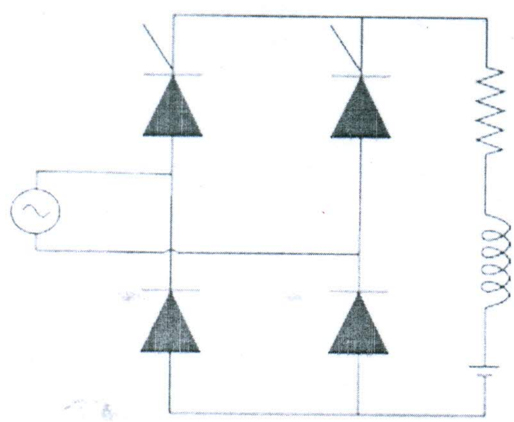
	OR			
2(a)	Draw the circuit diagram of UJT Triggering circuit and **Illustrate** its working with relevant waveforms.	5	K3	CO2
Sol	If a small positive input voltage which is less than the voltage developed across resistance, RB1 (ηV_{BB}) is now applied to the Emitter input terminal, the diode p-n junction is reverse biased, thus offering a very high impedance and the device does not conduct. The UJT is switched "OFF" and zero current flows. ¬However, when the Emitter input voltage is increased and becomes greater than VRB1 (or ηV_{BB} + 0.7V, where 0.7V equals the p-n junction diode volt drop) the p-n junction becomes forward biased and the unijunction transistor begins to conduct.   Simplified Equivalent Circuit The result is that Emitter current, ηI_E now flows from the Emitter into the Base region. The effect of the additional Emitter current flowing into the Base reduces the resistive portion of the channel	**Circuit – 2M Explanation – 2M Waveform – 1M**		

between the Emitter junction and the B1 terminal. This reduction in the value of R_{B1} resistance to a very low value means that the Emitter junction becomes even more forward biased resulting in a larger current flow. The effect of this results in a negative resistance at the Emitter terminal.



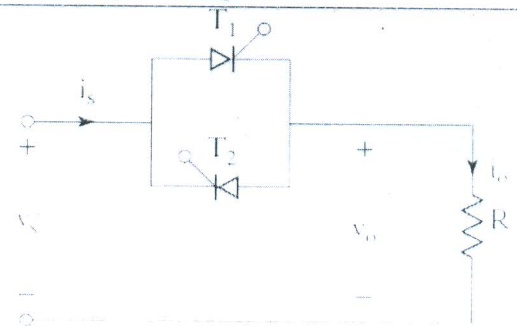
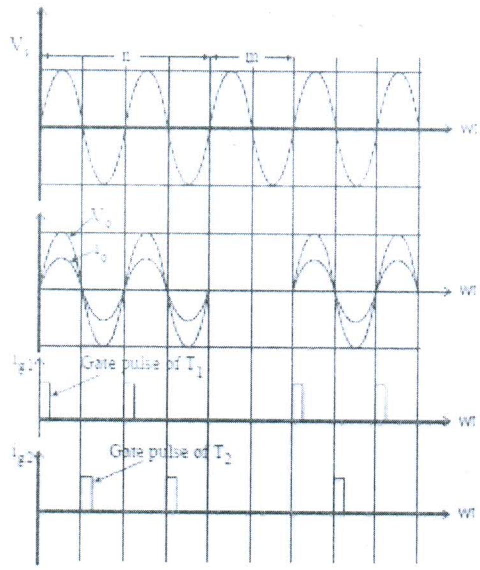
(b)	**Explain** the working of semi converter (Half Bridge) with RL Load along with relevant circuit diagram.	5	K2	CO3

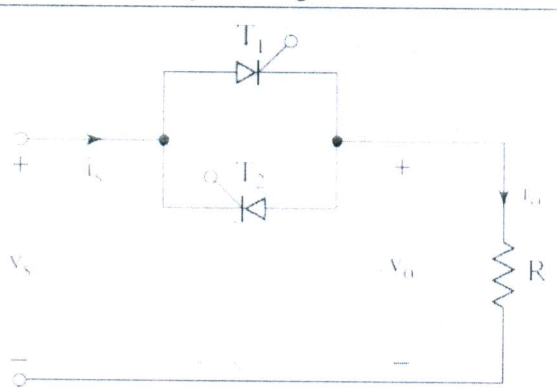
Sol

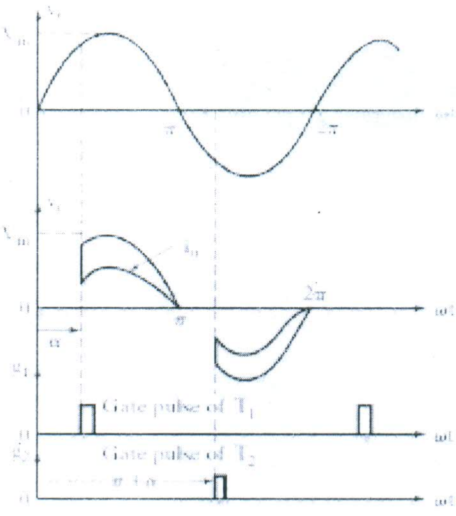


Since diodes can block only negative voltage, it can be concluded that diodes D2 and D3 conducts for positive and negative half cycle of the input voltage respectively. For the positive half cycle, when thyristor T1 is fired at its firing angle α, load current flows through T1 and D2. When diode D3 starts conduction in the negative half cycle, T1 is reverse biased and is turned off. Then load current is transferred to diodes D2 and D3 as observed in the waveforms. Thyristor T4 will come in once it is fired, which turns off diode D2. Thus load current is continuous through out and this mode of operation is known as continuous mode of operation. If load current becomes zero for some time, then it is known as discontinuous mode of operation.

Circuit – 2M
Explanation – 2M
Waveform – 1M

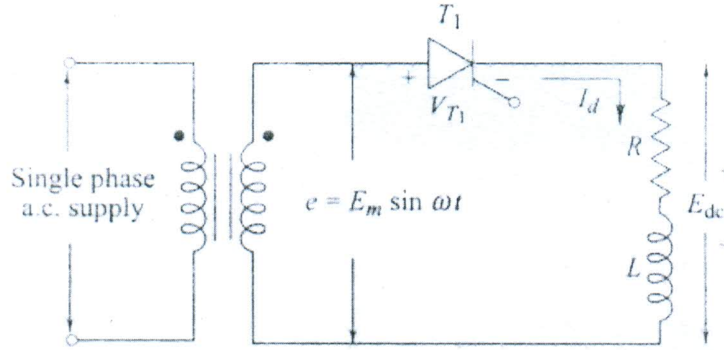
(c)	Explain the working of ON-OFF type AC voltage controller. **Derive** the expression for RMS output voltage.	5	K3	CO3
Sol	 The basic principle of on-off control technique is explained with reference to a single phase full wave ac voltage controller circuit shown below. The thyristor switches and are turned on by applying appropriate gate trigger pulses to connect the input ac supply to the load for 'n' number of input cycles during the time interval . The thyristor switches T_1 & T_2 are turns OFF by blocking the gate triggering pulse for m number of input cycles during time interval t_{OFF}.  $V_{O(RMS)} = \sqrt{\frac{1}{\omega T_O} \int_{\omega t=0}^{\omega t_{ON}} V_m^2 Sin^2 \omega t . d(\omega t)}$ $V_{O(RMS)} = \sqrt{\frac{V_m^2}{\omega T_O} \int_{0}^{\omega t_{ON}} Sin^2 \omega t . d(\omega t)}$ $V_{O(RMS)} = V_{i(RMS)} \sqrt{\frac{t_{ON}}{T_O}} = V_S \sqrt{\frac{t_{ON}}{T_O}}$	**Circuit – 1M** **Explanation – 1M** **Waveform – 1M** **Derivation – 2M**		

	Where $V_{i(RMS)} = \frac{V_m}{\sqrt{2}} = V_S =$ RMS value of input supply voltage $\frac{t_{ON}}{T_O} = \frac{t_{ON}}{t_{ON}+t_{OFF}} = \frac{nT}{nT+mT} = \frac{n}{(n+m)} = k =$ duty cycle (d) $V_{O(RMS)} = V_S\sqrt{\frac{n}{(m+n)}} = V_S\sqrt{k}$			
	PART-B			
3(a)	A UJT is used to trigger the thyristor whose minimum gate triggering voltage is 6.2 V. The UJT ratings are η = 0.66, I_P = 0.5 mA, I_V = 3 mA, $R_{B1} + R_{B2}$ = 5 KΩ, leakage current = 3.2 mA, V_P = 14 V, V_V = 1 V. Oscillator frequency is 2 KHz and the capacitor C = 0.04 μF. **Design** the circuit.	5	K3	CO2
Sol	$T = R_C C \ln\left(\frac{1}{1-\eta}\right)$ $R_C = 11.6\,K\Omega$ $V_P = \eta V_{BB} + V_D$ $V_{BB} = 20V$ $R_2 = \frac{0.7(R_{B2}+R_{B1})}{\eta V_{BB}}$ $R_2 = 265\,\Omega$ $V_{BB} = I_{leakage}(R_1 + R_2 + R_{B1} + R_{B2})$ $R_1 = 985\,\Omega$	**Calculation of R_C = 2M** **Calculation of R_2 = 2M** **Calculation of R_2= 1M**		
(b)	Explain the operation of single phase bidirectional AC voltage controller for resistive load with the help of neat circuit diagram and **derive** expression for rms output voltage.	5	K3	CO3
Sol	 During the positive half of the input signal, Thyristor T_1 is ON with the application of gate pulse. Hence output voltage is controlled by thyristor T_1.During the negative half of the input signal, Thyristor T_2 is	**Circuit – 1M** **Explanation – 1M** **Waveform – 1M** **Derivation – 2M**		

	ON with the application of gate pulse. Hence output voltage is controlled by thyristor T_2.  The expression for rms output voltage is given by $$V_{0(r.m.s)} = V_m \left(\frac{(\pi - \alpha) + \frac{\sin 2\alpha}{2}}{2\pi} \right)^{\frac{1}{2}}$$			
(c)	An AC voltage controller has a resistive load of R = 10Ω and rms input voltage is 120 V, 50 Hz. The thyristor switch is ON for n = 25 cycles and OFF for M = 75 cycles. **Calculate**: rms output voltage, input power factor, average and rms thyristor current.	5	K3	CO3
Sol	$V_{0(rms)} = V_S \sqrt{k}$ $V_{0(rms)} = 60V$ $I_{0(rms)} = \frac{V_{0(rms)}}{R}$ $I_{0(rms)} = 6\,A$ $Active\,load\,power = I^2_{0(rms)}\,R$ $Active\,load\,power = 360W$ $I_{s(rms)} = I_{0(rms)} = 6\,A$ $Total\,rms\,power = V_{s(rms)}\,I_{s(rms)}$ $Total\,rms\,power = 720W$ $Power\,Factor = \frac{Active\,Load\,Power}{Total\,rms\,Power}$ $Power\,Factor = 0.5$	**Calculation of $V_{0(rms)}$ = 2M** **Calculation of $I_{0(rms)}$ = 1M** **Calculation of PF = 2M**		
	OR			

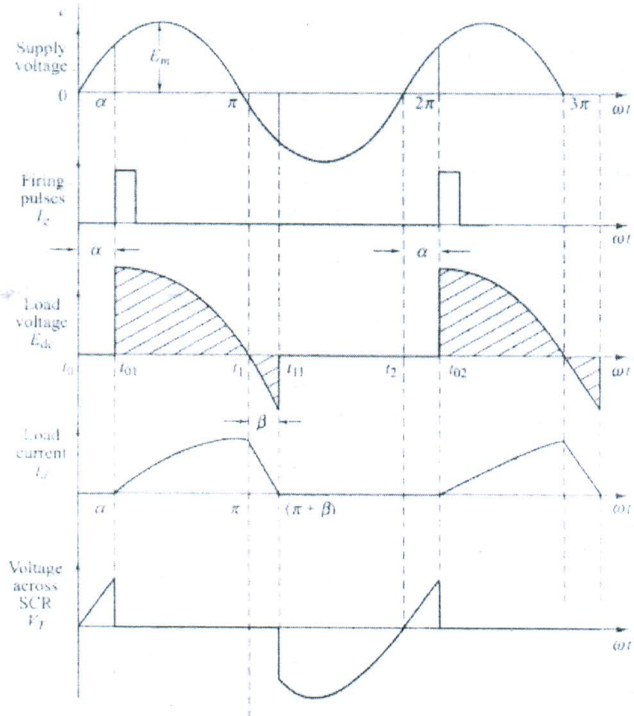
4(a)	Explain the working of half wave converter with RL load. Also **derive** the expression for average output voltage.	5	K3	CO2

Sol



When the SCR is triggered, the supply voltage appears across the load. Output voltage is same as supply voltage after α. Because of RL load, output current starts increasing slowly from zero. The shape of i_0 depends on the values of R & L. Due to the negative supply voltage after Π, SCR tries to turn OFF. Due to energy stored in the inductor, SCR is maintained in ON state. At Π, output current is maximum. As SCR tries to turn OFF due to negative supply voltage, output current tries to go to zero.

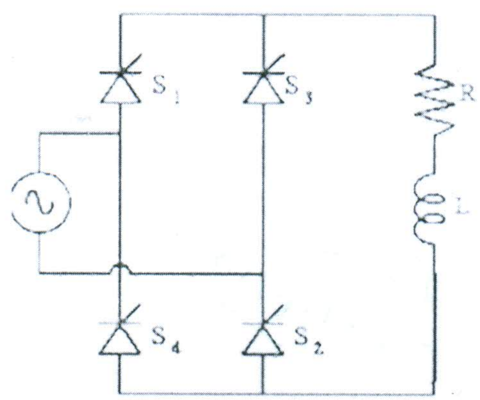
Circuit – 1M
Explanation – 1M
Waveform – 1M
Derivation – 2M

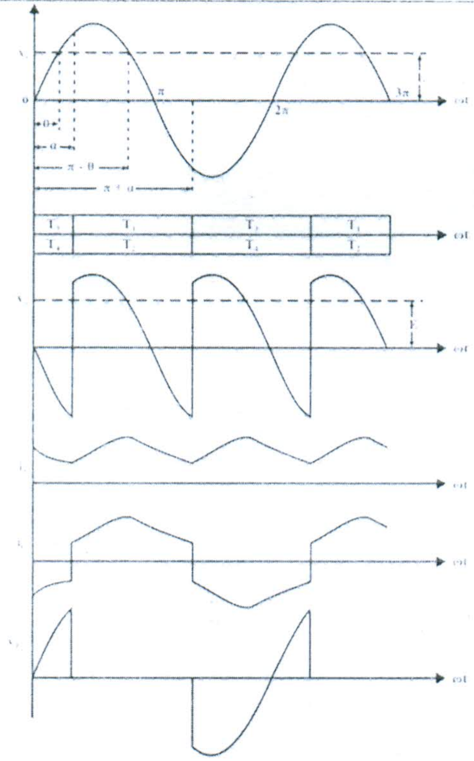


The output voltage expression for half wave converter is given by

$$V_{0(av)} = \frac{V_m}{2\pi}(\text{Cos}\,\alpha - \text{Cos}\,\beta)$$

(b)	A single phase half wave ac voltage controller has an input voltage of 120 V and a load resistance of 5Ω. The firing angle of thyristor is 60^0. **Calculate** average output voltage, rms output voltage, power factor.	5	K3	CO3

Sol	$V_{0(rms)} = \frac{V_m}{2}\left(\frac{(2\pi-\alpha)+\frac{\sin 2\alpha}{2}}{\pi}\right)^{\frac{1}{2}}$ $V_m = V_s\sqrt{2}$ $V_{0(rms)} = 114V$ $I_{0(rms)} = \frac{V_{0(rms)}}{R}$ $I_{0(rms)} = 22.79\,A$ $Active\,load\,power = I^2_{0(rms)}\,R$ $Active\,load\,power = 2598.47W$ $I_{s(rms)} = I_{0(rms)} = 22.79\,A$ $Total\,rms\,power = V_{s(rms)}\,I_{s(rms)}$ $Total\,rms\,power = 2735.64W$ $Power\,Factor = \frac{Active\,Load\,Power}{Total\,rms\,Power}$ $Power\,Factor = 0.9498$	**Calculation of $V_{0(rms)}$ = 2M** **Calculation of $I_{0(rms)}$ = 1M** **Calculation of PF = 2M**		
(c)	With the help of circuit diagram, explain the operation of a single phase full converter with RL load. **Derive** expression for rms and average output voltages.	5	K3	CO3
Sol	 During the positive half of the input signal, thyristor S_1 & S_2 are ON, with the application of gate pulse to both the thyristor. Current flows through the load and inductor charges. During the negative half of the input signal, thyristor S_1 & S_2 should turn ON. Because of the inductive effect, it forces the thyristors S_1 & S_2 to be OFF condition till the inductor discharges completely.	Circuit – 1M Explanation – 1M Waveform – 1M Derivation – 2M		

	 Expression for average output voltage is given by $V_{o(avg)} = \frac{2V_m}{\Pi} \cos\alpha$ Expression for average output voltage is given by $V_{o(rms)} = \frac{V_m}{\sqrt{2}}$			

Course In charge

Head - Dept

21/10/19

Principal

K.S. SCHOOL OF ENGINEERING AND MANAGEMENT, BANGALORE - 560109
DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING
III SESSIONAL TEST QUESTION PAPER 2019 – 20 ODD SEMESTER
SET-A

USN: | | | | | | | | | | |

Degree	:	**B.E**	**Semester**	:	**VII 'A'&'B'**
Branch	:	**ECE**	**Date**	:	**25-11-2019**
Course Title	:	**Power Electronics**	**Course Code**	:	**15EC73**
Duration	:	**90 Minutes**	**Max Marks**	:	**30**

Note: Answer ONE full question from each part

Q. No.	Question	Marks	K Level	CO mapping
	PART-A			
1(a)	**Explain** the operation of step-down chopper with R load. Also **derive** the expression for average and rms output voltage.	5	Applying (K3)	CO4
(b)	With a neat sketch and waveforms, **explain** the working of buck regulator.	5	Understanding (K2)	CO4
(c)	**Illustrate** the working of half bridge inverter with R load.	5	Applying (K3)	CO5
	OR			
2(a)	For the step down chopper with source voltage of 230 V, load resistance of 10 Ω with a voltage drop across chopper of 2 V. Duty cycle is 0.4. **Calculate** i) average and rms output voltage ii) Chopper efficiency.	5	Applying (K3)	CO4
(b)	**Explain** the performance parameters of Inverters.	5	Understanding (K2)	CO4
(c)	**Illustrate** the working of full bridge inverter with RL load.	5	Applying (K3)	CO5
	PART-B			
3(a)	**Illustrate** the working principle of step up chopper.	5	Applying (K3)	CO4
(b)	A step up DC chopper has an input voltage of 200 V and an output voltage of 250 V. The blocking period in each cycle of operation is 0.6 μsec. **Calculate** the period of conduction in each cycle.	5	Applying (K3)	CO4
(c)	The single phase half bridge inverter has the DC input of 48 V. The load resistance is 4.8 Ω. **Determine** the i) rms value of output voltage ii) RMS value of fundamental component iii) Total harmonic distortion	5	Applying (K3)	CO5
	OR			
4(a)	**Illustrate** the working of class E chopper.	5	Applying (K3)	CO4
(b)	**Illustrate** the working of boost regulator.	5	Applying (K3)	CO4
(c)	With a neat sketch, **illustrate** the working of single phase thyristorized current source inverter.	5	Applying (K3)	CO5

Course In charge　　　　Head - Dept 20/11/19　　　　Principal

K.S. SCHOOL OF ENGINEERING AND MANAGEMENT, BANGALORE - 560109

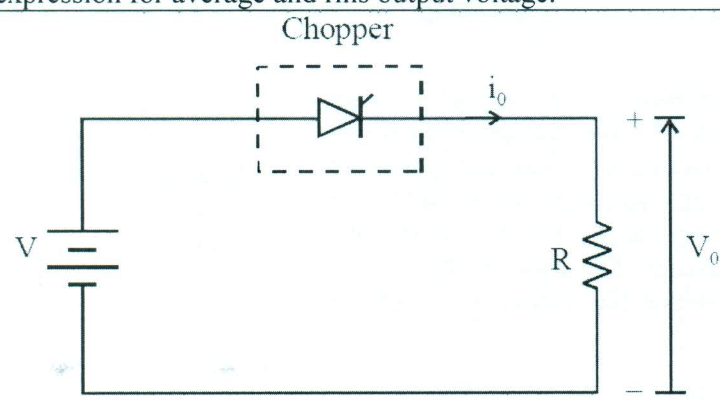
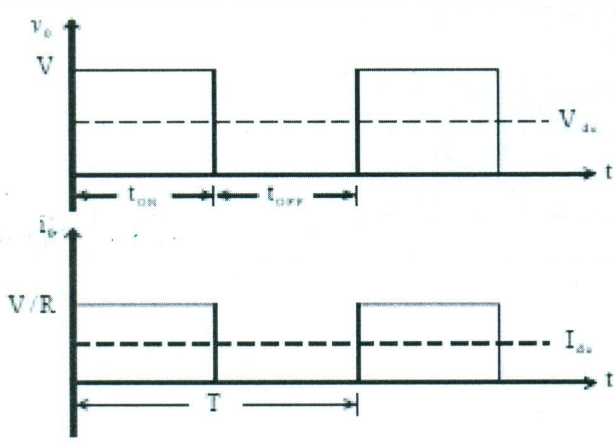
DEPARTMENT OF ELETRONICS AND COMMUNICATION ENGINEERING

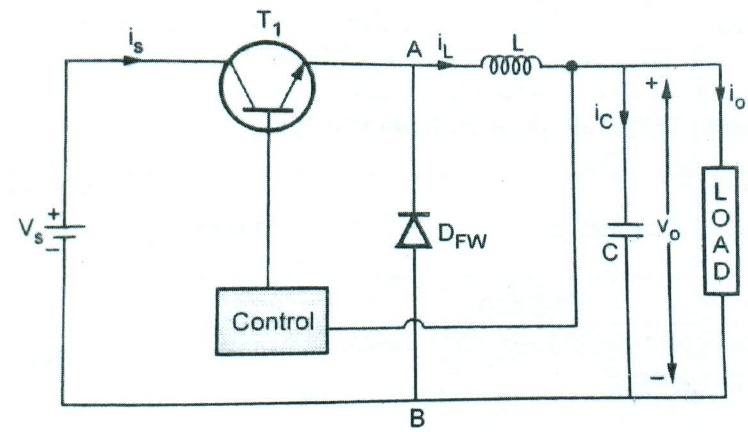
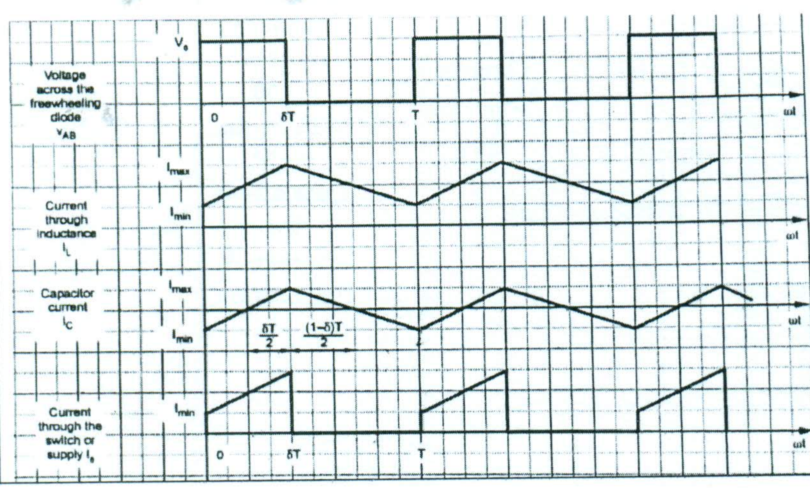
III SESSIONAL TEST SCHEME & SOLUTION 2019 – 20 ODD SEMESTER

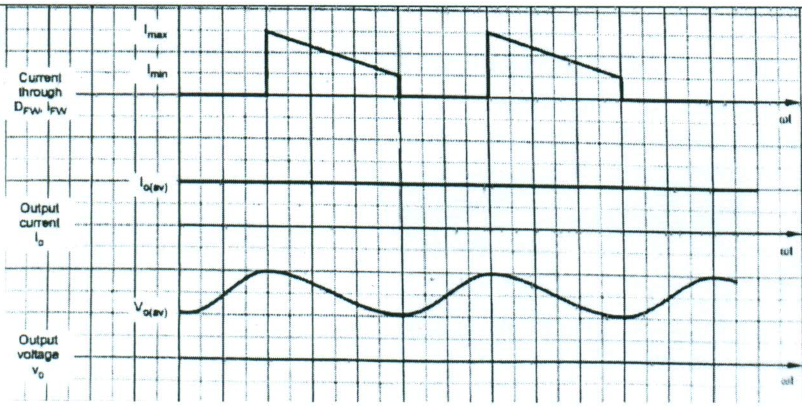
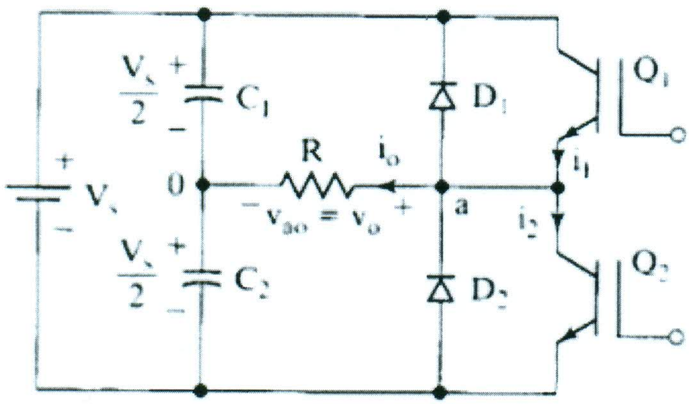
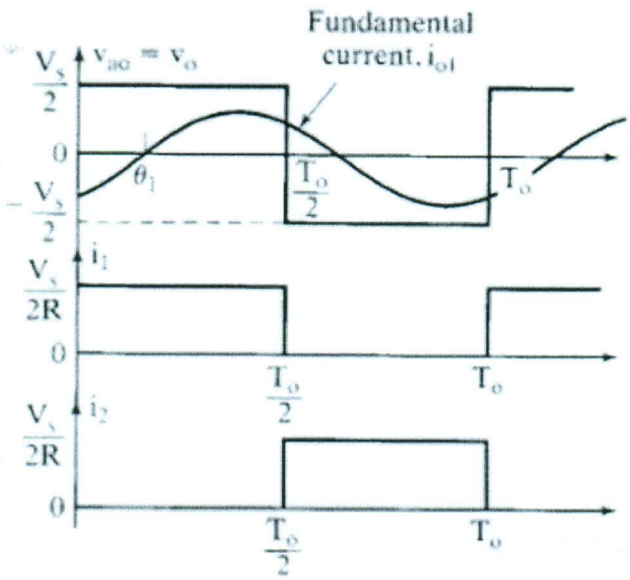
SET-A

Degree	**:**	**B.E**	**Semester**	**:**	**VII 'A'&'B'**
Branch	**:**	**ECE**	**Date**	**:**	**25-11-2019**
Course Title	**:**	**Power Electronics**	**Course Code**	**:**	**15EC73**
Duration	**:**	**90 Minutes**	**Max Marks**	**:**	**30**

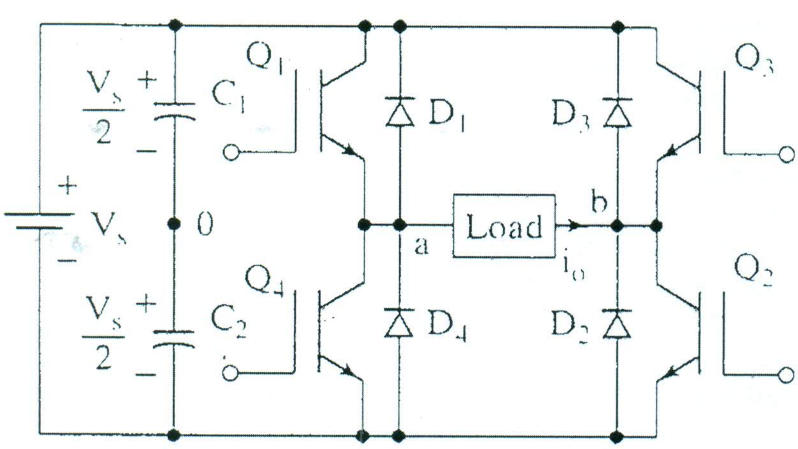
Note: Answer ONE full question from each part

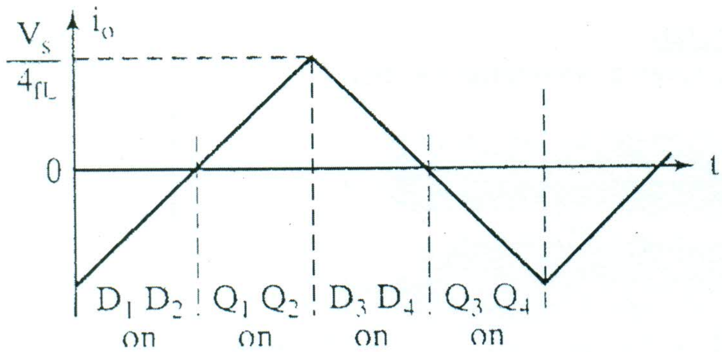
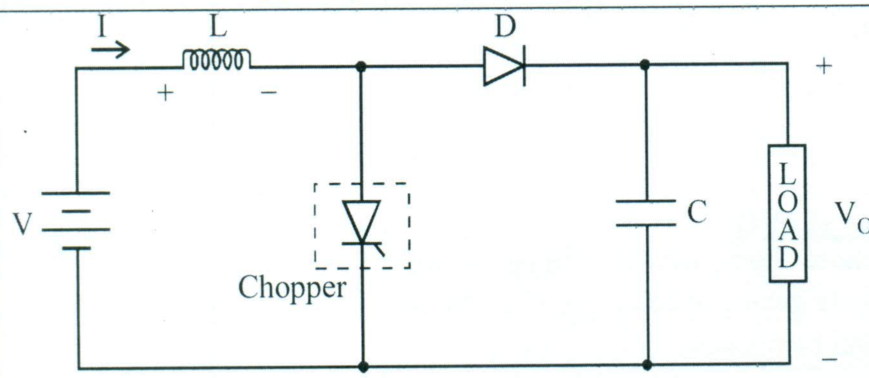
Q. No.	Questions with Scheme & Solution	Marks	K Level	CO mapping
	PART-A			
1(a)	**Explain** the operation of step-down chopper with R load. Also **derive** the expression for average and rms output voltage.	5	K3	CO2
Sol	 The switch is turned for the duration 0 to δT (T_{ON}).Hence supply gets connected to load. Therefore $V_0 = V_S$. From δT to T switch is turned OFF. Hence load voltage is zero. Since load is resistive, Output current is same at output voltage. 	Circuit + Explanation – 2M – 1M Waveform – 1M Expression for Average & rms current – 2M		

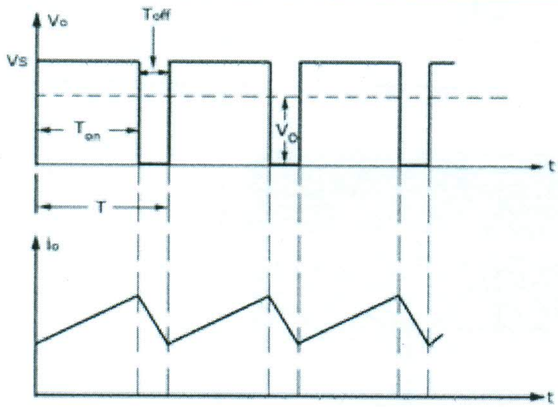
	The expression for average current is given by $V_{0(av)} = \delta V_S$ The expression for rms current is given by $V_{0(rms)} = \sqrt{\delta}\, V_S$			
(b)	With a neat sketch and waveforms, **explain** the working of buck regulator.	**5**	**K2**	**CO3**
Sol	 The switch is turned ON from 0 to δT. Hence current through inductor increases. The current reaches to I_{max} at δT. The transistor switch is turns OFF at δT. The inductance tries to maintain inductor current in the same direction. Voltage across inductor forward biases FWD. The inductance current reduces and becomes minimum at T. The inductance tries to remove ripple in the output current. The capacitance tries to remove ripple in the output voltage. Hence the capacitance value is increased to remove the ripple in V_0. 	Circuit – 2M Explanation – 2M Waveform – 1M		

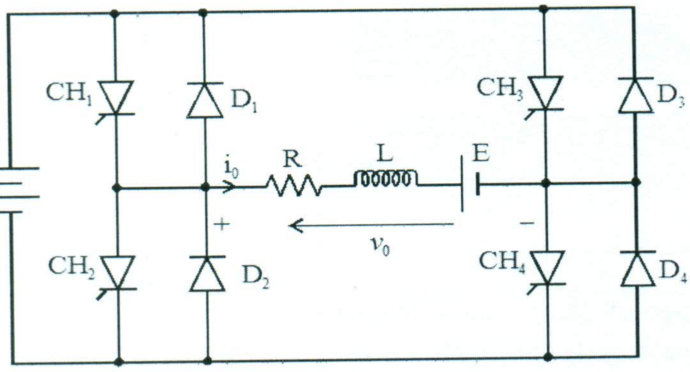
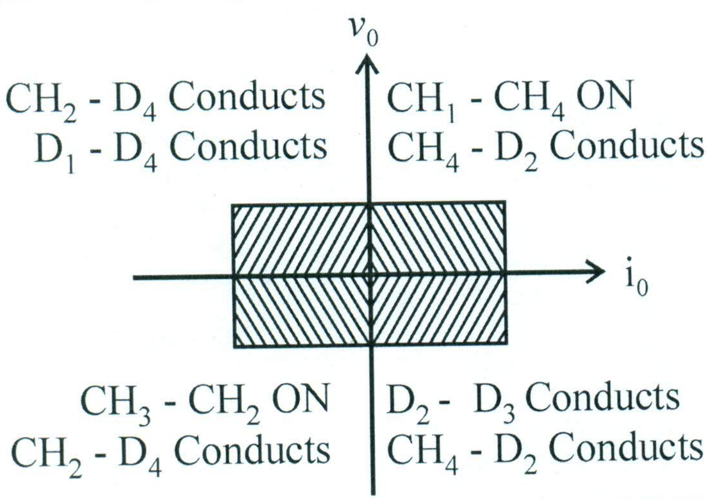
				
(c)	**Illustrate** the working of half bridge inverter with R load.	**5**	**K3**	**CO3**
Sol	 	Circuit – 2M Explanation – 2M Waveform – 1M		

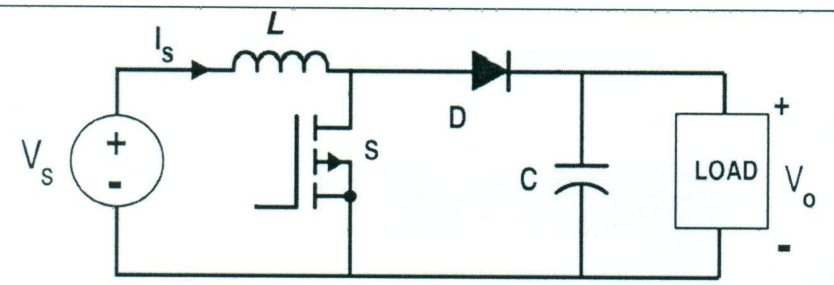
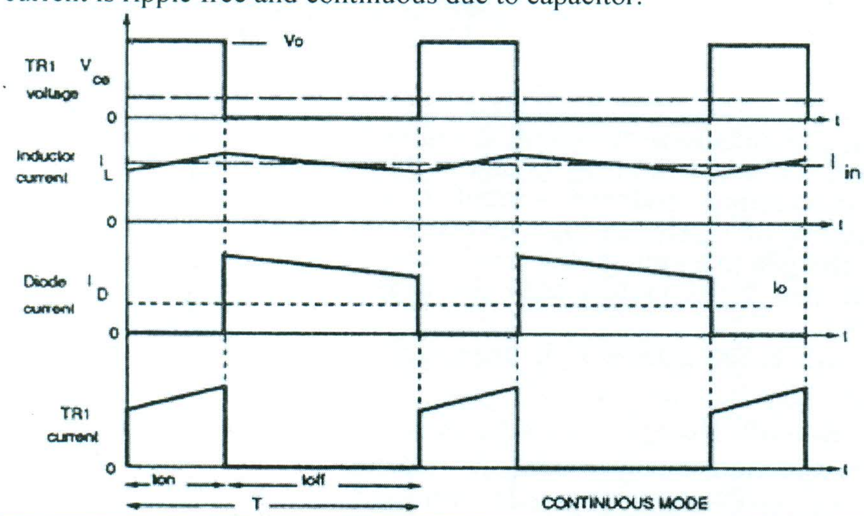
	1. When Q1 is ON, Q2 is OFF and the voltage at the terminal a of the load is $+V_s/2$ with irrespective of the direction of current through the load. Similarly, when Q2 is ON, the Q1 is OFF and the potential at point a is $-V_s/2$. 2. The load voltage is a square-wave of amplitude $V_s/2$. For a resistive load the current waveform follows the voltage waveform (as shown). For an inductive load the current waveform lags the voltage waveform by an angle which is, approximately, the load power factor angle.			
	OR			
2(a)	For the step down chopper with source voltage of 230 V, load resistance of 10 Ω with a voltage drop across chopper of 2 V. Duty cycle is 0.4. **Calculate** i) average and rms output voltage ii) Chopper efficiency.	**5**	**K3**	**CO2**
Sol	$V_{0(av)} = \delta(V_s - V_{ch})$ $V_{0(av)} = 91.2V$ $V_{0(rms)} = \sqrt{\delta}\, V_s$ $V_{0(rms)} = 144.2V$ $P_0 = \frac{1}{T}\int_0^{\delta} \frac{V_0^2}{R} dt$ $P_0 = \delta \frac{(V_s - V_{ch})^2}{R}$ $P_0 = 2079.36W$ $P_s = \delta V_s \frac{V_s - V_{ch}}{R}$ $P_s = 2079.6W$ $\eta = \frac{P_0}{P_S}$ $\eta = 99.13\%$	Calculation of P_0 – 2M P_S – 2M η – 1M		
(b)	**Explain** the performance parameters of Inverters.	**5**	**K2**	**CO3**
Sol	1. **<u>Harmonic factor of the nth harmonic (HF_n)</u>** $HF_n = \frac{V_{on}}{V_{o1}}$ for n>1 V_{on} = rms value of the nth harmonic component V_{01} = rms value of the fundamental component			

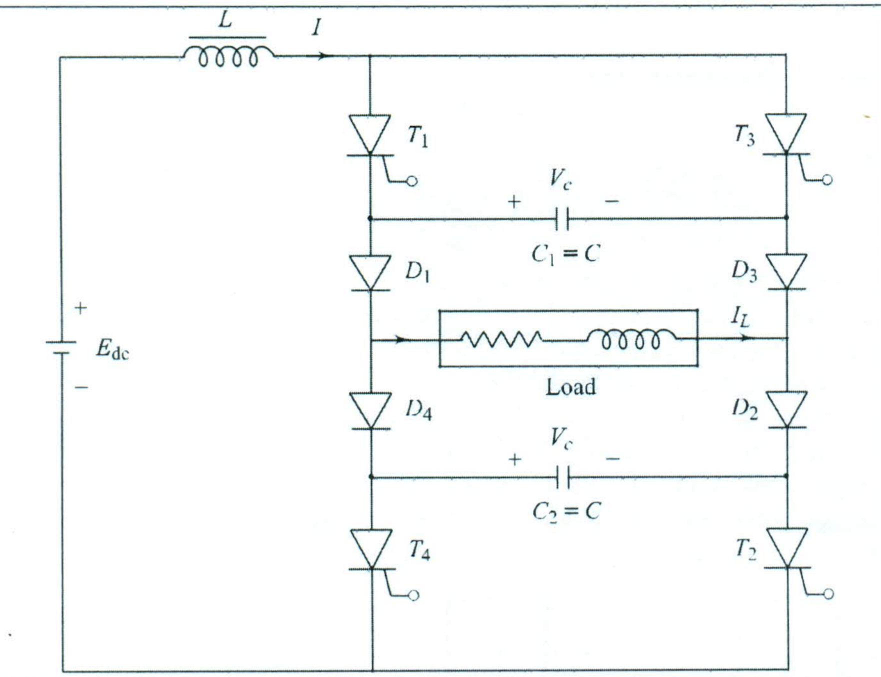
	2. Total Harmonic Distortion (THD) Measures the "closeness" in shape between a waveform and its fundamental component $$THD = \frac{1}{V_{o1}}\left(\sum_{n=2,3,\ldots}^{\infty} V_{on}^2\right)^{\frac{1}{2}}$$ **3. Distortion Factor (DF)** Indicates the amount of HD that remains in a particular waveform after the harmonics have been subjected to second-order attenuation. $$DF = \frac{1}{V_{o1}}\left[\sum_{n=2,3,\ldots}^{\infty}\left(\frac{V_{on}}{n^2}\right)^2\right]^{\frac{1}{2}}$$ $$DF_n = \frac{V_{on}}{V_{o1}n^2}$$ **4. Lowest order harmonic (LOH)** The harmonic component whose frequency is closest to the fundamental, and its amplitude is greater than or equal to 3% of the amplitude of the fundamental component.	Explanation – 5M		
(c)	**Illustrate** the working of full bridge inverter with RL load.	**5**	**K3**	**CO3**
Sol	 • Consists of 4 choppers and a 3-wire DC source • Q_1-Q_2 and Q_3-Q_4 switched on and off alternately • Need to isolate the gate signal for Q_1 and Q_3 (upper) • Each pair provide opposite polarity of V_s across the load • Q_1-Q_2 on, Q_3-Q_4 off, $v_o = V_s$ • Q_3-Q_4 on, Q_1-Q_2 off, $v_o = -V_s$ Load current for a highly inductive load	Circuit – 2M Explanation – 2M Waveform – 1M		

				
	PART-B			
3(a)	**Illustrate** the working principle of step up chopper.	**5**	K3	CO2
Sol	 • Step-up chopper is used to obtain a load voltage higher than the input voltage *V*. • The values of *L* and *C* are chosen depending upon the requirement of output voltage and current. • When the chopper is *ON,* the inductor *L* is connected across the supply. • The inductor current *'I'* rises and the inductor stores energy during the *ON* time of the chopper, t_{ON}. • When the chopper is off, the inductor current *I* is forced to flow through the diode *D* and load for a period, t_{OFF}. • The current tends to decrease resulting in reversing the polarity of induced EMF in *L*. • Therefore voltage across load is given by:- $V_O = V + L\frac{dI}{dt}$ *i.e.,* $V_O > V$	Circuit – 2M Explanation – 2M Waveform – 1M		

				
(b)	A step up DC chopper has an input voltage of 200 V and an output voltage of 250 V. The blocking period in each cycle of operation is 0.6 msec. **Calculate** the period of conduction in each cycle.	**5**	**K3**	**CO3**
Sol	$V_{0(av)} = \frac{V_S}{1-\delta}$ $1-\delta = \frac{V_S}{V_{0(av)}}$ $\delta = 1 - \frac{V_S}{V_{0(av)}}$ $\delta = 0.2$ $\delta = \frac{T_{ON}}{T_{ON}+T_{OFF}}$ $T_{ON} = 0.15\,m\sec$	Calculation of δ– 3M T_{ON} – 2M		
(c)	The single phase half bridge inverter has the DC input of 48 V. The load resistance is 4.8 Ω. **Determine** the i) rms value of output voltage ii) RMS value of fundamental component iii) Total harmonic distortion	**5**	**K3**	**CO3**
Sol	$V_{0(rms)} = \frac{V_s}{2}$ $V_{0(rms)} = 24V$ $V_{1(rms)} = \frac{2V_S}{\sqrt{2}\pi}$ $V_{1(rms)} = 21.6\ V$ $THD = \frac{\sqrt{V_{0(rms)}^2 - V_1^2}}{V_1}$ $V_{(harmonics)} = \left(V_{0(rms)}^2 - V_1^2\right)^{1/2}$ $V_{(harmonics)} = 10.46$ $THD = 48.4\,\%$	Calculation of $V_{0(rms)}$ - 1M $V_{1(rms)}$ –1M $V_{(harmonics)}$ – 2M THD – 2M		

	OR			
4(a)	**Illustrate** the working of class E chopper.	**5**	**K3**	**CO2**
Sol	<u>Class E Chopper</u>  Four Quadrant Operation • Class E is a four quadrant chopper • When CH_1 and CH_4 are triggered, output current i_O flows in positive direction through CH_1 and CH_4, and with output voltage $v_O = V$. • This gives the first quadrant operation. • When both CH_1 and CH_4 are OFF, the energy stored in • the inductor L drives i_O through D2 and D_3 in the same direction, but output voltage $v_O = -V$. • Therefore the chopper operates in the fourth quadrant. • When CH_2 and CH_3 are triggered, the load current i_O flows in opposite direction & output voltage $v_O = -V$. • Since both i_O and v_O are negative, the chopper operates in third quadrant • When both CH_2 and CH_3 are OFF, the load current i_O continues to flow in the same direction D_1 and D_4 and the output voltage $v_O = V$. • Therefore the chopper operates in second quadrant as v_O is positive but i_O is negative.  	Circuit – 2M Explanation – 3M		
(b)	**Illustrate** the working of boost regulator.	**5**	**K3**	**CO3**

Sol	 The switch is turned ON. It conducts for the time interval 0 to δT. Hence current flows in the inductance. Inductance stores energy during this period. The output voltage and current is maintained by the filter capacitor. The output voltage drops slightly due to discharge of capacitor from 0 to δT. The switch is turned OFF at δT. Hence inductance generates a large voltage . This voltage forward biases diode D to maintain current. The current flows through load. The output current is ripple free and continuous due to capacitor. 	Circuit – 2M Explanation – 2M Waveform – 1M		
(c)	With a neat sketch, **illustrate** the working of single phase thyristorised current source inverter.	**5**	**K3**	**CO3**
Sol	The two capacitors store the energy necessary for commutation. The four series diodes effectively prevent the capacitors from discharging through the load in the interval between inverter commutations. Thyristor pair T_1, T_2 and T_3, T_4 are alternatively switched to obtain a nearly square-wave load current. As usual, the triggering frequency of the thyristors determines the output frequency. The circuit behavior during the commutation interval is highly load dependent. The circuit operation proceeds as follows:			

	 *Mode 1:* In this mode between commutations, the constant source current I is flowing in the load, and hence the load voltage is RI. Thyristors T_1 and T_2 are conducting, and the current I is established in the circuit consisting of T_1, D_1, the load, D_2 and T_2. The capacitors C_1 and C_2 are charged to a voltage $V_c = +E_L$ from the previous half-cycle. Note that E_L is greater than the load voltage RI, as shown in Fig. 9.3. *Mode 2:* When thyristors T_3 and T_4 are gated-on, the capacitors C_1 and C_2 apply a reverse-bias to thyristors T_1 and T_2, respectively, causing them to turn-off. However, the load current I continue to flow in the same direction as before, through T_3, C_1 D_1 the load, D_2, C_2 and T_4. The capacitors are in series with the load and are discharged by the constant current I. When the capacitor voltages have fallen from E_L to R_1, diodes D_4 and D_3 conduct and Mode 2 is terminated. *Mode 3:* Thyristors T_3 and T_4, and all four-diodes are now conducting so that the load is effectively connected in parallel with both commutating capacitors. This RLC circuit undergoes a transient response during which the load current falls to zero and reverse. When a load current attains a value – I, diodes D_1 and D_2 become reverse biased. This terminates Mode 3 and completes the commutation process. *Mode 4:* For the next half-cycle, the source current I is flowing through T_3, D_3, the load, D_4, and R_4. Note that the capacitor voltage is now $-E_L$, as shown in Fig and the capacitor hold this voltage until the next commutation.	Circuit – 2M Explanation – 3M		

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