

## 1. PREAMBLE

The significance of the power electronics Lab is renowned in the various fields of engineering applications. For an Electrical Engineer, it is obligatory to have the practical ideas about the power electronics Circuits. By this perspective we have introduced a Laboratory manual cum Observation for power electronics.

The manual uses the plain, cogent and simple language to explain the fundamental aspects of power electronics. The manual prepared very carefully with our level best. It gives all the steps in executing an experiment.

## 2 OBJECTIVE & RELEVANCE

The objective of this Power Electronics laboratory is to study the characteristics of switching devices and its applications in rectifier inverter, chopper and resonant converter. It also introduces the application of electronic devices for conversion, control conditioning of electric power. Further it helps the students to get an overview of different types of power semiconductor devices and their switching characteristics and to understand the operation, characteristics and performance parameters of controlled rectifiers, to study the operation , switching techniques, modulation techniques of pulse width modulated inverters and to understand the harmonic reduction method

### **OUTCOME:**

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- After the completion of this course students are able to analyze the all types of converters by using simulation through PSPICE software
- Understanding of all converters practically .
- Applications of converters

### **3 List of Experiments**

1. Study of Characteristics of SCR, MOSFET & IGBT
2. Gate firing circuits for SCR's
3. Single Phase AC Voltage Controller with R and RL Loads
4. Single Phase fully controlled bridge converter with R and RL loads
5. Single Phase Half controlled converter with R and RL load.
6. Single Phase Cycloconverter with R and RL loads
7. Single Phase series inverter with R and RL loads
8. Single Phase Parallel, inverter with R and RL loads
9. DC Jones chopper with R and RL Loads
10. Forced Commutation circuits ( Class A, Class B, Class C, Class D & Class E)

#### **Any two simulation experiments with PSPICE/PSIM**

1. PSPICE simulation of single-phase full converter using RLE loads
2. PSPICE simulation of single-phase AC voltage controller using RLE loads
3. PSPICE simulation of resonant pulse commutation circuit and Bulk chopper

#### 4 Text and Reference Books:

- T1. M.D Singh & K.B. Kanchandhani ***“Power Electronics”*** Tata Mc Graw – Hill Publishing Company, 2007
- T2. M.H. Rashid ***“Power Electronics: Circuits, Devices and Applications”*** Prentice Hall of India, 2<sup>nd</sup>

#### REFERENCE BOOKS

- R1. Vedam Subramanyam ***“Power Electronics”*** New Age International (P) Limited, Publishers.
- R2 : V.R. Murthy ***“Power Electronics”*** 1<sup>st</sup> Edition 2005, Oxford University Press
- R3 : P.C. Sen ***“Power Electronics”*** Tata Mc Graw-Hill Publishing.

**5. SESSION PLAN**

Sl.No	Name of the Experiment	Week of Experiment
1	Study of Characteristics of SCR, MOSFET & IGBT	Week #1
2	Gate firing circuits for SCR's	Week #2
3	Single Phase AC Voltage Controller with R and RL Loads	Week #3
4	Single Phase fully controlled bridge converter with R and RL loads	Week #4
5	Single Phase Half controlled converter with R and RL load	Week #5
6	Single Phase Cycloconverter with R and RL loads	Week #6
7	Single Phase series inverter with R and RL loads	Week #7
8	Single Phase Parallel, inverter with R and RL loads	Week #8
9	DC Jones chopper with R and RL Loads	Week #9
10	Forced Commutation circuits ( Class A, Class B, Class C, Class D & Class E)	Week #10
11	PSPICE simulation of single-phase full converter using RLE loads	<u>Week #11</u>
12	PSPICE simulation of and single-phase AC voltage controller using RLE loads	<u>Week #12</u>
13	PSPICE simulation of resonant pulse commutation circuit and Bulk chopper	<u>Week #13</u>

## 6 Experiment write up

### 6.1 Study of Characteristics of SCR, MOSFET & IGBT

#### 6.1.1 STUDY OF CHARACTERISTICS OF SCR

**Aim:** To obtain and study the V-I characteristics of SCR and to obtain the values of Latching and Holding currents.

**Apparatus:**

S.No	Equipment	Range	Type	Qty
1	PE Trainer Kit		-	01
2	Ammeter	( 0 – 2 )A	DC	01
3	Ammeter	( 0 – 200 )A	DC	01
4	Voltmeter	(0 – 600) V	DC	01
5	Lamp Load			01
6	Power Oscilloscope			01

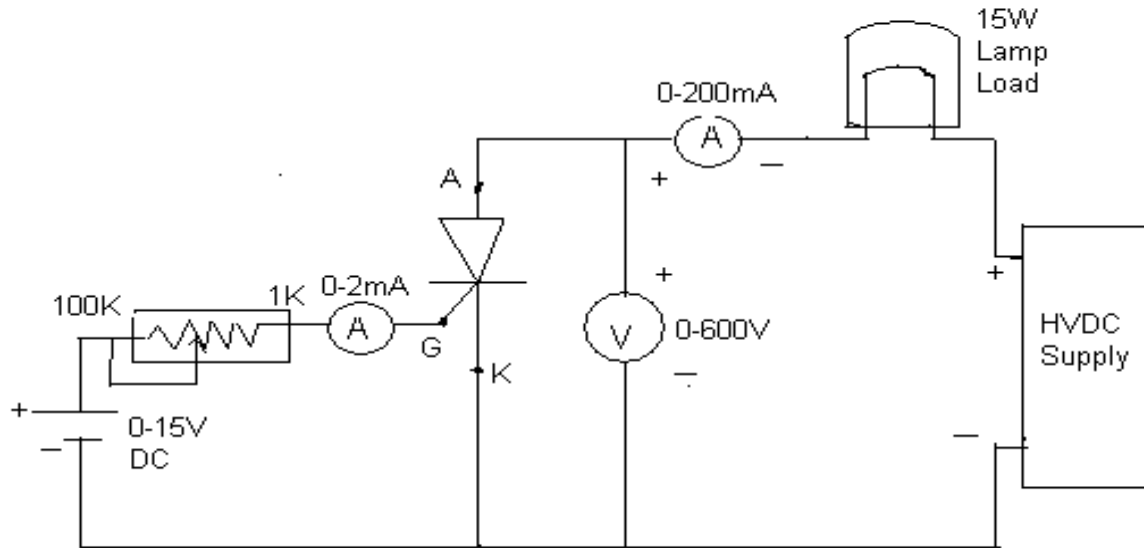
**Theory:**

When Anode is positive with respect to the cathode, SCR is said to be forward biased. Whenever the applied voltage becomes more than the Forward Breakover Voltage ( $V_{BO}$ ), SCR starts conducting. By giving a suitable triggering pulse to the gate, the SCR can be made to conduct at a lower anode to cathode voltage. When the SCR is reverse biased it acts as an open circuit upto Reverse Breakdown voltage after which the SCR breaks down.

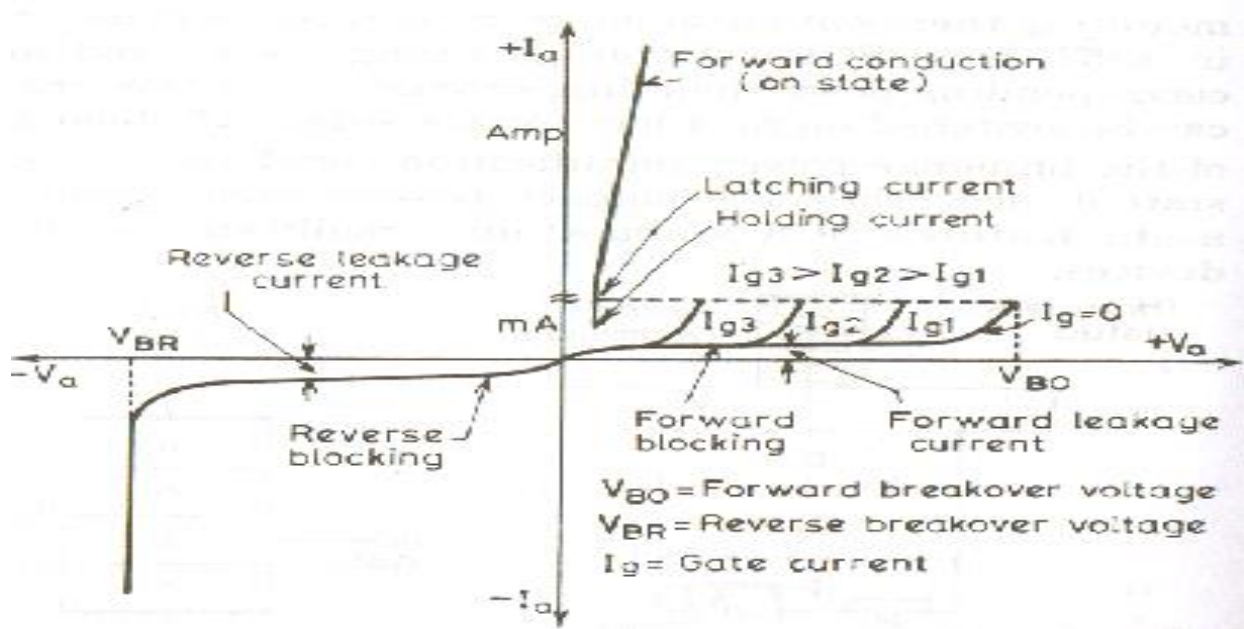
Latching current is the minimum value of anode current which it must attain during turn-on process to maintain conduction when gate signal is removed. Holding current is defined as the minimum value of anode current below which SCR turns off.



**Circuit Diagram :**





**MODEL GRAPH:****PROCEDURE:**

- 1) Connect the circuit as per the circuit diagram. Make sure that the voltage knobs of the power supply are in the minimum position.
- 2) Switch ON the power supply.
- 3) Keep the gate voltage in the zero voltage position.
- 4) Gradually increase the anode voltage from 0V to 200V.
- 5) Observe and note down the anode current and voltage across the SCR for each value of anode voltage.
- 6) Increase the gate voltage to a higher value, say 2.1V & repeat steps (4) & (5).
- 7) Repeat steps (4) & (5) for a higher value of gate voltage.
- 8) For a particular value of gate current reduce the anode voltage. Note down the value of current at which the SCR turns OFF as Holding current.

- 9) Keep the gate voltage at a particular value .Turn ON the SCR .Reduce the gate current in steps and note down the value of current at which SCR remains ON even when the gate current is reduced to zero as Latching current.
- 10) Bring the voltage knobs to the initial position and switch off the supply.
- 11) Draw the graph between anode to cathode voltage and current.

**OBSERVATIONS & TABULAR COLUMN:**

S No	I <sub>g</sub> =    μ A		I <sub>g</sub> =    μ A		I <sub>g</sub> =    μ A	
	V <sub>a</sub> ( V )	I <sub>a</sub> ( A )	V <sub>a</sub> ( V )	I <sub>a</sub> ( A )	V <sub>a</sub> ( V )	I <sub>a</sub> ( A )

**Result:**

### 6.1.2 STUDY OF CHARACTERISTICS OF MOSFET

**AIM:** To obtain and study the V-I characteristics of MOSFET

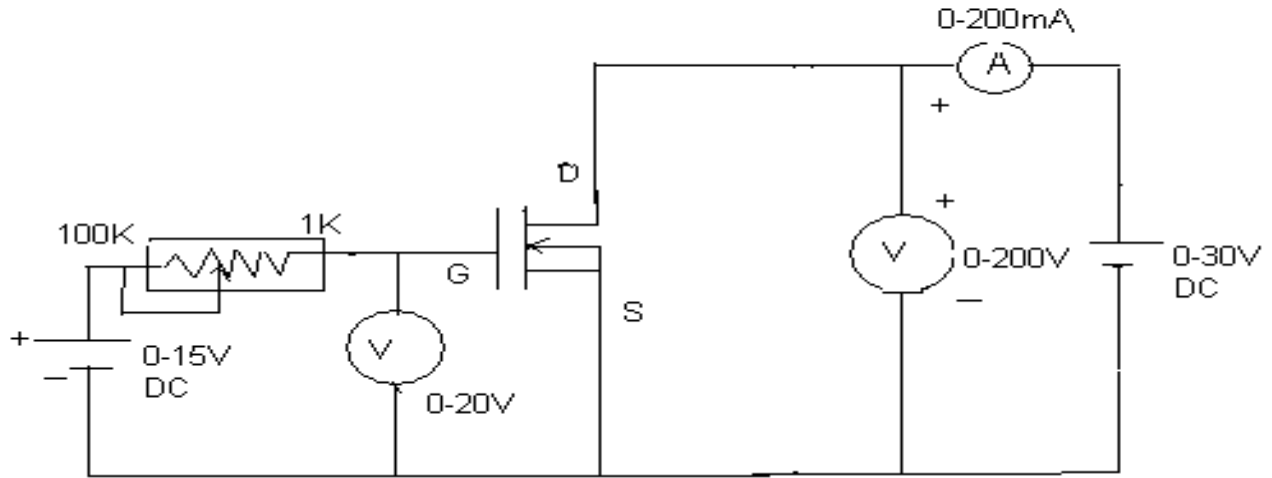
**Apparatus:**

S.No	Equipment	Range	Type	Qty
1	PE Trainer Kit		-	01
2	Ammeter	( 0 – 2 )A	DC	01
3	Ammeter	( 0 – 200 )A	DC	01
4	Voltmeter	(0 – 600) V	DC	01
5	Lamp Load			01
6	Power Oscilloscope			01

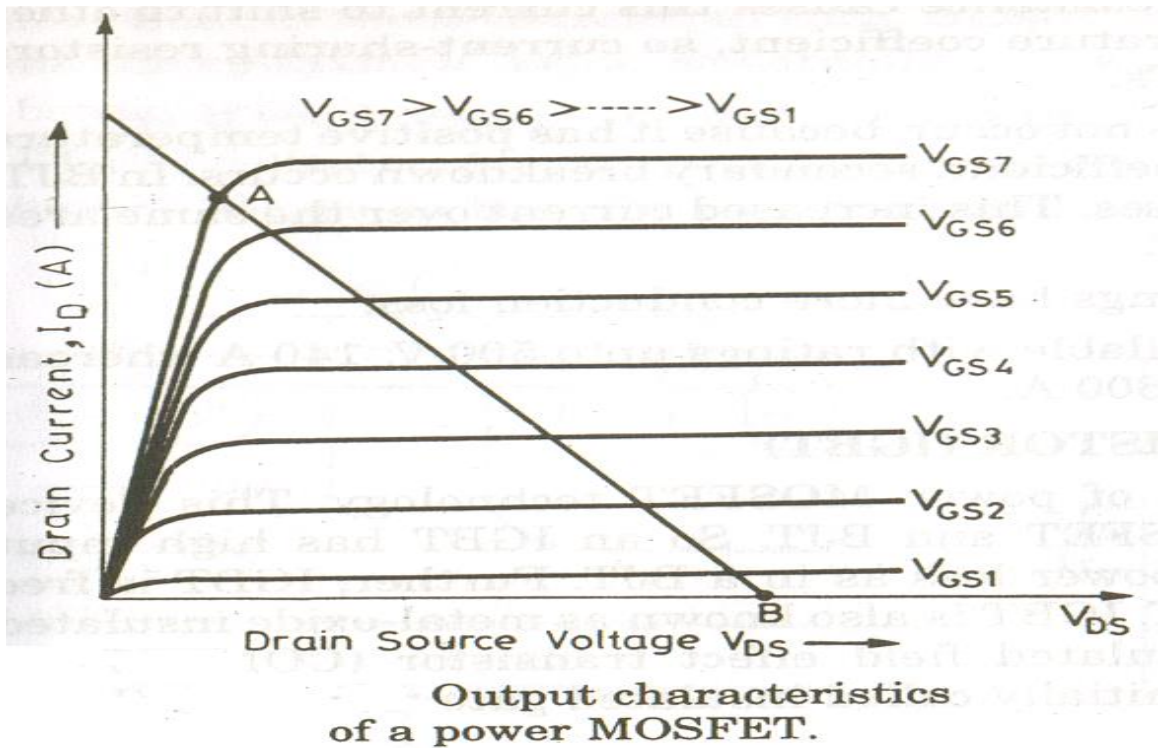
**THEORY:**

A Metal Oxide Semiconductor Field Effect Transistor is a recent device developed by combining the areas of Field-effect concept and MOS Technology. A MOSFET is a voltage controlled device. When gate circuit is open, no current flows from drain to source and load. When gate is made positive with respect to source, an electric field is established and current can flow from drain to source. If  $V_{GS}$  is made more positive more current flows from drain to source which shows that drain current  $I_D$  is enhanced by the gradual increase of gate voltage.

**CIRCUIT DIAGRAM:-**



**MODEL GRAPH:**



**PROCEDURE:**

- 1) Connect the circuit as per the circuit diagram. Make sure that the voltage knobs of the power supply are in the minimum position.
- 2) Switch ON the power supply.
- 3) Keep the gate to source voltage ( $V_{GS}$ ) at zero value.
- 4) Change the value of Drain to source voltage ( $V_{DS}$ ) from zero to maximum value, and for each value of  $V_{DS}$ , note down the value of  $I_D$ .
- 5) Adjust  $V_{DS}$  to a higher value (say 3V) and repeat step(4).
- 6) Repeat step (5) for different values of  $V_{GS}$ .
- 7) Bring the voltage knobs to the initial position and switch off the supply.
- 8) Draw the output characteristics of MOSFET.

**OBSERVATIONS & TABULAR COLUMN:**

S No	$V_{GS} = \quad (V)$		$V_{GS} = \quad (V)$		$V_{GS} = \quad (V)$	
	$I_D$ (A)	$V_{DS}$ (V)	$I_D$ (A)	$V_{DS}$ (V)	$I_D$ (A)	$V_{DS}$ (V)

**Result:**

## 6.2. GATE FIRING CIRCUITS

**AIM:** To learn about different firing circuits ( R,RC & UJT ) used for triggering SCRs..

**Apparatus:**

S.No	Equipment	Range	Type	Qty
1	PE Trainer Kit		-	01
2	Multimeter		Digital	01
3	Lamp Load			01
4	Power Oscilloscope			01

**THEORY:**

There are different methods for triggering an SCR. The most commonly used method is gate triggering. By applying a positive signal at the gate terminal of the SCR, it can be triggered much before the specified break over voltage. The gate triggering is of different types:

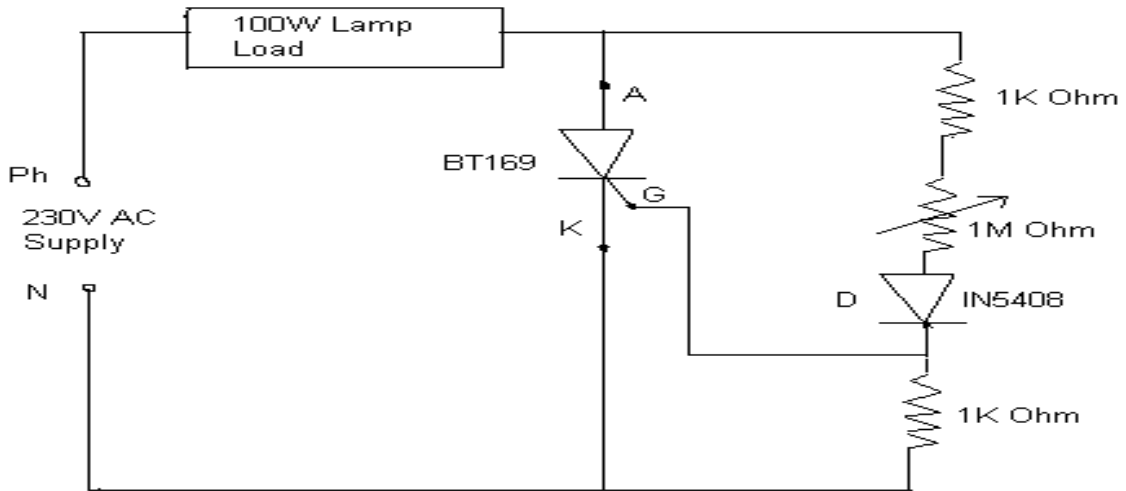
**R-Triggering:** Here the gate current is supplied by an ac source through a fixed resistance, variable resistance and a diode. During the positive half cycle of the input ac voltage, SCR becomes forward biased. Gate current increases as the input increases towards peak value. When  $I_g$  reaches a value equal to the minimum current required for turning ON the SCR, it turns on. By varying the variable resistance connected in the gate circuit, the firing angle can be varied. Limitation of this method is that firing angle can be varied only up to  $90^\circ$ .

**RC Triggering:** Using this circuit, a larger variation in firing angle can be obtained by changing the phase and amplitude of the gate current. By varying the variable resistor, the firing angle can be controlled from 0 to  $180^\circ$ . In the negative half cycle, the capacitor charges through diode D2 with lower plate positive to the peak supply voltage. The capacitor voltage remains constant at  $-E_{\max}$  until the supply voltage attains zero value. Now, as the SCR anode voltage passes through zero and becomes positive, capacitor begins to discharge and charge in the opposite direction. When the capacitor charges to positive voltage equal to gate trigger voltage  $V_{gt}$ , SCR is triggered, and after this capacitor holds to  $V_{gt}$ . During the negative half cycle, diode D1 prevents the turning on of the SCR.

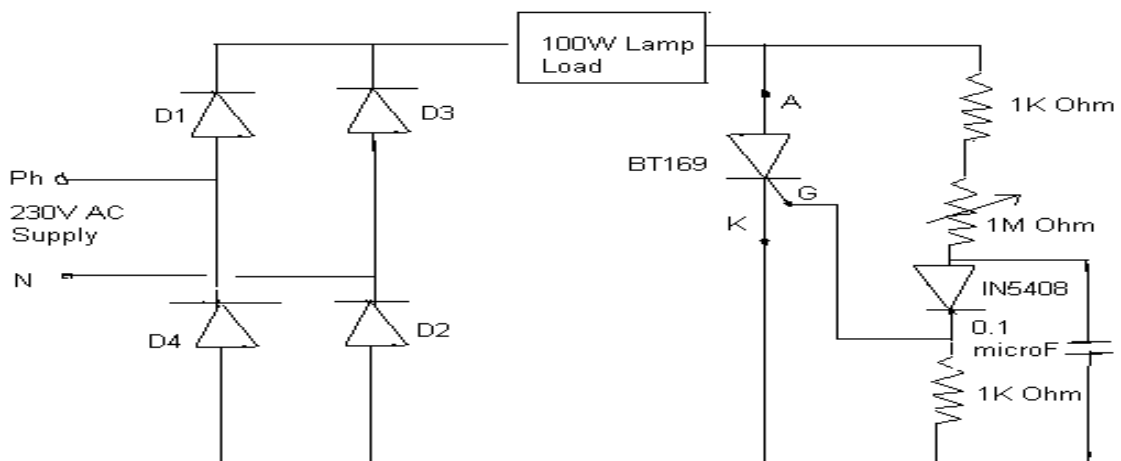
**UJT Triggering:** UJT is often used as a triggering device for SCRs and TRIACs. Here, UJT is used as a relaxation oscillator. The capacitor gets charged, when the supply is ON. When the capacitor voltage becomes equal to the peak voltage, UJT turns on. The capacitor discharges through the low resistance path containing  $R_{B1}$  and  $R_1$ . The pulses produced by the quick discharge of the capacitor is applied across the gate-cathode region of the SCR, to make it turn-on. By varying the resistance  $R_c$ , the charging of the capacitor can be varied, which in turn will vary the time at which UJT turns on and which will vary the firing angle.

**CIRCUIT DIAGRAM:**

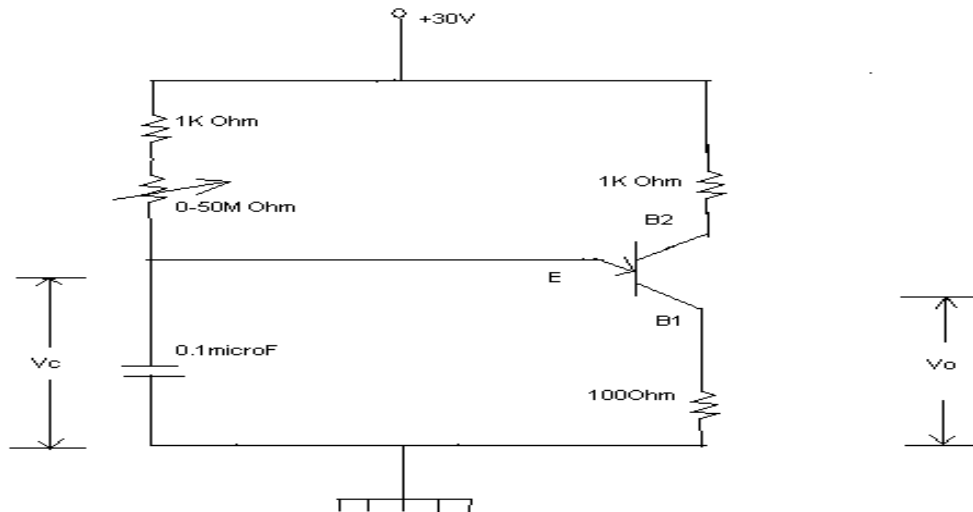
**(1) R- Triggering**



**(ii) RC- Triggering**





**(iii) UJT Triggering****PROCEDURE:**

- 1) Make connections as per the circuit diagram (1).
- 2) Switch on the supply.
- 3) Observe the output waveform in the CRO.
- 4) Vary the firing angle. Observe the change in the waveform.
- 5) Note down the firing angle and corresponding voltage from the multimeter.
- 6) Switch off the supply.
- 7) Make connections as per the circuit diagram (2).
- 8) Repeat the steps (2) to (5).
- 9) Make connections as per the circuit diagram (3).
- 10) Repeat the steps (2) to (5).

**OBSERVATIONS & TABULAR COLUMN:****For R-Triggering**

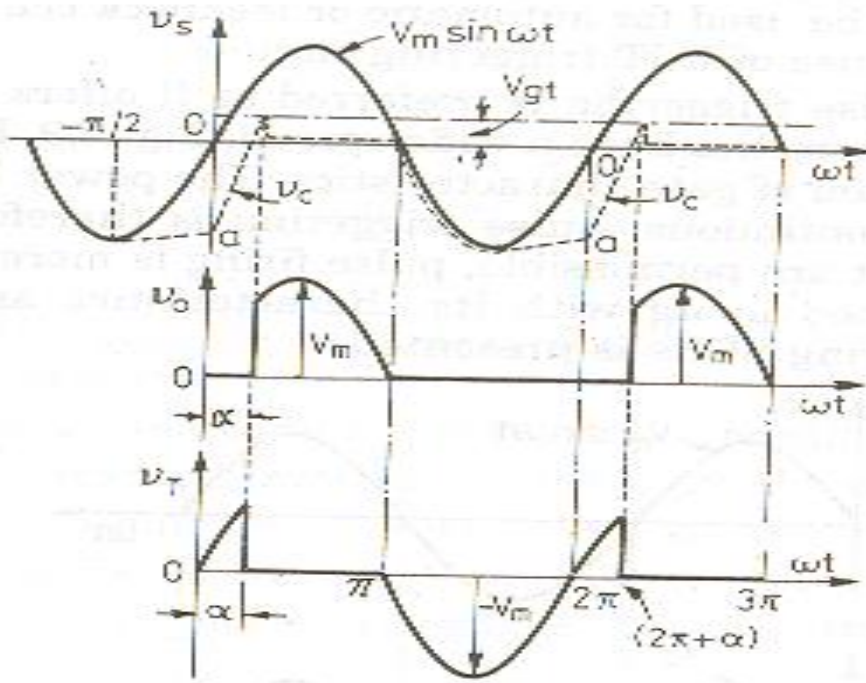
S no.	Firing angle, $\alpha$ (degrees)	Average Voltage (Voltmeter reading)

**For RC -Triggering**

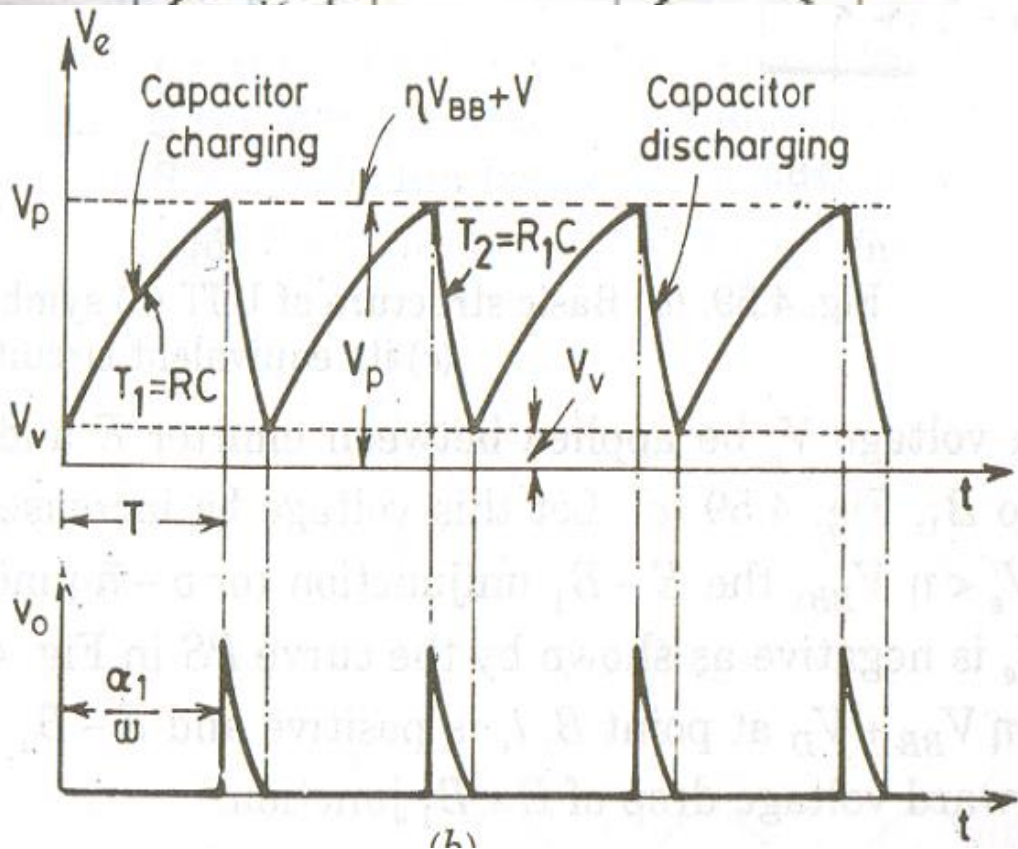
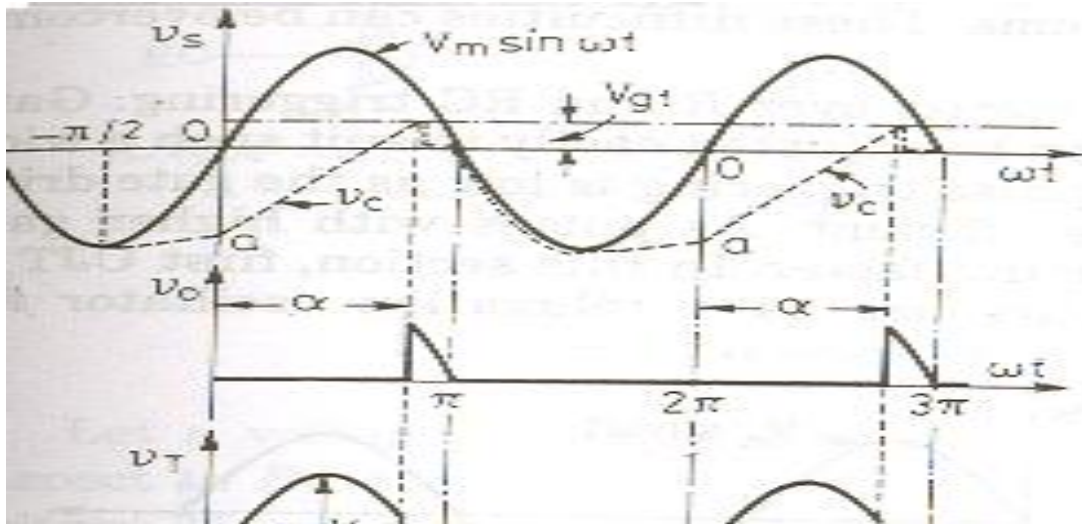
S no.	Firing angle, $\alpha$ (degrees)	Average Voltage (Voltmeter reading)

**For UJT-Trigging**

S no.	Firing angle, $\alpha$ (degrees)	Discharge Time constant, msec



**MODEL GRAPH**



**Result:**

### 6.3. AC VOLTAGE CONTROLLER

**AIM:** To study the operation and observe the waveforms of an A.C. Voltage controller with R & RL load.

**Apparatus:**

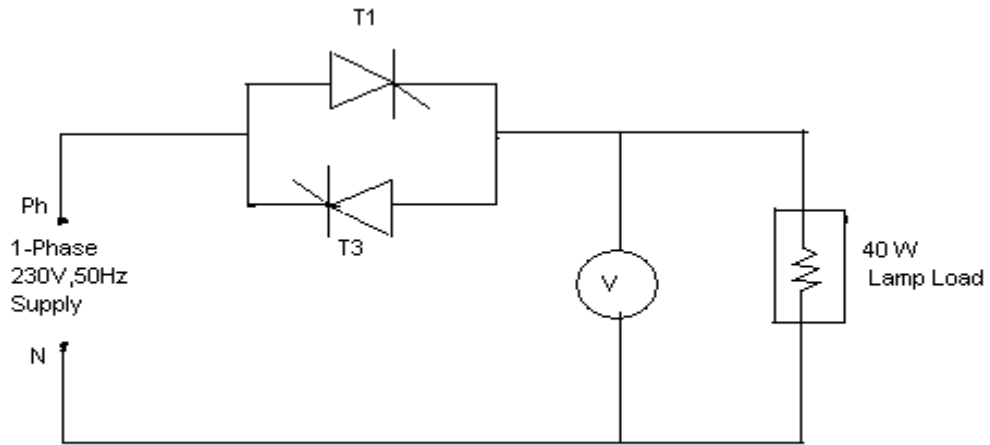
S.No	Equipment	Range	Type	Qty
1	PE Trainer Kit		-	01
2	Multimeter		Digital	01
3	Lamp Load			01
4	Power Oscilloscope			01

**THEORY:**

Ac Voltage controllers are thyristor based devices which convert fixed alternating voltage directly to variable alternating voltage without a change in frequency. A.C voltage controller uses two thyristors connected in antiparallel. Thyristor T1 is forward biased during the positive half cycle of the input voltage. When T1 is triggered at a firing angle  $\alpha$ , it starts conducting. During the conduction period of the SCR ( from  $\alpha$  to  $\pi$  for R load and from  $\alpha$  to  $(\pi + \alpha)$  for RL load) output voltage follows the input voltage.

During the negative half of input voltage T1 is reverse biased and is OFF and T2 is forward biased and it starts conducting from  $(\pi + \alpha)$ . Output voltage follows the input voltage . By changing the firing angle, output voltage can be controlled.

**CIRCUIT DIAGRAM:**



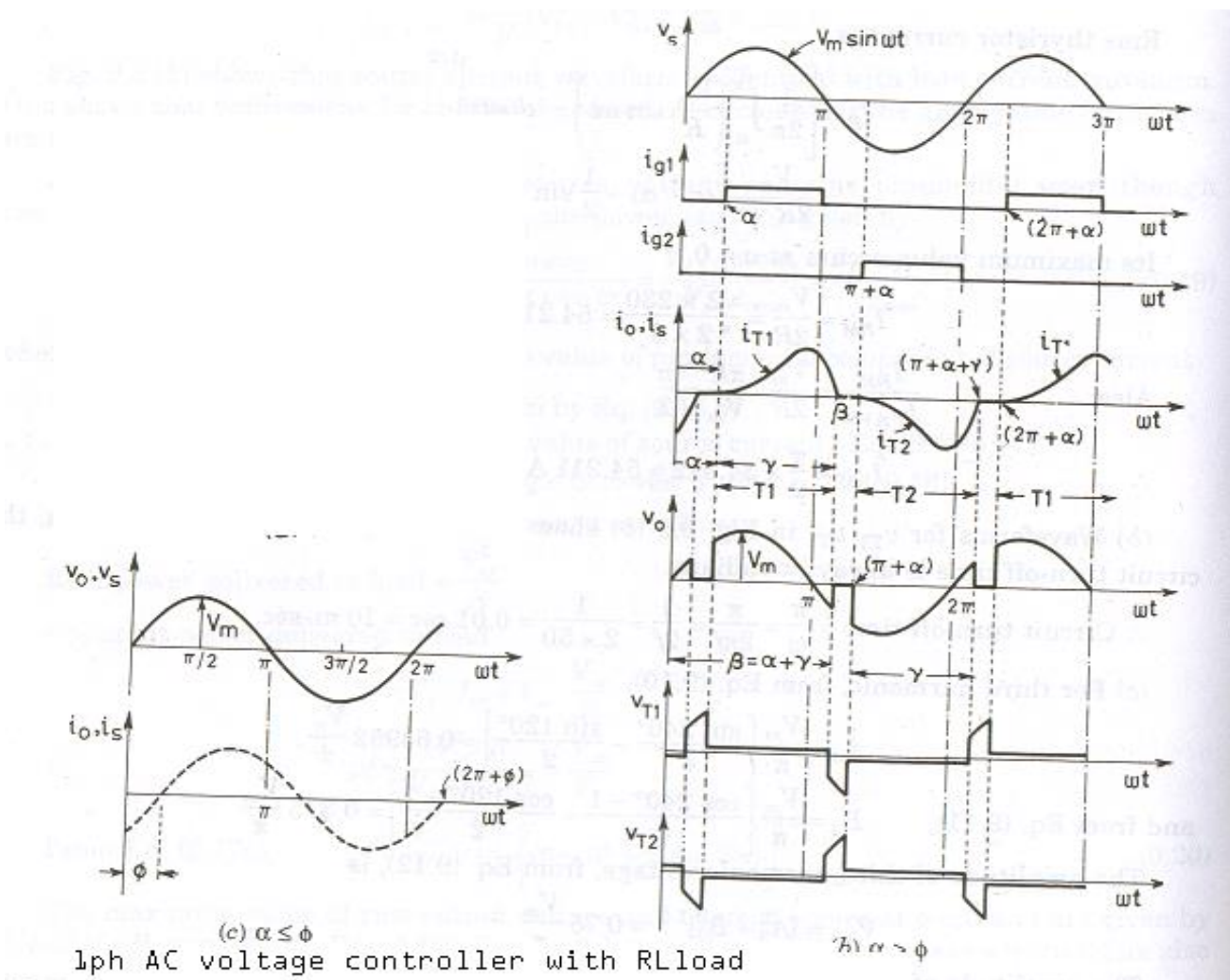
**OBSERVATIONS AND TABULAR COLUMN:**

Firing Angle , $\alpha$	Measured value of Output voltage (volt)	Calculated value of Output voltage (volt)

**Sample Calculation:**

**PROCEDURE:**

- 1) Make connections as per the circuit diagram. Use 100W / 230V lamp as the load.
- 2) Keep the firing pulse selector switch in the 4<sup>th</sup> position ( UJT relaxation oscillator based firing) to get the required gate pulses.
- 3) Switch on the supply.
- 4) Observe the output waveform in the powerscope. Vary the conduction angle and observe the change in the waveform. Note down the output voltage value from the multimeter.



**Result:**

### **6.4. FULLY CONTROLLED CONVERTER**

**AIM:** To study the operation of a fully controlled converter with R & RL loads.

**Apparatus:**

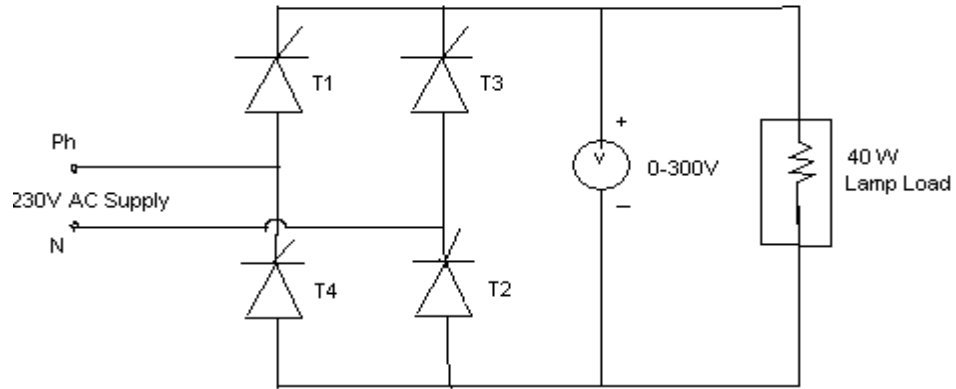
S.No	Equipment	Range	Type	Qty
1	PE Trainer Kit		-	01
2	Multimeter		Digital	01
3	Lamp Load			01
4	Power Oscilloscope			01

**THEORY:**

A fully controlled converter controls output voltage in both the half cycles of the input voltage. T1 & T2 are forward biased in the positive half cycle of the input voltage. When triggered at a firing angle  $\alpha$ , T1 & T2 start conducting from  $\alpha$ . Thus from  $\alpha$  to  $\pi$ , output voltage follows positive half of the input voltage. From  $\pi$  to  $\pi+\alpha$ , thyristors T1 & T2 are reverse biased and T3 & T4 are forward biased. At  $\pi+\alpha$ , T3 & T4 are triggered. Current flows through the load in the same direction giving a positive value of output voltage. Thus unidirectional current flows through the load in both the half cycles of input AC. By controlling the value of  $\alpha$ , we can control the output voltage.



**CIRCUIT DIAGRAM:**



**PROCEDURE:**

- 1) Make connections as per the circuit diagram. Use 100W / 230V lamp as the load.
- 2) Keep the firing pulse selector switch in the 4<sup>th</sup> position( UJT relaxation oscillator based firing) to get the required gate pulses. $I_p$
- 3) Switch on the supply.
- 4) Observe the output waveform in the power scope. Vary the conduction angle and observe the change in the waveform. Note down the output voltage value from the multimeter and compare with the value obtained from the formula.

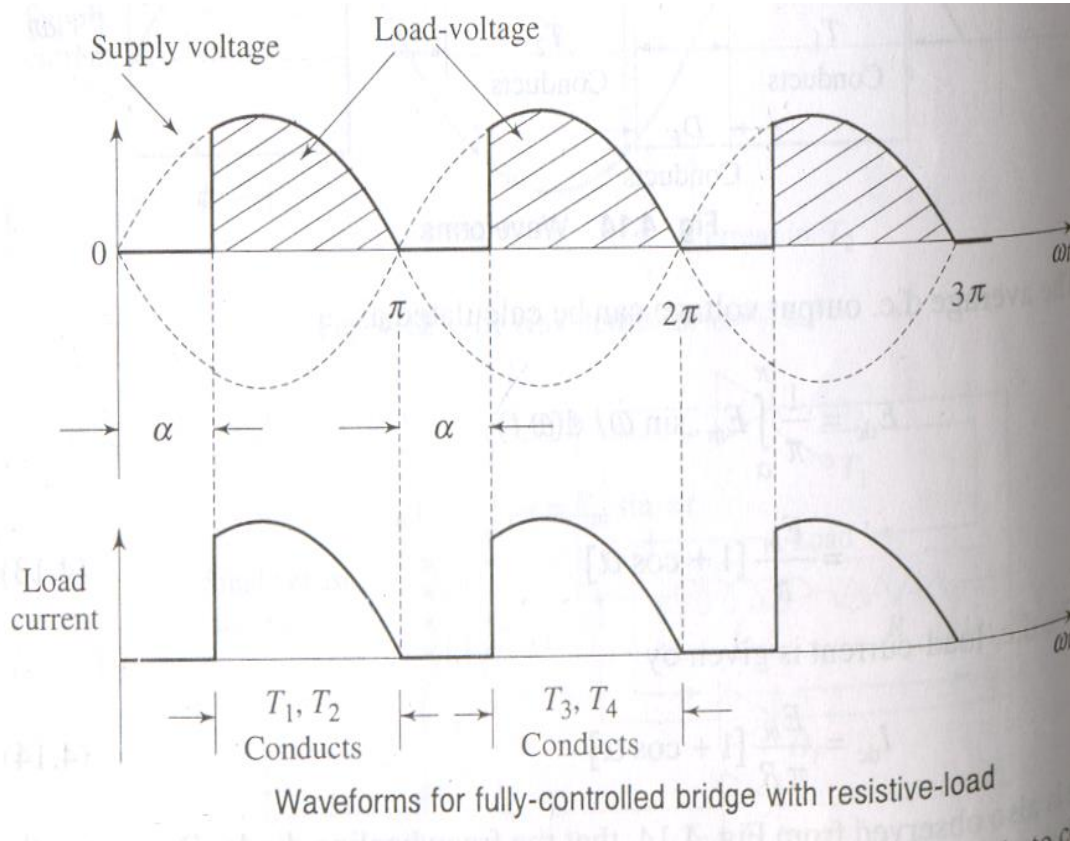
**OBSERVATIONS & TABULAR COLUMN:**

Peak Voltage,  $V_m =$

S no.	Firing angle, $\alpha$ (degrees)	Average voltage (as per formula)	Average Voltage (Voltmeter reading)

**SAMPLE CALCULATION:**

**Model graph:**



**MODEL GRAPH:**

**Result:**

### 6.5. HALF CONTROLLED CONVERTER

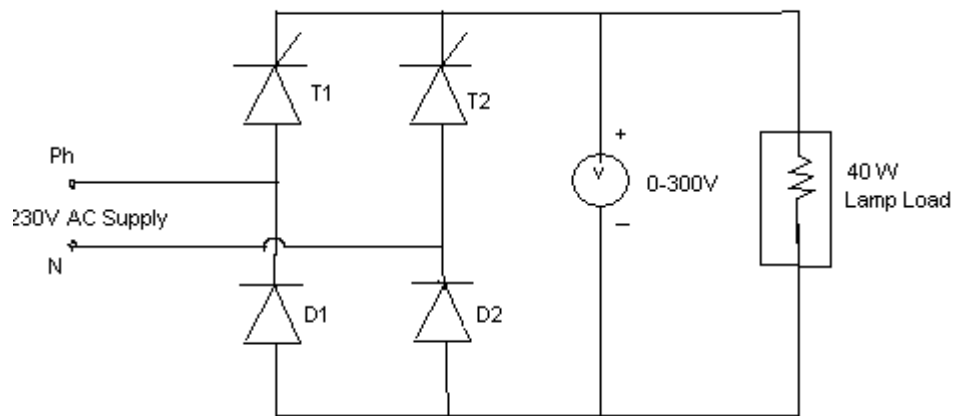
**AIM:** To study the operation of a half controlled converter with R & RL loads.

**Apparatus:**

S.No	Equipment	Range	Type	Qty
1	PE Trainer Kit		-	01
2	Multimeter		Digital	01
3	Lamp Load			01
4	Power Oscilloscope			01

**THEORY:**

A half controlled converter controls output voltage in both the half cycles of the input voltage. T1 & D2 are forward biased in the positive half cycle of the input voltage. When triggered at a firing angle  $\alpha$ , T1 starts conducting from  $\alpha$ . Thus from  $\alpha$  to  $\pi$ , output voltage follows positive half of the input voltage. From  $\pi$  to  $\pi+\alpha$ , thyristor T1 & diode D2 get reverse biased and D1 & T2 are forward biased. At  $\pi+\alpha$ , T2 is triggered. Current flows through the load in the same direction giving a positive value of output voltage. Thus unidirectional current flows through the load in both the half cycles of input AC. By controlling the value of  $\alpha$ , we can control the output voltage.

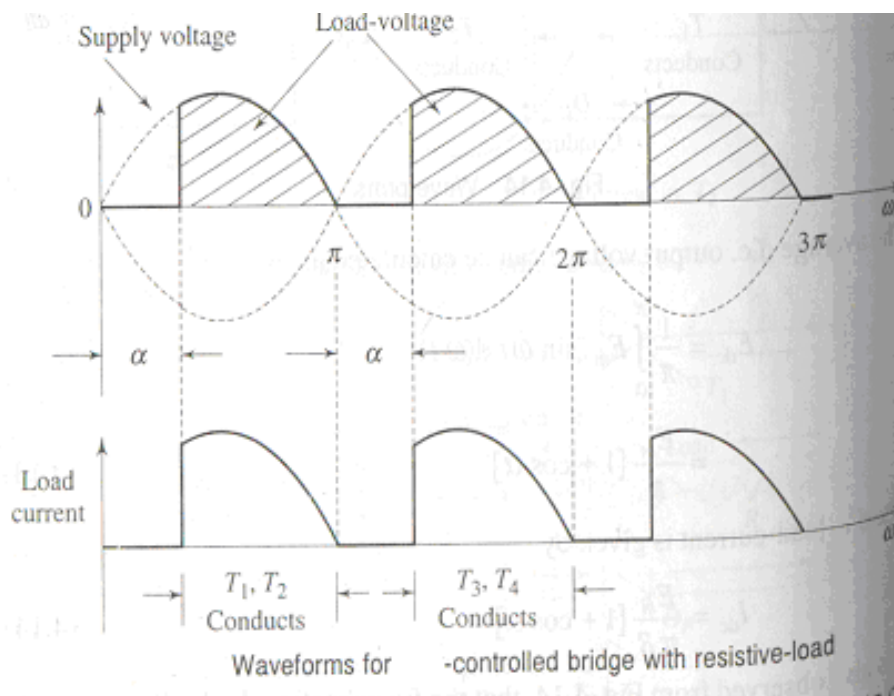
**CIRCUIT DIAGRAM:****PROCEDURE:**

- 1) Make connections as per the circuit diagram. Use 40W / 230V lamp as the load.
- 2) Switch on the supply.
- 3) Observe the output waveform in the powerscope.
- 4) Vary the conduction angle and observe the change in the waveform. Note down the output voltage value from the multimeter and compare with the value obtained from the formula

**OBSERVATIONS & TABULAR COLUMN:** Peak Voltage,  $V_m =$

S no.	Firing angle, $\alpha$ (degrees)	Average voltage (as per formula)	Average Voltage (Voltmeter reading)

**SAMPLE CALCULATION:**



Model Graph

**Result:**

**6.6. SINGLE PHASE CYCLO CONVERTER**

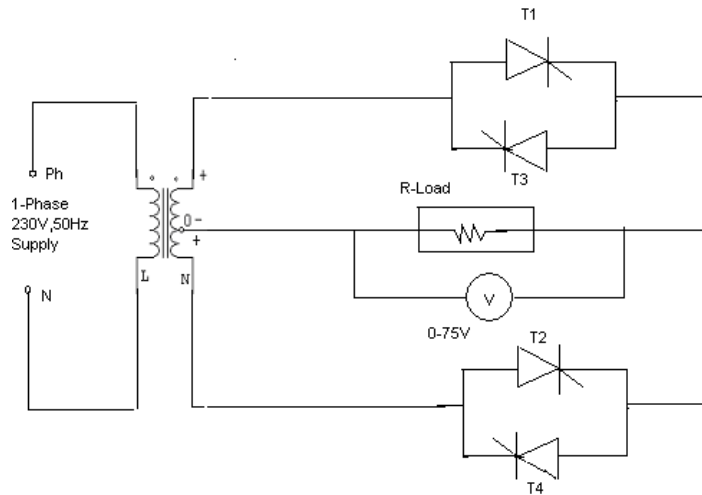
**AIM:** To study the operation of a cyclo converter with R load.

**Apparatus:**

S.No	Equipment	Range	Type	Qty
1	PE Trainer Kit		-	01
2	Multimeter		Digital	01
3	Lamp Load			01
4	Power Oscilloscope			01

**THEORY:**

Cyclo converters are used for frequency conversion. Groups of antiparallely connected SCRs are used here. By selecting which SCR is to be triggered at a particular time, we can change the output voltage frequency according to the requirement.

**CIRCUIT DIAGRAM:****PROCEDURE:**

- 1) Make connections as per the circuit diagram.
- 2) Keep the firing pulse selector switch in the 2<sup>nd</sup> position ( for 25Hz output) to get the required gate pulses.
- 3) Switch on the supply.
- 4) Observe the output waveform in the CRO.
- 5) Repeat the procedure with mode selector switch in position 3 (for 12.5Hz operation).

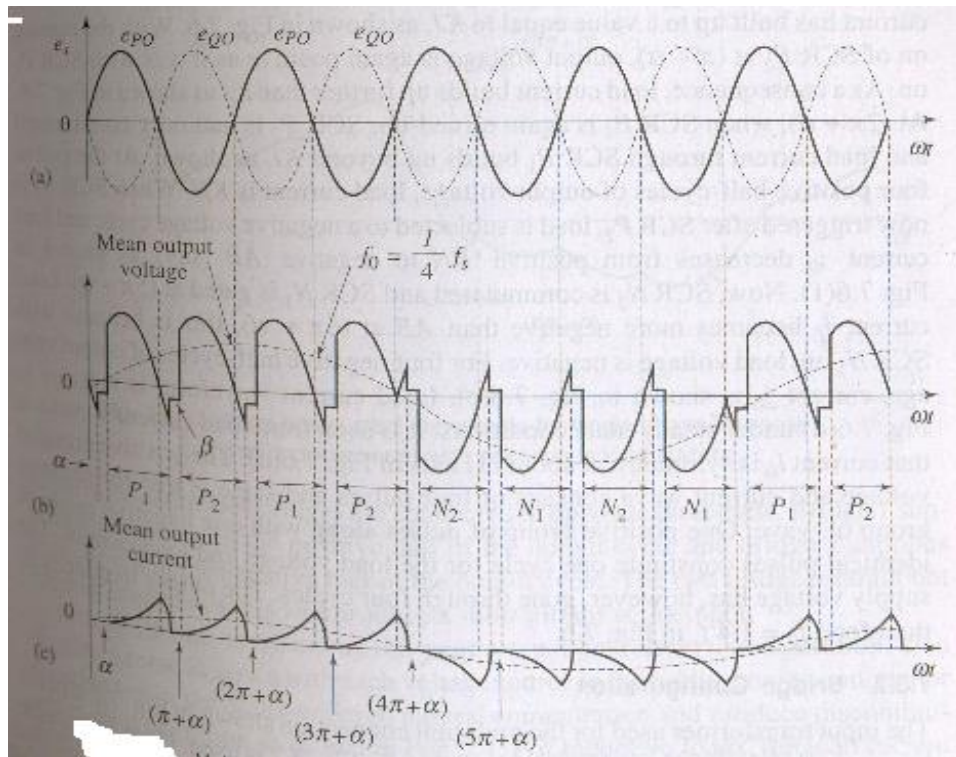
**OBSERVATIONS**

Frequency of the input voltage =

Frequency of the output voltage =

**SAMPLE CALCULATION:**

**MODEL GRAPH:**



**Result:**



### 6.7. SERIES INVERTER

**AIM:** To study the operation of a  $1\Phi$  series inverter.

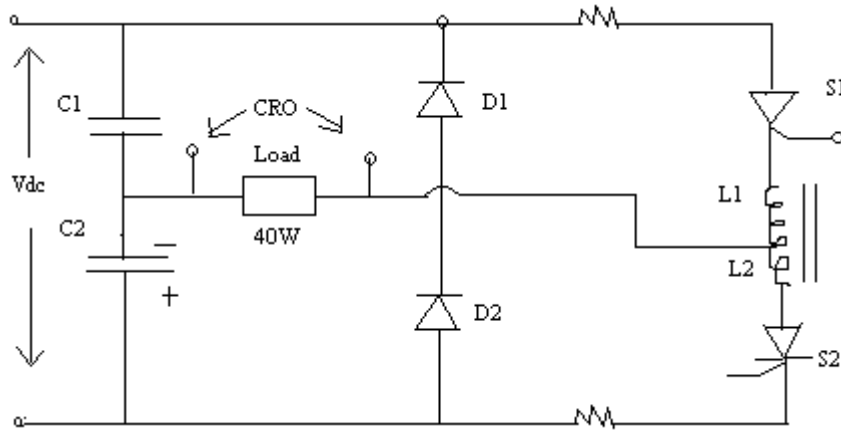
**Apparatus:**

S.No	Equipment	Range	Type	Qty
1	PE Trainer Kit		-	01
2	Multimeter		Digital	01
3	External power supply	(0-30)V, 2A	DC	01
4	Power Oscilloscope			01

**THEORY:**

In a series inverter the commutation elements are in series with the load. Assumer that voltage across capacitor  $C_2$  is  $E_c$  in the polarity shown, Capacitor  $C_1$  is charged to  $(E_{dc} + E_c)$  When SCR1 is fired, there will be two parallel paths for load current  $I_L (=i_1+i_2)$  current  $i_1$  will flow form positive dc terminal through SCR1; L1 load and capacitor  $C_2$  to the negative supply terminal. Current  $i_2$  will flow from  $C_1$  through SCR11 and L1 to the load. The driving voltage, the circuit elements and the initial conditions re identical for both the parts. Therefore, the two currents are equal Hence, one half of the load current will come from the DC supply and the other half from the discharge of the capacitor. AT the end of the half zero, SCR1 will be turned off, end the voltage across the capacitors reversed. Identical operations take place when SCR2 is triggered.

**CIRCUIT DIAGRAM:**



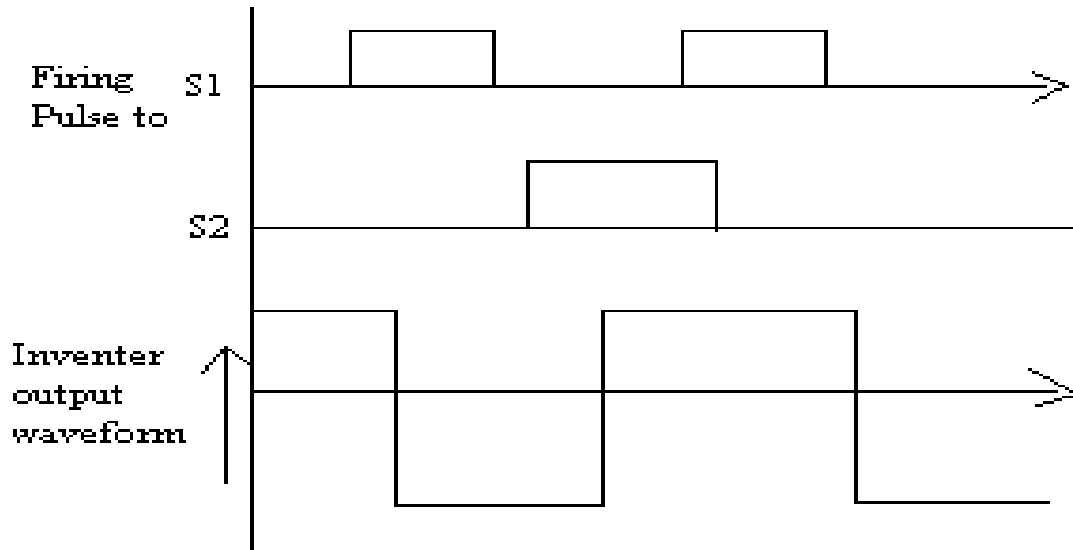
**PROCEDURE:**

1. Switch ON the supply & observe for the power indication.
2. Check the firing pulses for both thyristors individually on CRO.
3. Measure the DC supply.
4. Switch off the supply and connect the circuit as per the circuit diagram.
5. Observe the output voltage waveform across the output.
6. Vary the frequency and observe and note down the change in the waveform with frequency.

**OBSERVATION TABLE :**

S.No	Inverter frequency (Hz)	O/p AC

**MODEL GRAPH:**



**Result:**

### 6.8. PARALLEL INVERTER

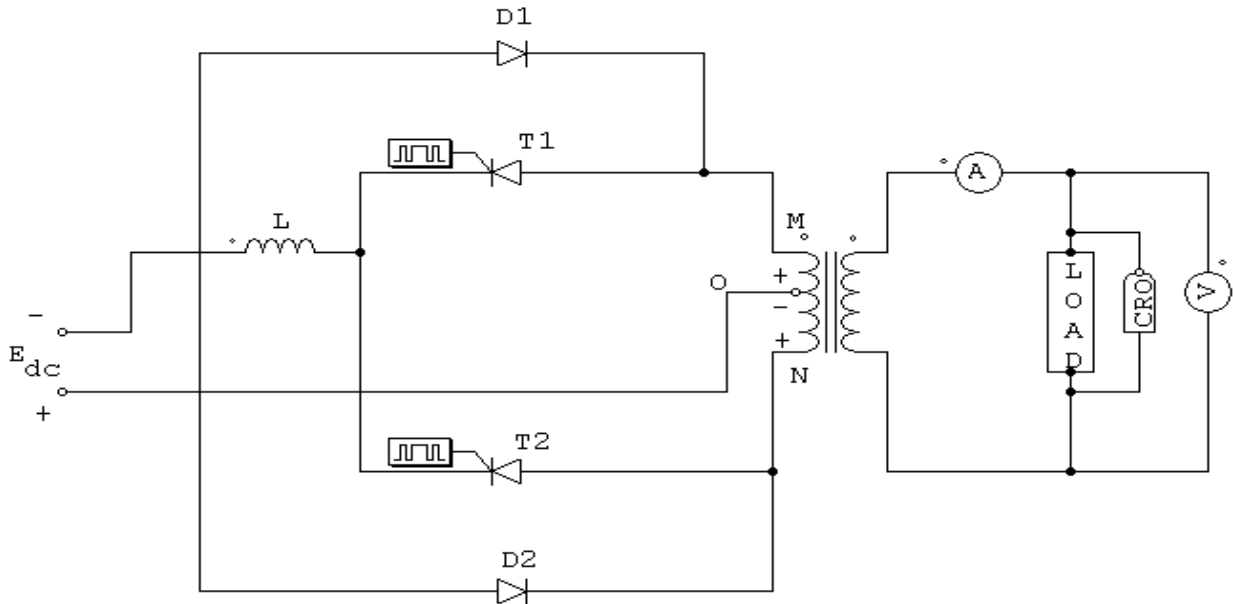
**AIM:** To study the operation of SCR parallel inverter

**Apparatus:**

S.No	Equipment	Range	Type	Qty
1	PE Trainer Kit		-	01
2	Multimeter		Digital	01
3	External power supply	(0-30)V, 2A	DC	01
4	Power Oscilloscope			01

**THEROY:**

SCRs 1 & 2 are the main load carrying SCR. The commutating components are L&C. Diodes 1& 2 permit load reactive power to be fed back to the DC supply. These are called the feedback diodes. When sCR1 is conducting supply voltage  $E_{dc}$  will appear across the left half of the transformer primary winding OA. Terminal O is positive with reference to A thus, capacitor C will get charged to twice the input voltage. The load voltage will be positive and of magnitude  $E_{dc}$ . At the end of the half period, SCR2 is fired. Capacitor C will immediately apply a reverse voltage of  $2E_{dc}$  across SCR 1 and turns it off. When SCR 1 is turned off the capacitor will discharge through SCR2, inductor L, Diode D1 and a portion of the transformer winding LA. Thus the energy stored in the capacitance will be fed back to the load through the transformer coupling of windings LA and PQ. During this period, the potential of point L will be fixed by the DC input supply and voltage will still be positive. The load current which earlier was flowing through SCR1 will flow through OL and diode D1 to the negative input terminal. The current through the inductor L will now flow through D2, M, B & S2 . The trapped energy in L will be fed back to the load. Since the point M is now connected to the negative supply terminal, the load voltage polarity will be reversed. Also the capacitor will be charged in the opposite direction.

**CIRCUIT DIAGRAM:**

## PARALLEL INVERTER

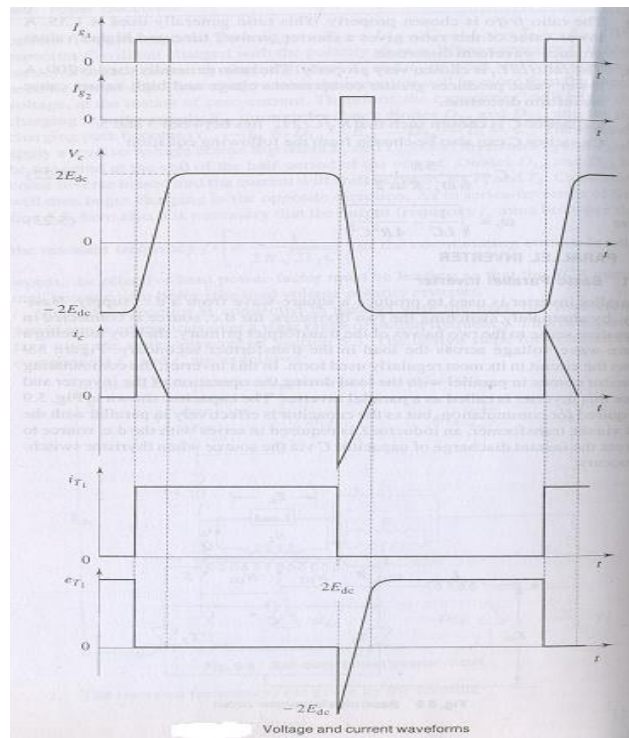
**PROCEDURE:**

1. Connect the circuit as per the circuit diagram connect an external voltage supply across the  $V_{dc}$  terminals
2. Apply the triggering pulses to SCR1 & SCR2
3. Keep the triggering frequency minimum
4. Switch ON the CRO, experiment kit and the external power supply.
5. Observe the output waveforms in the CRO. Change the frequency and observe the change in waveform with frequency. Note down the voltage values for different frequencies.
6. Keep the frequency knob in the minimum position and switch off the supply.

**OBSERVATION TABLE :**

S.No	Inverter frequency (Hz)	O/p AC

**MODEL GRAPH:**



**Result:**

### 6.9. JONES CHOPPER

**AIM:** To study the operation of Jones chopper.

**Apparatus:**

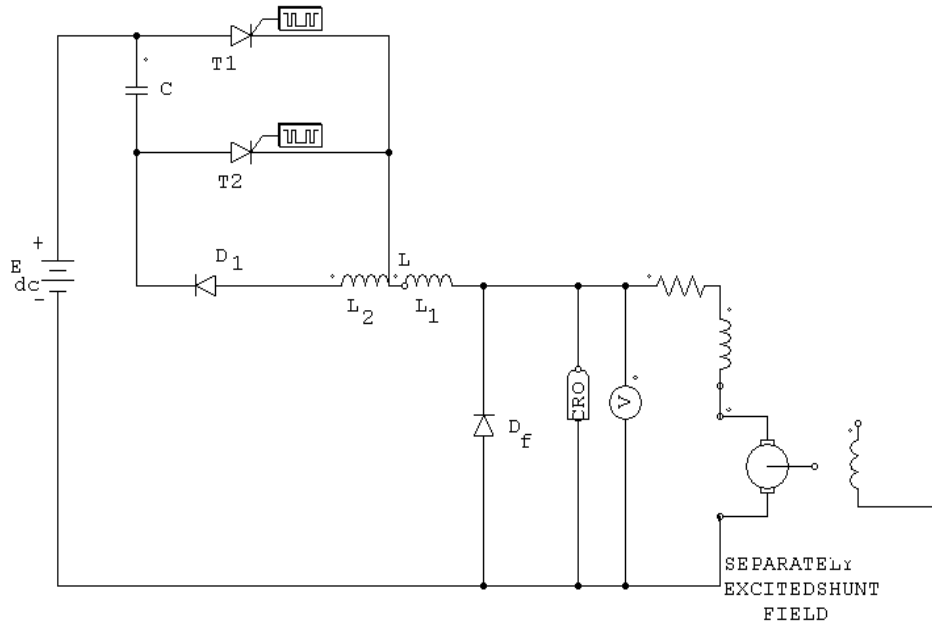
S.No	Equipment	Range	Type	Qty
1	PE Trainer Kit		-	01
2	Multimeter		Digital	01
3	Power Oscilloscope			01

**THEORY:**

This chopper is an example of class D commutation. In this circuit, T<sub>1</sub> is the main thyristor. T<sub>2</sub>, C, D<sub>2</sub> & auto transformer forms the commutating circuit for the main thyristor T<sub>1</sub>. Therefore the special feature of this circuit is the tapped auto transformer T through which the load current flows. Here L<sub>1</sub> & L<sub>2</sub> are closely coupled so that the capacitor always gets sufficient energy to turn-off the main SCR T<sub>1</sub>.

Let us assume that initially capacitor E is charged to a voltage E<sub>dc</sub> with the polarity shown. T<sub>1</sub> is triggered at time t = t<sub>1</sub>, current flows through path CA-T<sub>1</sub>-L<sub>2</sub>-D<sub>2</sub>-CB & plate A is negative. However diode D<sub>1</sub> prevents further oscillation of the resonating L<sub>2</sub>C circuit. Hence capacitor C retains its charge until SCR T<sub>2</sub> is triggered.

**CIRCUIT DIAGRAM:**



DC JONES CHOPPER

**PROCEDURE:**

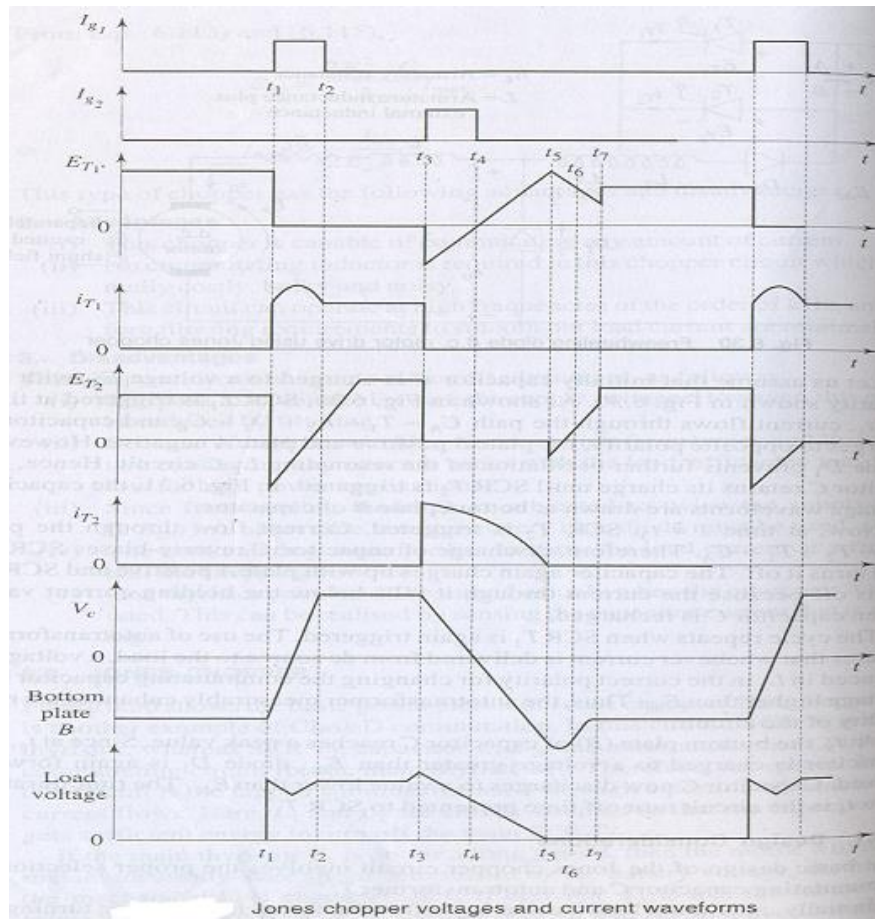
1. Connect the circuit as shown in figure.
2. Connect the CRO across the output
3. Switch ON the power supply
4. Observe the output waveform in CRO
5. Note down its amplitude & time-period.

**Observation:**

S.No	Amplitude ( V )	Time period(Sec)



**MODEL GRAPH**



**Result:**

## **6.10 Forced Commutation circuits**

### **6.10.1. CLASS A COMMUTATION**

#### **(SELF COMMUTATION BY RESONATING THE LOAD)**

#### **AIM :**

To study the class A forced com mutation circuit.

#### **Apparatus :**

1. Forced Commutation Unit.
2. C.R.O. and Probes
3. Patch Cords
4. Differential Module
5. Variable Resistive Load -  $360\Omega / 2A$

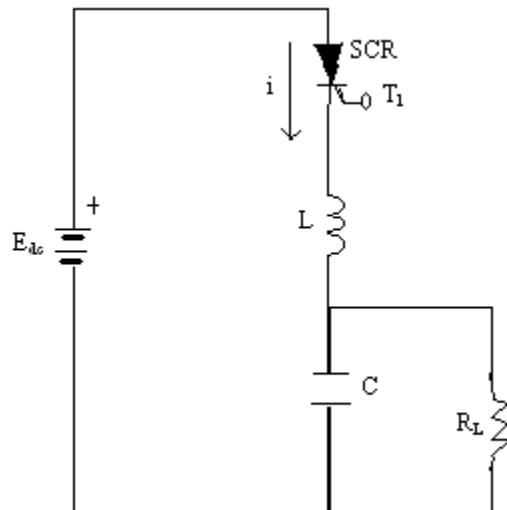
#### **THEORY :**

This is also known as resonant commutation, load commutation. L and C are used as a commutating components in the circuit. We have two arrangements in class A commutation one is a high value of load RC is connected across capacitor and another is one is small value of load RC is series with the LC circuit.

Actually in this process of commutation the forward current passing through the device is reduced to less than the level of holding current of the device. Hence this method also known as the current commutation method. When the forward current is become less than zero then the device is automating turned off. This has happened by load RL and commutation components forms an under damped resonant circuit. When SCR is in ON Capacitor charged to  $E_{dc}$ , When it charges full supply voltage  $E_{dc}$  the current passing through the device delay to a value less than the holding current of the device, then turns off the device takes place. This is called self commutation because SCR turns off automatically after it has been turned ON. Turn OFF time is determined by R-L-C components. These are most suitable for with frequency i.e., above 1000Hz it is used in series inverter. If the 'SCR' is active

region the commutation intervals (freq. pot) only and is dormant of the rest of the time period (Duty Cycle) is called Auxiliary Commutation.

### Class A commutation Circuit Diagram.



(a) Load in parallel with capacitor

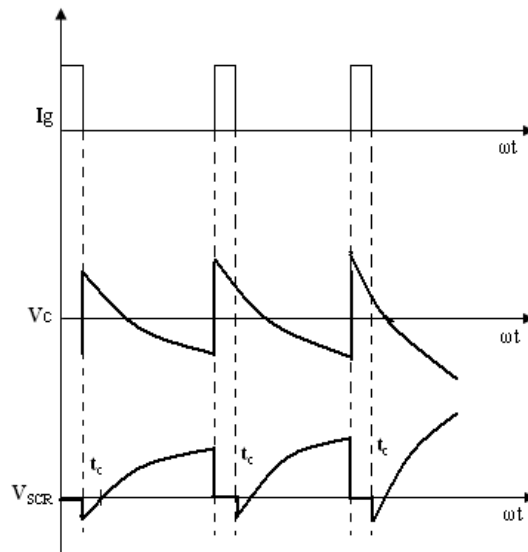
### CLASS A COMMUTATION CIRCUIT

#### Procedure :

1. Make all connections in the power circuit as per the circuit diagram.
2. Connect Trigger output  $T_1$  to the gate and cathode of  $T_1$  SCR in the power circuit.
3. Switch ON the DC supply, trigger outputs and observe the voltage waveforms across SCR, Load and Capacitor.
4. Vary the frequency and observe the waveforms but no use of duty cycle in this circuit.
5. Commutation will fails by varying  $R_L$  Load as well as frequency Intervals.
6. If commutation fails switch OFF the DC supply trigger outputs and retry again after changing the frequency.

7. Repeat the same for different values of RL & C.
8. Large resistive load is connected in parallel with capacitor and low value of resistive load connected in series with C.

### **CLASS A COMMUTATION WAVEFORMS :**



Voltage and currents in Class A (load is parallel with capacitor)

$t_c$  = SCR turn off time in  $\mu$  sec's

**Result:**

### **6.10.2 Class B Commutation** **(Self Commutation by an LC Circuit)**

#### **AIM :**

To study the class B Commutation circuits

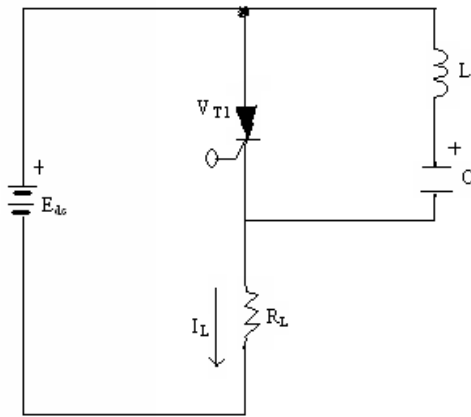
#### **Apparatus :**

1. FORCED COMMUTATION unit
2. C.R.O. and Probes.
3. Patch Cords
4. Differential Module
5. Variable Resistive Load  $360\Omega / 2A$ .

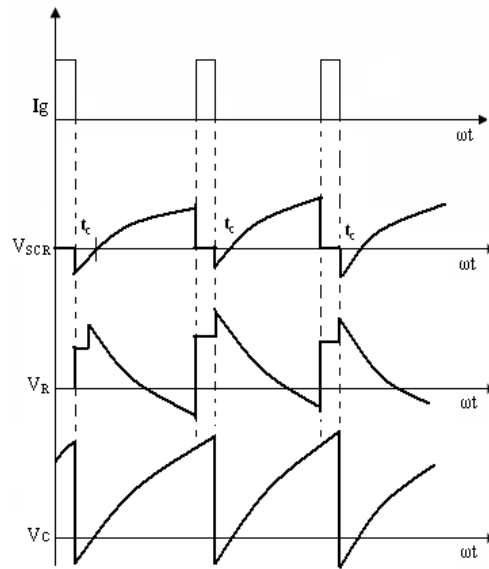
#### **Theory:**

In this method the LC resonating circuit is across the SCR. In this commutations reverse voltage is applied to the thyristor to turn off it. In this arrangement soon the supply voltage applied the capacitor C starts getting charged up to the  $E_{dc}$  at no triggering signal. When thyristor is get triggered current flows through the load RL and a pulse current through the resonating LC circuit. When thyristor gets triggered the capacitor get discharges and get charged in reverse direction. Due to the reverse voltage a commutating current is starts flows through the SCR to opposes the load current  $I_L$ . When  $I_c > I_L$  SCR becomes turned off. When it turns off capacitor again gets charged through RL process continued.

From above we clear that thyristor after getting on for some time automatically gets off and after remaining in off state for some time is again gets turned ON. This process ON / OFF is continuous frequency of ON / OFF states desired by commutating components. This is self commutating circuit because turns off takes place automatically after turned ON. This type circuits used in DC chopper circuits.

**Class B Commutation Circuit Diagram :****CLASS B COMMUTATION CIRCUIT****Procedure:**

1. Make all connections as per the circuit diagram.
2. Connect the trigger output  $T_1$  to the gate and cathode of the SCR  $T_1$
3. Switch ON the power supply and put ON the trigger output supply.
4. Observe the voltage waveforms across load and SCR and Capacitor by varying the frequency control potentiometer. Duty cycle is of no use in the circuit.
5. Commutation will fails by varying frequency intervals as well as load resistance.
6. If commutation fails switch OFF the DC supply trigger outputs and retry again after changing the frequency.
7. Repeat the same for different values of R load C.

**8. CLASS B COMMUTATION WAVEFORM:**

Voltages and currents in class B  
 $t_c$  = SCR turn off time in  $\mu$  sec's.

**Result:**

### **6.10.3 . Class C commutation**

#### **(Complementary Commutation)**

#### **AIM :**

To study the CLASS C FORCED COMMUTATION circuit.

#### **Apparatus :**

1. Forced Commutation Unit.
2. C.R.O. and Probes
3. Patch cords
4. Differential Module
5. Two Resistive Loads  $360\Omega / 2A - 2\text{No's}$ .

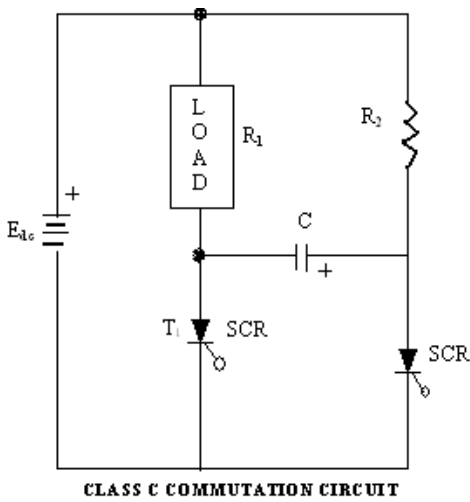
#### **Theory:**

In this type of commutation circuit the transfer of current between two loads, that is a thyristor carrying load current is commutated by transferring its load current to another incoming thyristor called complementary thyristor is connected in parallel with main thyristor.

Actually in this circuit initially both  $T_1$  &  $T_2$  at off, when trigger pulse is applied to the gate 0 &  $T_1$  it is triggered  $I_c$  &  $I_L$  starts flowing, and C gets charged by the supply voltage  $E_{dc}$ . When triggering pulse is applied to the gate of  $T_2$ , it will turned ON soon reverse voltage applies across the main thyristor and immediately it turns off.

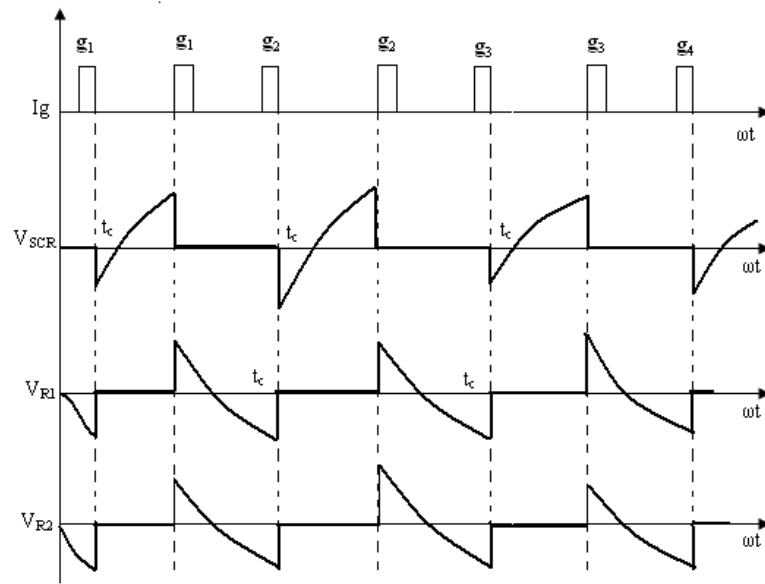
Now capacitor charges in reverse polarity when  $T_1$  triggered ON the discharging current of capacitor turns off the  $T_2$ . This is very much used frequencies below. This is used in MC Murray bed ford inverter.



**Class C Commutation Circuit Diagram:****Procedure:**

1. Make all connections as per the circuit diagram.
2. Connect the trigger outputs from firing circuit to the Gate and Cathode of thyristor  $T_1$  &  $T_2$  in the power circuit.
3. Switch ON supply and put on the trigger output pulse switch and observe the waveforms across  $R_1$ ,  $R_2$  and  $C$  by varying frequency and duty cycle potentiometer.
4. If commutation will fails by varying load as well as freq. pot and duty cycle.
5. If commutation fails switch OFF the DC supply trigger outputs and retry again after changing the frequency.
6. Repeat the same for different value of Capacitor and inductors as given in power circuit.

**Class C Commutation Waveforms:**



Voltages and currents in class C

$t_c = \text{SCR turn off time in } \mu \text{ sec's}$

**Result:**

#### **6.10.4. CLASS D COMMUTATION**

##### **(Auxiliary Commutation)**

##### **AIM :**

To study the Class D Forced Commutation Circuit.

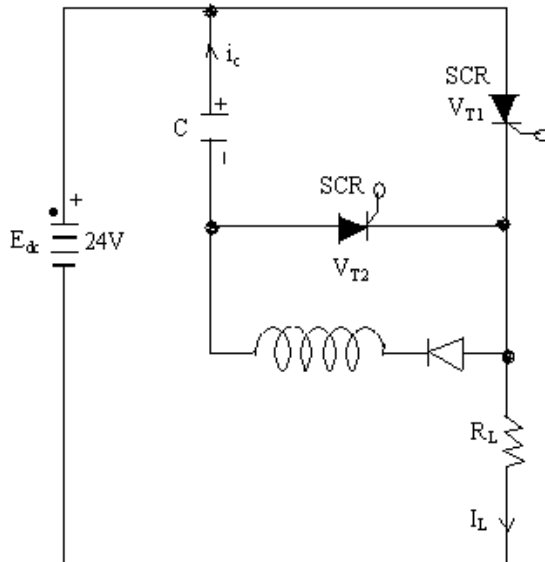
##### **Apparatus :**

1. **Hi-Q Electronic Systems**, FORCED COMMUTATION Unit.
2. C.R.O. and Probes
3. Patch cords
4. Differential Module
5. Variable Resistive Load  $360\Omega/2A$
6. Regulated DC Power Supply of 30V / 2A

##### **Theory :**

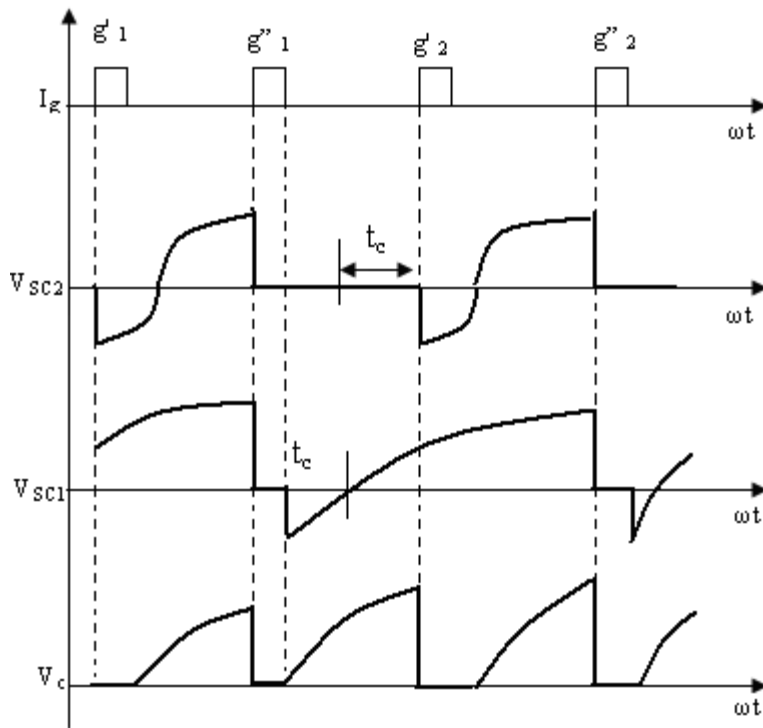
In this Commutation circuit method and auxiliary thyristor  $T_2$  is required to commutate the main thyristor  $T_1$ . Here L, D, and  $T_2$  are commutating components. Initially  $T_2$  is triggered first to charge up the capacitor, when C has to charged fully,  $T_2$  gets turns off owing lack of current this is due to increase of voltage across capacitor. Then  $T_1$  is triggered ON two currents appears, which are load current through  $R_L$  and commutation current through C,  $T_2$ , L and D. Now capacitor starts discharging, reverse discharge is not possible due to blocking diode D. When  $T_2$  is triggered C gets reverse discharging. When this discharging current that is commutating current  $I_c$  becomes more than the load current  $I_L$ ,  $T_1$  get turned off. After  $T_1$  gets off C again get charged after fully charge  $T_2$  gets off repeats above sat again.

Choppers and invertors under this auxiliary commutation circuit by circuit high efficiency is possible mainly used in Jones Chopper circuit.

**Class D commutation Circuit Diagram:****CLASS D COMMUTATION CIRCUIT****Procedure:**

1. Make all connections as per the circuit diagram.
2. Connect trigger output from firing circuit and power circuit thyristor  $T_1$  &  $T_2$  Gate and Cathode connect firing pulses  $T_1$  to  $T_2$  and  $T_2$  to  $T_1$  Initially keep the trigger ON/OFF at OFF position to initially charge the capacitor, this can be observed by connecting C.R.O. terminals across the capacitor, when capacitor is not charged to give DC supply externally.
3. Now switch ON the supply and observe voltage waveforms across load  $T_1$ ,  $T_2$  and capacitor.
4. Change the commutating components and observe waveforms at different frequency and duty cycle.
5. If commutation fails switch OFF the DC supply trigger outputs and retry again after changing the frequency.

**Class D commutation waveforms:**



**Result:**

### **6.10.5. Class E commutation**

#### **(External Pulse commutation)**

#### **AIM :**

To study the class E forced Commutation circuit.

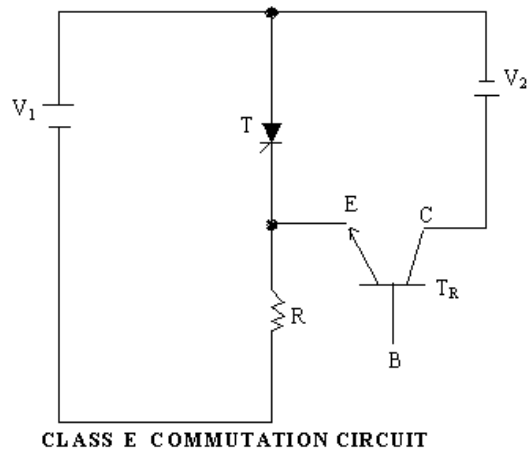
#### **Apparatus :**

1. FORCED COMMUTATION Unit.
2. C.R.O. and Probes
3. Patch cords
4. Differential Module
5. Variable Resistive Load  $360\Omega/2A$
6. Regulated DC Power Supply of 30V / 2A

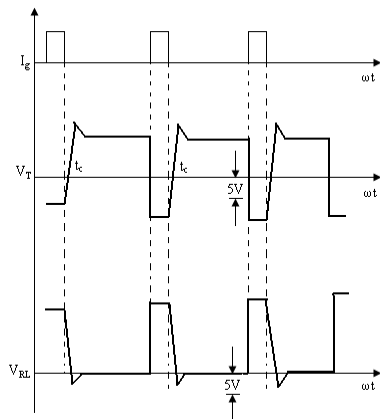
#### **THEORY :**

In class E commutation the reverse voltage is applied to the current carrying thyristor from an external pulse source across or in series with the conducting thyristor near the commutating pulse is applied through a transistor emitter. The turn off time of the thyristor is smaller than the width of the pulse.

When  $T_1$  is triggered, current flows through the R load and the transistor. A voltage  $V_2$  is connected to the collector of transistor the emitter is connected to cathode of  $T_1$ . The voltage  $V_2$  appears across  $T_1$  as a reverse voltage then  $T_1$  gets turns off. This type of commutating method is capable of very high efficiency.

**Class E Commutation Circuit Diagram:****PROCEDURE:**

1. Make all connections as per circuit diagram.
2. Connect  $V_2$  supply of 5V from an external DC supply
3. Connect trigger outputs  $T_1$  &  $T_2$  from firing circuit to the power circuit  $T_2$  to gate and cathode of SCR and  $T_1$  to transistor base and emitter.
4. Switch ON DC power supply, trigger output switch and external DC supply.
5. Observe the voltage waveforms across load and SCR by varying frequency and duty cycle controls. If commutation fails switch OFF the DC supply trigger outputs and retry again after changing the frequency.
6. Repeat the same by varying frequency and duty cycle.

**CLASS E COMMUTATION WAVEFORMS:****Fault:**

1. If power ON (IRS) indicator not glowing.
  - a. Check the input AC power supply
  - b. Check mains chord
  - c. Check the 500mA, AC fuse in 3 pin power inlet socker on back panel of unit.
  - d. Check the power ON/OFF (IRS) switch.
  
2. for no output in power circuit.
  - a. Check internal unregulated DC supply.
  - b. Check the 2A fuse on front panel
  - c. Check the device 2A fuses on back panel
  - d. Check for any loose connections

After external checking if the problem persists contact to our company.

**Result:**



## 6.11. PSPICE Simulation of Single Phase full Converter Circuit with R, RL and REE loads.

### 6.11.1 USING R – LOAD

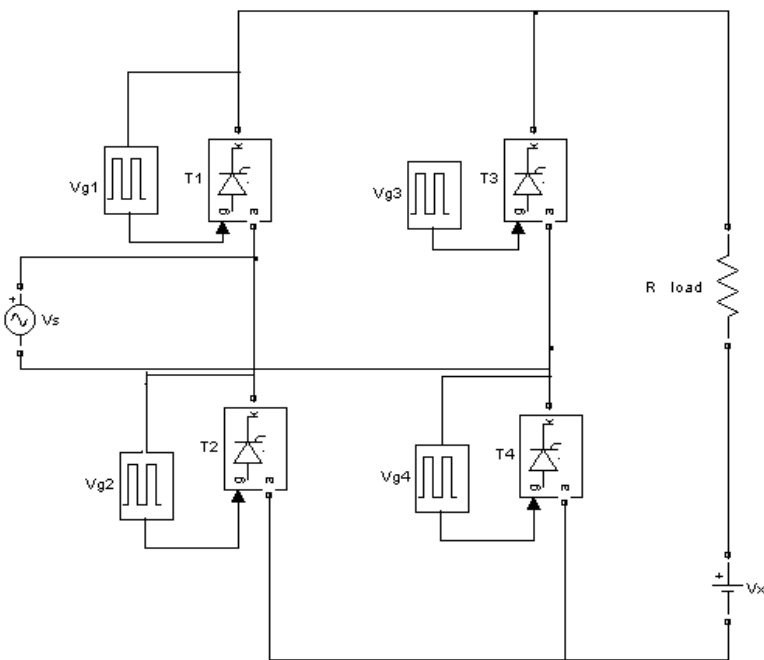
#### AIM :

PSPICE SIMULATION of single phase full converter circuit for R-load.

#### PROBLEM :

Simulate single phase full converter circuit to find load current with a voltage source of value 230V, 50Hz and plot the waveforms of average load current, average load voltage for the firing angles of  $\alpha=30^\circ$ ;  $\alpha=90^\circ$ ;  $\alpha=120^\circ$ . for R,  $R=50\Omega$ .

#### CIRCUIT DIAGRAM:



**PROCEDURE**

1. Represent nodes of given circuit
2. Write PSPICE program according to flow chart
3. Execute the program in Microsim ten editor and run the program.
4. Make the corrections if required
5. Observe the o/p and plot the waveform.

**PROGRAM:**

```
. SUBCKT DCSCR 1234
```

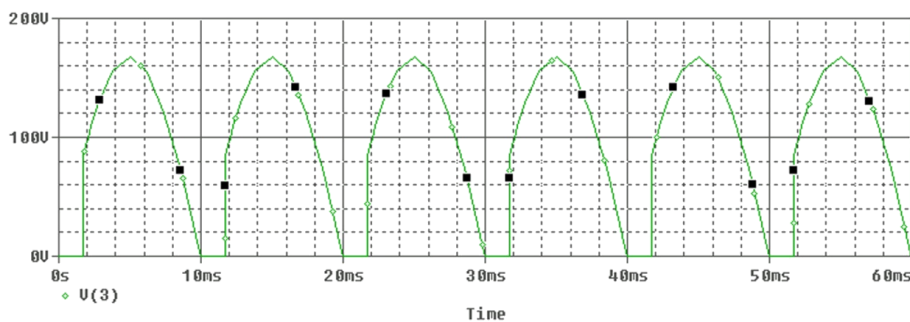
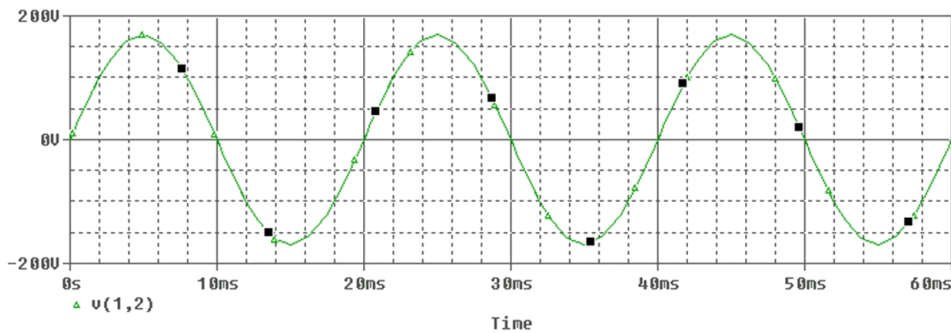
```
Dt 5 2 dmod
```

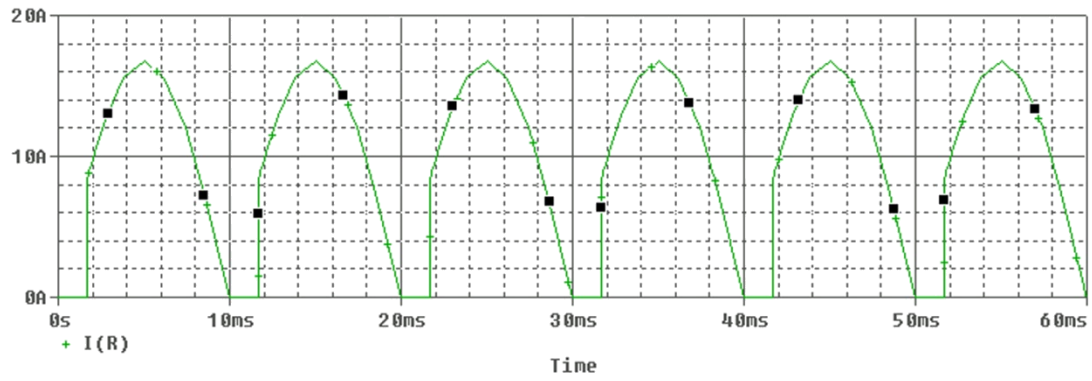
```
St 1 5 3 4 smod
```

```
.model dmod d (Is = 1e - 25 fv = 1000v)
```

```
.model smod Vswitch (Ron = 0.125 Roff = 1e+ 5 Von = 0.1V Voff = 0v)
```

```
.Ends DCSCR
```

**OUT PUT WAVEFORMS:**



**RESULT:**

### 6.11.2 USING R L- LOAD AND R-L-E LOADS.

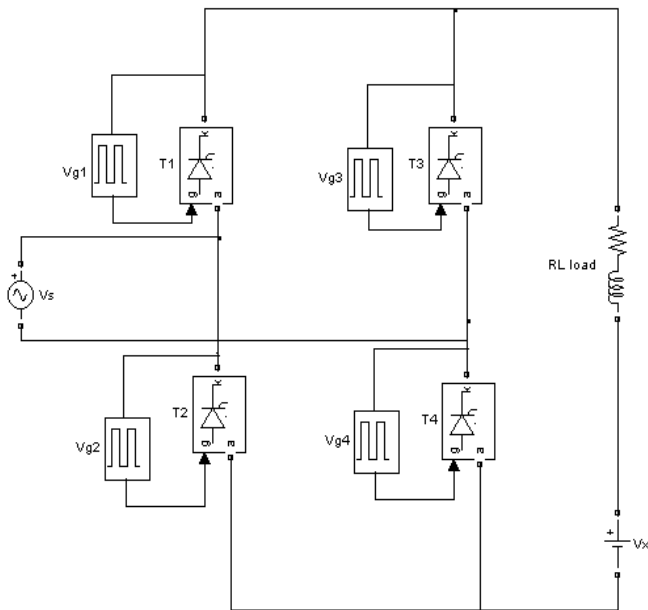
#### AIM :

PSPICE SIMULATION of single phase full converter circuit for RL-load.

#### PROBLEM :

Simulate single phase full converter circuit to find load current with a voltage source of value 230V, 50Hz and plot the waveforms of average load current, average load voltage for the firing angles of  $\alpha \leq 30^\circ$ ;  $\alpha \leq 90^\circ$ ;  $\alpha \leq 120^\circ$ . for RL and RLE loads,  $R=50\Omega$ ,  $L=10\text{mH}$ .

#### CIRCIUT DIAGRAM:



**PROGRAM:**

```
. SUBCKT DCSCR 1234
```

```
Dt 5 2 dmod
```

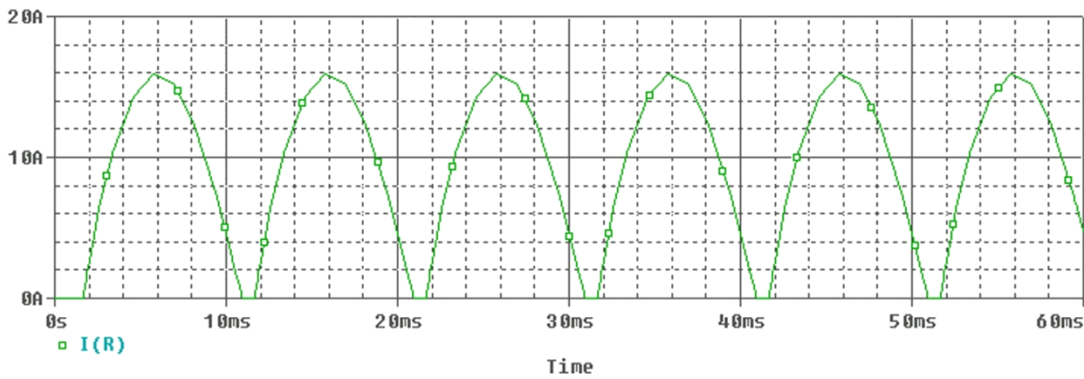
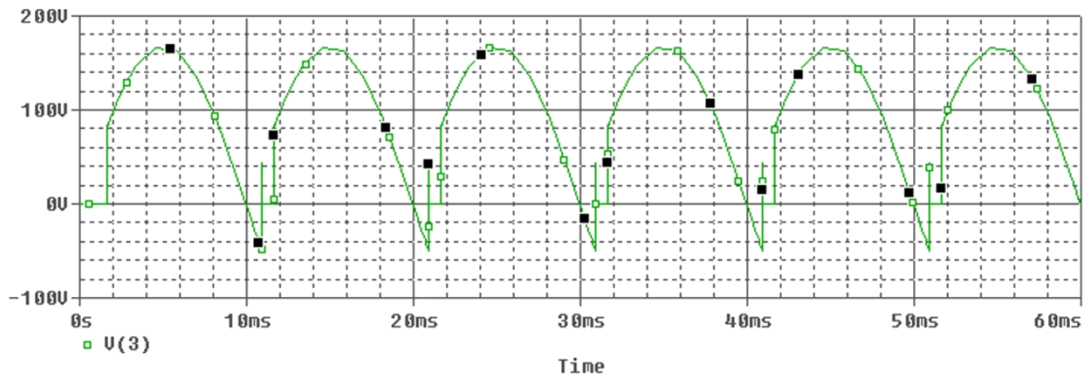
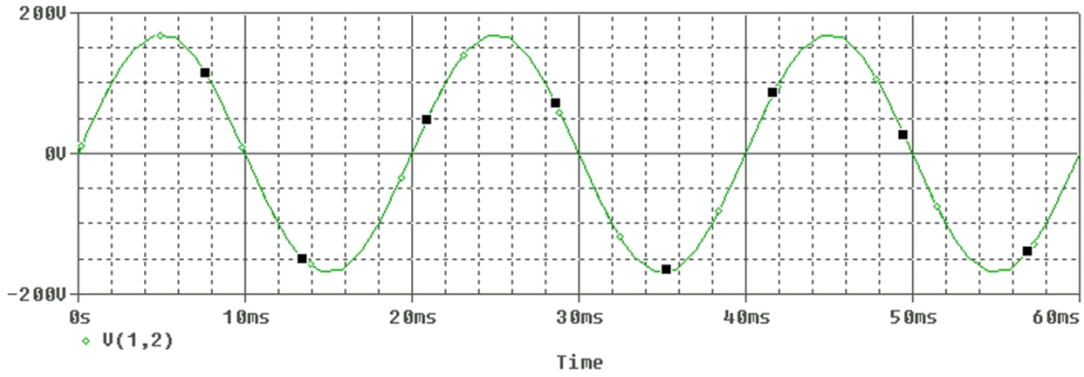
```
St 1 5 3 4 smod
```

```
.model dmod d (Is = 1e - 25 fv = 1000v)
```

```
.model smod Vswitch (Ron = 0.125 Roff = 10e+ 5 Von = 0.1V Voff = 0v)
```

```
.Ends DCSCR
```

➤ **OUT PUT WAVEFORMS:**



**RESULT:**

## 6.12. 3-PH AC VOLTAGE CONTROLLER

### 6.12.1 USING R - LOAD

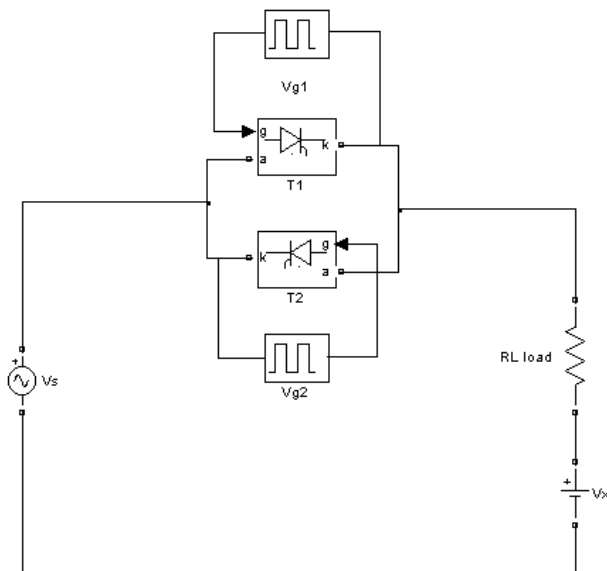
#### AIM :

PSPICE SIMULATION of single phase AC voltage controller circuit for R-load.

#### PROBLEM:

Find out the load current with AC voltage controller taking 10V as source magnitude,  $R=50\Omega$ ,  $L = 30\text{mH}$ .

#### CIRCIUT DIAGRAM:



**PROGRAM:**

```
. SUBCKT DCSCR 1234
```

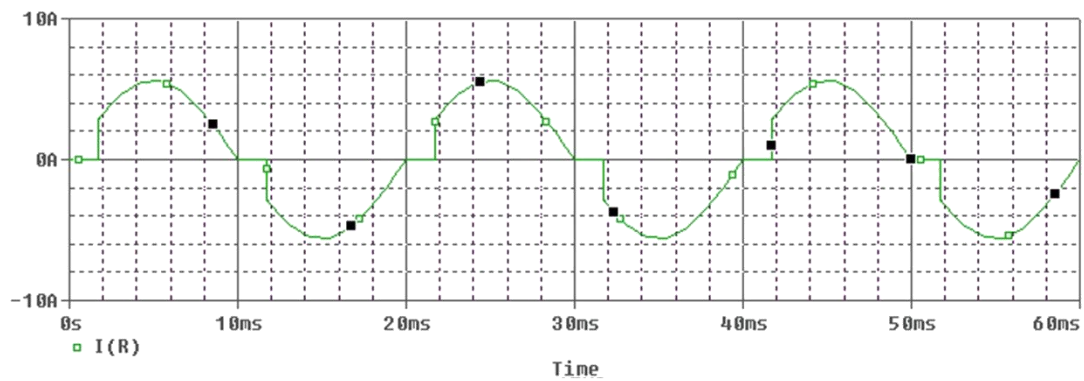
```
Dt 5 2 dmod
```

```
St 1 5 3 4 smod
```

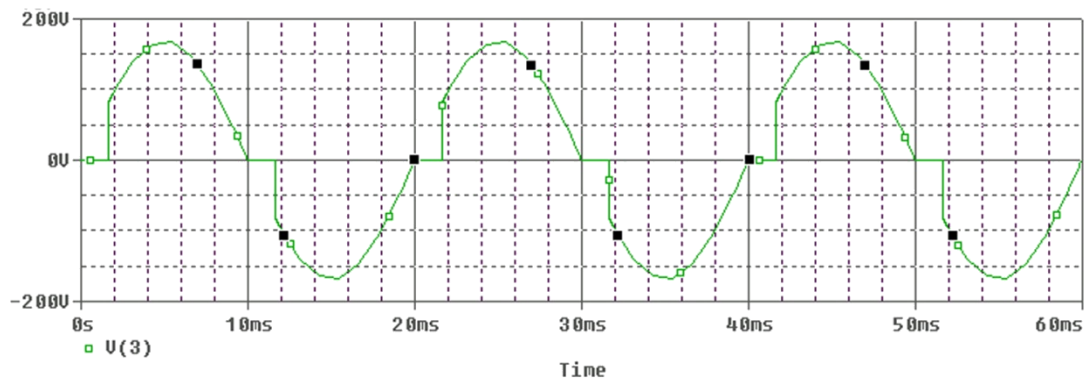
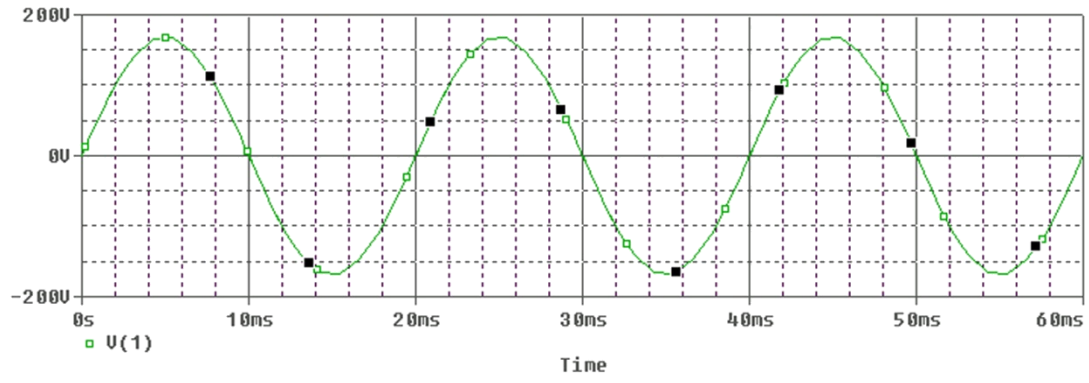
```
.model dmod d (Is = 1e - 25 fv = 1000v)
```

```
.model smod Vswitch (Ron = 0.125 Roff = 1e+5 Von = 0.1V Voff = 0v)
```

```
.Ends DCSCR
```

➤ **OUT PUT WAVEFORMS:**





**RESULT:**

### 6.12.2 USING RL - LOAD)

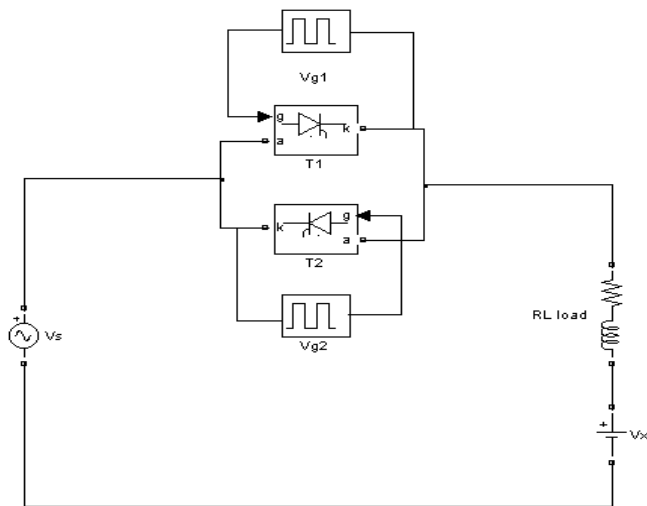
#### AIM :

PSPICE SIMULATION of single phase AC voltage controller circuit for RL-load.

#### PROBLEM:

Find out the load current with AC voltage controller taking 10V as source magnitude,  $R=50\Omega$ ,  $L = 30\text{mH}$ .

#### CIRCIUT DIAGRAM:



**PROGRAM:**

```
. SUBCKT DCSCR 1234
```

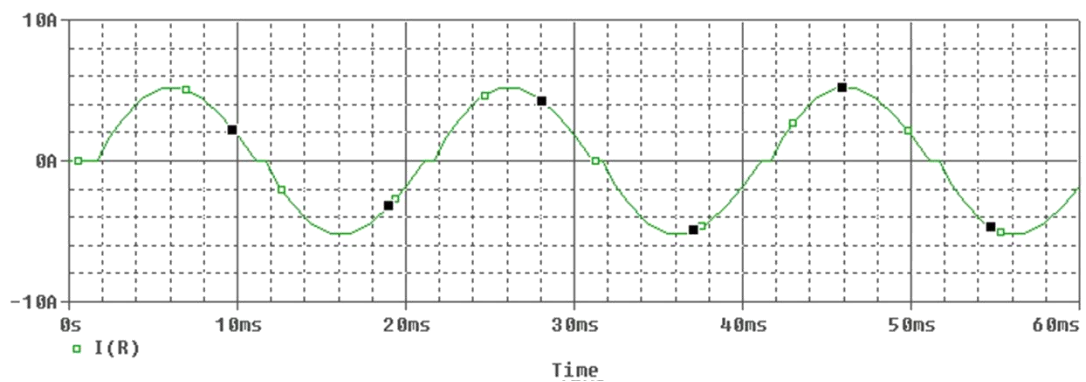
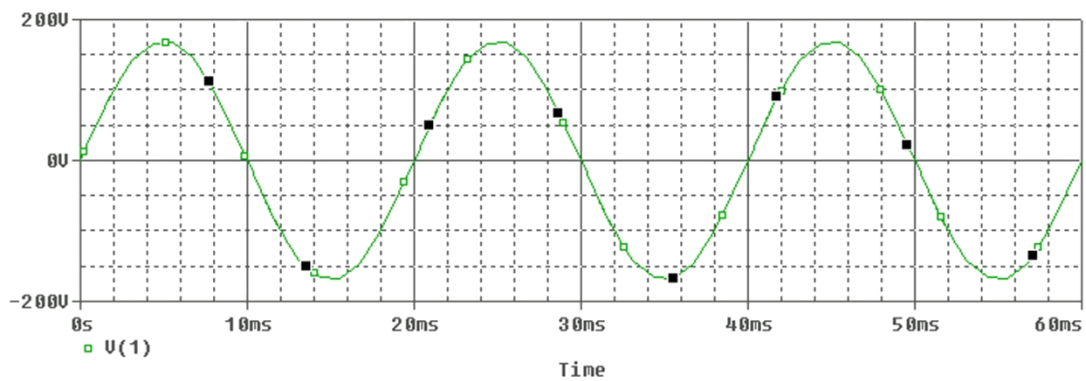
```
Dt 5 2 dmod
```

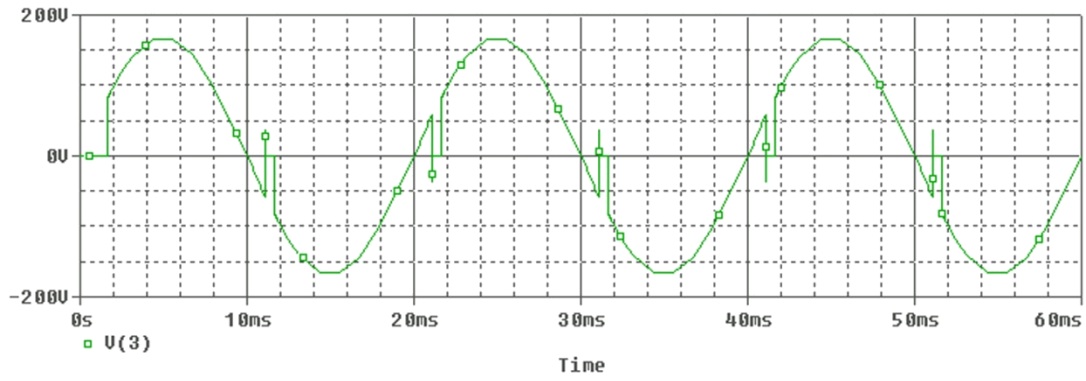
```
St 1 5 3 4 smod
```

```
.model dmod d (Is = 1e - 25 fv = 1000v)
```

```
.model smod Vswitch (Ron = 0.125 Roff = 1e+ 5 Von = 0.1V Voff = 0v)
```

```
.Ends DCSCR
```

➤ **OUT PUT WAVEFORMS:**



**RESULT:**

### 6.13. BUCK CHOPPER

#### AIM:

To study and analyze the operation of buck chopper for required load conditions.

#### PROBLEM:

A buck chopper with input  $V_s = 100V$ , average load voltage 60V, average load current 20A, chopping frequency 20KHz, peak to peak ripples are 25% of load voltage, 5% for load current, 10% for filter current (LC circuit).

Plot capacitor voltage, instantaneous load current and input current using PSPICE.

#### PROCEDURE:

1. Represent nodes of a given circuit
2. Write PSPICE program according to flow chart
3. Execute the program in micro sim text editor and run the program
4. Make corrections if required
5. Observe the waveforms.

#### PROGRAM CODE:

\* Buck chopper

\* Source Description

$V_s$     1    0    DC    110V

$V_{x1}$    1    2    DC    0V

$V_{x2}$    8    0    DC    0V

$V_g$     4    5    PULSE (0 25 0 IN IN 27.27V 100U)

## \* Component Description

Rb 3 4 230 OHM

Le 6 7 68.18 UM

L 6 7 20.4 UM

R 7 8 30 HM

Ce 6 0 4.14 UF

Dm 0 5 DMOD

. MODEL DMOD D(IS = 2.2E-15 BV = 1800 IT = 0)

Q1 2 3 5 QMOD

. MODEL QMOD NPN (IS = 6.734 BF = 416.4 BR = 0.7371 CJC = 3.638P CJE =

➤ **OUT PUT WAVEFORMS:**

4. 493P TR = 239.5N TF = 301.2P)

## \* Analysis Description

. TRAN IU 1.6M 1.5M

. FOUR 20KHz I(VS)

## \* Output Description

. PROBE

. END

**RESULT :** The BUCK Chopper circuit has been analysed and capacitor voltage, instantaneous load current and input current have been plotted

**7. Content beyond syllabus:**

1. Simulation of three phase converter
2. Three phase converter with R, L and RL load
3. Three phase cyclo converter
4. Three phase inverter
5. Three phase midpoint type converter

## 8. Sample Viva Voce Questions

### Exp: 6.1.1

- 1) Explain V-I characteristics of SCR?
- 2) What are Latching current and Holding current?
- 3) Define  $V_{BO}$  &  $V_{BR}$ ? Which has a greater value and why?
- 4) Why is Latching current greater than Holding current?
- 5) What is the effect of increasing gate current in the turning on of SCR?

### Exp: 6.1.2

- 1) What is MOSFET?
- 2) What are the advantages of MOSFET over SCR?
- 3) Explain the characteristics of MOSFET?
- 4) Why is MOSFET able to give a very high gain ?
- 5) What is the symbol of a MOSFET? Why, usually a diode is shown connected across the terminals of MOSFET?

### Exp: 6.2

- 1) Explain R,RC and UJT triggering? Which is the most effective?
- 2) What is the maximum possible firing angle in R-Triggering?
- 3) How the triggering pulses are generated in UJT triggering?
- 4) How to change the triggering instants in UJT triggering?
- 5) Explain the waveforms?

### Exp: 6.3

- 1) Explain the working of AC Voltage controller?
- 2) Define Displacement angle, Displacement factor and distortion factor?
- 3) Displacement angle \* Displacement factor = \_\_\_\_\_
- 4) Explain the waveforms with R & RL load?



- 5) With RL load, the firing angle should be always greater than power factor. Why? (What is the effect of power factor in the working of an AC voltage controller with RL load?)

**Exp: 6.4**

- 1) What are the different configurations for a Fully Controlled converter?
- 2) Explain the working of a Fully Controlled converter?
- 3) Explain the waveforms with R & RL loads?
- 4) What is the equation for average voltage in a Fully Controlled converter?
- 5) What are the applications of a Fully Controlled converter?

**Exp: 6.5**

- 1) Explain the working of a Half controlled converter?
- 2) What are the disadvantages ?
- 3) Explain the waveforms with R & RL loads?
- 4) What is the equation for average voltage in a Half controlled converter?
- 5) What are the two different modes of operation in a Half controlled converter?

**Exp: 6.7**

- 1) What are the applications of cycloconverters?
- 2) How the frequency change is made possible in cycloconverters?
- 3) What are the different types of cycloconverters? Explain each?
- 4) Explain the sequence of triggering for  $(1/3)^{\text{rd}}$  frequency?
- 5) Draw & Explain waveforms for RL load?

**Exp: 6.8**

- 1) Explain the working of a series inverter?

- 2) Explain the waveforms?
- 3) What are the applications?
- 4) What are the differences between a basic series inverter and a modified one?

**Exp: 6.9**

- 1) What is a chopper?
- 2) What are the different types of Choppers?
- 3) Explain the working?
- 4) Explain the waveforms?

**Exp: 6.10**

- 1 what is other name for class A commutation?
- 2 what is other name for class B commutation?
- 3 what is other name for class C commutation?
- 4 what is other name for class D commutation?
- 5 what is other name for class E commutation?

**Exp: 6.11**

- 1) What are the different configurations for a Fully Controlled converter?
- 2) Explain the working of a Fully Controlled converter?
- 3) Explain the waveforms with R & RL loads?
- 4) What is the equation for average voltage in a Fully Controlled converter?
- 5) What are the applications of a Fully Controlled converter?

**Exp: 6.12**

- 1) Explain the working of AC Voltage controller?

- 2) Define Displacement angle, Displacement factor and distortion factor?
- 3) Displacement angle \* Displacement factor = \_\_\_\_\_
- 4) Explain the waveforms with R & RL load?
- 5) With RL load, the firing angle should be always greater than power factor. Why? (What is the effect of power factor in the working of an AC voltage controller with RL load?)

**Exp: 6.13:**

- 1) What is a chopper?
- 2) What are the different types of Choppers?
- 3) Explain the working?
- 4) Explain the waveforms?

**9. Sample Question paper of the lab external**

- 1 Perform the experiment on SCR, MOSFET & IGBT and draw the Characteristics
2. Perform the experiment on Gate firing circuits for SCR's and draw the waveforms
3. Perform the experiment on Single Phase AC Voltage Controller with R and RL Loads and draw the waveforms
4. Perform the experiment on Single Phase fully controlled bridge converter with R and RL loads and draw the waveforms
5. Perform the experiment on Forced Commutation circuits ( Class A, Class B, Class C, Class D & Class E) and draw the waveforms
6. Perform the experiment on DC Jones chopper with R and RL Loads and draw the waveforms
7. Perform the experiment on Single Phase Parallel, inverter with R and RL loads and draw the waveforms
8. Perform the experiment on Single Phase Cycloconverter with R and RL loads and draw the waveforms
9. Perform the experiment on Single Phase Half controlled converter with R load. and draw the waveforms
10. Perform the experiment on Three Phase half controlled bridge converter with R-load. and draw the waveforms
11. Perform the experiment on Single Phase series inverter with R and RL loads. and draw the waveforms
12. Perform the experiment on Single Phase Bridge converter with R and RL loads. and draw the waveforms
13. Perform the experiment on Single Phase dual converter with RL loads. and draw the waveforms
- 14 simulate the single-phase full converter using RLE loads and draw the waveforms
- 15 simulate the resonant pulse commutation circuit and Bulk chopper and draw the waveforms
- 16 simulate the and single-phase AC voltage controller using RLE loads and draw the waveforms

**10. Applications of the laboratory :**

- 1 With the help of this lab the student can be able to learn the simulation of many power electronics converters
- 2 He or she can be able to do the analysis of different power electronics devices
- 3 Can be able to learn the performance of many power devices

**11. Precautions to be taken while conducting the lab**

- Power must be switched-OFF while making any connections.
- Do not come in contact with live supply.
- Power should always be in switch-OFF condition, EXCEPT while you are taking readings.
- The Circuit diagram should be approved by the faculty before making connections.
- Circuit connections should be checked & approved by the faculty before switching on the power.
- Keep your Experimental Set-up neat and tidy.
- Check the polarities of meters and supplies while making connections.
- Always connect the voltmeter after making all other connections.
- Check the Fuse and it's ratify.
- Use right color and gauge of the fuse.
- All terminations should be firm and no exposed wire.
- Do not use joints for connection wire.

**SAFETY – II**

1. The voltage employed in electrical lab are sufficiently high to endanger human life.
2. Compulsorily wear shoes.
3. Don't use metal jewelers on hands.
4. Do not wear loose dress

Don't switch on main power unless the faculty gives the permission

## 12. Code of Conduct

1. Students should report to the labs concerned as per the timetable.
2. Students who turn up late to the labs will in no case be permitted to perform the experiment scheduled for the day.
3. After completion of the experiment, certification of the staff in-charge concerned in the observation book is necessary.
4. Students should bring a notebook of about 100 pages and should enter the readings/observations/results into the notebook while performing the experiment.
5. The record of observations along with the detailed experimental procedure of the experiment performed in the immediate previous session should be submitted and certified by the staff member in-charge.
6. Not more than three students in a group are permitted to perform the experiment on a set up.
7. The group-wise division made in the beginning should be adhered to, and no mix up of student among different groups will be permitted later.
8. The components required pertaining to the experiment should be collected from Lab-in-charge after duly filling in the requisition form.
9. When the experiment is completed, students should disconnect the setup made by them, and should return all the components/instruments taken for the purpose.
10. Any damage of the equipment or burnout of components will be viewed seriously either by putting penalty or by dismissing the total group of students from the lab for the semester/year.
11. Students should be present in the labs for the total scheduled duration.
12. Students are expected to prepare thoroughly to perform the experiment before coming to Laboratory.
13. Procedure sheets/data sheets provided to the students' groups should be maintained neatly and are to be returned after the experiment.

**13. Graphs if any.**