



Yashoda Shikshan Prasarak Mandal's  
**YASHODA TECHNICAL CAMPUS, SATARA**  
An Autonomous Institute  
FACULTY OF ENGINEERING  
Department of Electrical Engineering

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Department of Electrical Engineering

**LABORATORY MANUAL**

OF

**POWER ELECTRONICS LABORATORY**  
**(26AF1293PCL509)**

FOR

**T.Y. Semester – V**

Name of Student:- .....

Class:-.....

Roll No:-.....

PRN No:-.....

SEM:- ODD

Academic Year:- 2026-27

**Vision of the Department**

To emerge as a center of excellence in Electrical Engineering education producing knowledgeable, employable, and ethical engineering graduates to serve industry/society

**Mission of the Department**

We, at Department of Electrical Engineering, are committed to achieve our vision by-

**M1:** Preparing technically and professionally competent engineers by imparting quality education through effective teaching learning methodologies.

**M2:** Developing professional skills and right attitude among students that will help them to succeed and progress in their personal and professional career.

**M3:** Inculcating moral and ethical values in students with concern to society and environment.

## **SAFETY INSTRUCTIONS**

1. Safety is of paramount importance in the Power Electronics Laboratory. Students must strictly follow all safety instructions while performing experiments.
2. Electricity can be dangerous. Handle all electrical and electronic equipment carefully and follow the instructions given by the faculty/laboratory staff.
3. Never touch any live electrical terminal, conductor, component, or circuit.
4. Wear suitable footwear. Avoid loose clothing and secure long hair properly.
5. Remove metallic rings, bangles, bracelets, wristwatches, chains, and other conductive jewelry before performing experiments.
6. Ensure that your hands are dry and that the laboratory floor and working area are free from water or moisture.
7. Keep the power supply OFF while making or changing circuit connections.
8. Get the circuit diagram and connections checked by the faculty/laboratory staff before switching ON the power supply.
9. Check all connecting wires, power cords, plugs, probes, and equipment for damaged insulation before use. Do not use damaged leads or equipment.
10. Never bypass, short-circuit, or remove any fuse, MCB, circuit breaker, earthing connection, or other safety device.
11. Use only components and equipment having suitable voltage, current, power, and temperature ratings.
12. Check the polarity of DC supplies, capacitors, diodes, and other polarity-sensitive components before switching ON the supply.
13. Do not make any changes in the circuit while the power supply is ON.
14. Power electronic circuits may contain capacitors that remain charged even after the power supply is switched OFF. Ensure that capacitors are safely discharged before touching the circuit.
15. Use multimeters, oscilloscopes, probes, and other measuring instruments only within their specified ratings and as instructed by the faculty.
16. Do not connect or disconnect gate-driver circuits, power devices, or measuring probes while the circuit is energized.
17. If you observe sparking, smoke, burning smell, abnormal noise, excessive heating, or any other abnormal condition, immediately switch OFF the power supply and inform the faculty/laboratory staff.
18. Do not leave an energized circuit unattended.
19. Keep the laboratory workbench clean and properly arranged. Keep bags, books, water bottles, and other unnecessary items away from the experimental setup.
20. After completing the experiment, switch OFF the power supply and safely discharge stored electrical energy before dismantling the circuit.
21. Follow all instructions given by the faculty/laboratory staff and never compromise safety to complete an experiment.

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**This is certify that ..... and Roll No.....of T.Y. Electrical has completed all the experiment in the subject Power Electronics Laboratory (26AF1293PCL509) during academic Year 2026-27.**

**Sign of Student**

**Sign of Faculty**

**HOD- Electrical**

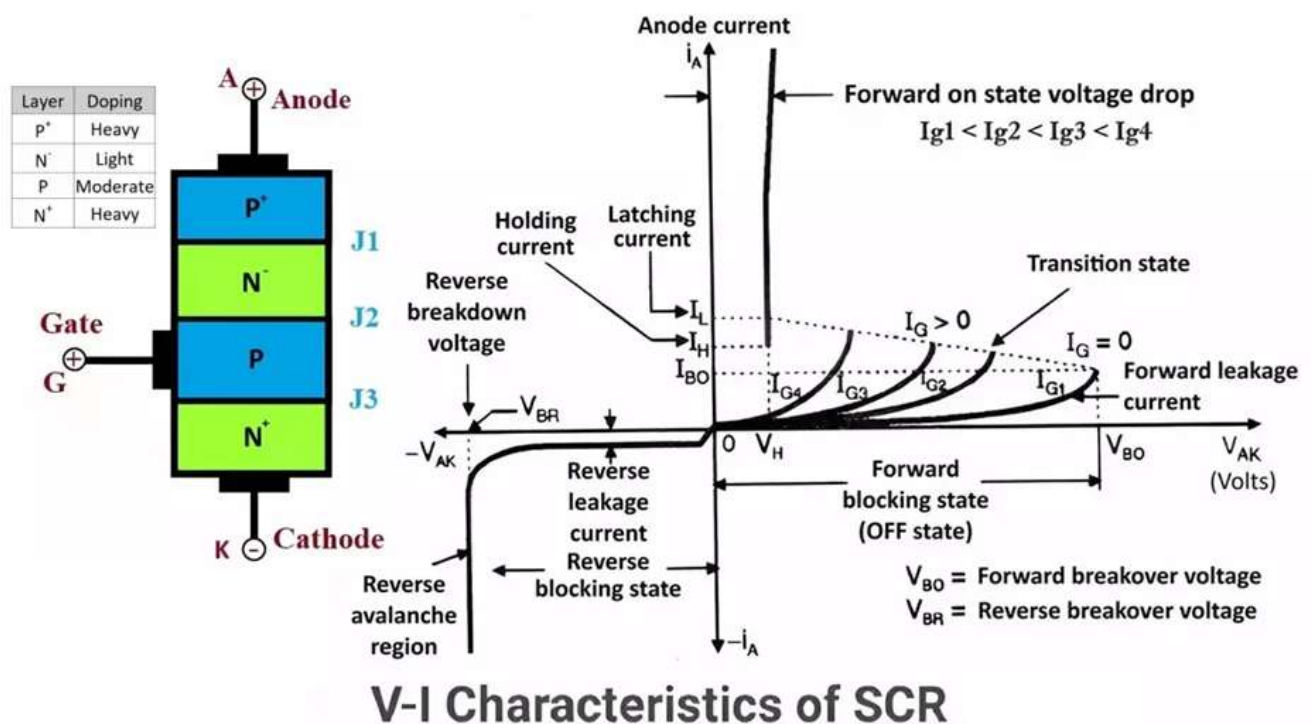
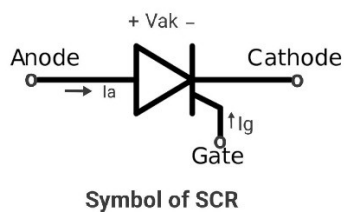
Date:-

**Experiment No. 1****Object**

To study the static and dynamic characteristics of power semiconductor devices (SCR, MOSFET, IGBT, and TRIAC).

**Objectives**

To plot V-I characteristics of various power electronics devices. (SCR, MOSFET, IGBT, and TRIAC).

**Theory****A. SCR – Silicon Controlled Rectifier****VI characteristic of SCR:**

The VI characteristics of SCR can be split into two parts namely

- **Forward characteristics**
- **Reverse characteristics**

For small reverse voltage, a small reverse leakage current flows. until the avalanche breakdown takes place at reverse breakover voltage  $V_{br}$ .

As soon as the reverse breakdown takes place due to avalanche breakdown, a large current flows through SCR whereas the voltage across the device remains constant.

It is dangerous to operate SCR in the reverse breakdown state because it may get damaged due to overheating.

The region from 0 Volts up to  $V_{br}$  volts in which the SCR is reverse biased and non-conducting is called as “reverse blocking state”. Reverse blocking means that the SCR is reverse biased and in the non-conducting (blocking) state.

### **Forward characteristics of SCR:**

The anode is positive with respect to the cathode. Hence SCR is forward biased.

The forward characteristics are divided into three regions of operation namely:

1. Forward blocking state.
2. Transition state.
3. ON state.

#### **1. Forward blocking state:**

This is the high voltage low current mode of operation in which SCR is in the OFF state. The current through it is “Forward Leakage Current”. This current flows due to thermally generated minority carriers.

#### **2. Transition state:**

SCR remains in the blocking state as long as the forward anode to cathode voltage is less than the breakover voltage.

As soon as  $V_{ak}$  becomes greater than the breakover value, and the anode current  $I_a$  increases sharply to a high value and the voltage across SCR reduces sharply to a low value (on-state voltage).

The switching of SCR from off state to on state and vice versa takes place in a short time. This changeover state is called as transition state. As this is an unstable state, it is shown by the dotted line.

#### **3. ON state:**

The voltage across SCR is low in this state. In the on-state the SCR anode currents is large, and the on-state voltage drop is small.

### **The important terms in the VI characteristics are as follows:**

1. The forward breakover voltage ( $V_{bo}$ ):  
This is the maximum forward voltage that can be applied between anode and cathode, without initiating forward conduction. This voltage is defined for a zero-gate current. In short, this is the maximum forward voltage across SCR in its off state.
2. The forward leakage current:  
The small forward current flowing in the forward blocking state of the device. This current is generated due to the minority current carriers and therefore is dependent on the operating temperature.
3. The holding current ( $I_h$ ):  
It represents the minimum current that can flow through SCR and still “hold” it in the on state. The voltage associated with the holding current is termed as holding voltage  $V_h$ .  
If the forward anode current is reduced below holding current, SCR will be turned off. The holding current is defined for zero gate current ( $I_g = 0$ ), it is denoted by  $I_h$  and its value is few mA.
4. ON-state voltage:  
Note that the voltage across SCR in its on state is very low as compared to the off-state voltage. It can be shown that the on-state voltage is equal to drop across one junction (1 to 1.5 Volts).

5. Latching current ( $I_L$ ):

It is the minimum anode current that must flow through SCR to latch it into the on-state. The latching current is higher than the holding current. The latching current is important when SCR is being turned on.

### Apparatus

| Sr. No. | Apparatus | Range | Quantity |
|---------|-----------|-------|----------|
| 1.      |           |       |          |
| 2.      |           |       |          |
| 3.      |           |       |          |
| 4.      |           |       |          |
| 5.      |           |       |          |
| 6.      |           |       |          |
| 7.      |           |       |          |
| 8.      |           |       |          |

### Procedure

1. Make circuit connections as shown in the figure.
2. To plot the V -I characteristics, proceed as follows.
3. Rotate both the potentiometer P1 and P2 in fully counter clockwise direction, connect voltmeter to point '6' & ground to read  $V_G$  and at point '3' & ground to read  $V_{AK}$ .
4. Connect ammeter at point '1' & '2' to indicate the current  $I_A$  and at point '4' & '5' to indicate the gate current  $I_G$ .
5. Switch on the Power Supply.
6. Vary potentiometer P2 to set the gate current  $I_G$  to a lower value (6.7mA, 5.7mA, 5.8mA, 7.3mA).
7. Increase anode voltage  $V_A$  gradually by varying potentiometer P1.
8. Observe the current  $I_A$  in the anode circuit, it shows almost zero current at the initial stage.
9. At certain point of positive anode voltage, current  $I_A$  shows sudden rise in reading & voltmeter reading falls down to almost zero. This action indicates the firing of SCR.
10. If this does not happen, repeat the procedure from step 5 for slightly higher value of gate current  $I_G$ .
11. Try for various values of gate current to get the firing of SCR.
12. Keeping gate current constant, observe precisely the firing voltage of SCR and record it in the observation table.

13. Also record the anode voltage  $V_A$  & anode current  $I_A$  after firing of the SCR.
14. Plot the graph of  $V_A$  versus  $I_A$ .

### Circuit Diagram

### Precaution:

1. Ensure correct polarity connections to avoid damaging the SCR.
2. Do not exceed the maximum rated voltage and current for the SCR.
3. Use appropriate resistors to limit current in the circuit.

### Observation Table

| Sr. No. | Anode<br>Voltage<br>$V_{AK}$ volt | $I_{G1} =$ mA | $I_{G2} =$ mA | $I_{G3} =$ mA |
|---------|-----------------------------------|---------------|---------------|---------------|
|         |                                   | $I_A$ (mA)    | $I_A$ (mA)    | $I_A$ (mA)    |
| 1.      |                                   |               |               |               |
| 2.      |                                   |               |               |               |
| 3.      |                                   |               |               |               |
| 4.      |                                   |               |               |               |
| 5.      |                                   |               |               |               |
| 6.      |                                   |               |               |               |
| 7.      |                                   |               |               |               |
| 8.      |                                   |               |               |               |
| 9.      |                                   |               |               |               |
| 10.     |                                   |               |               |               |

|     |  |  |  |  |
|-----|--|--|--|--|
| 11. |  |  |  |  |
| 12. |  |  |  |  |
| 13. |  |  |  |  |
| 14. |  |  |  |  |
| 15. |  |  |  |  |
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**Result and Conclusion: -**


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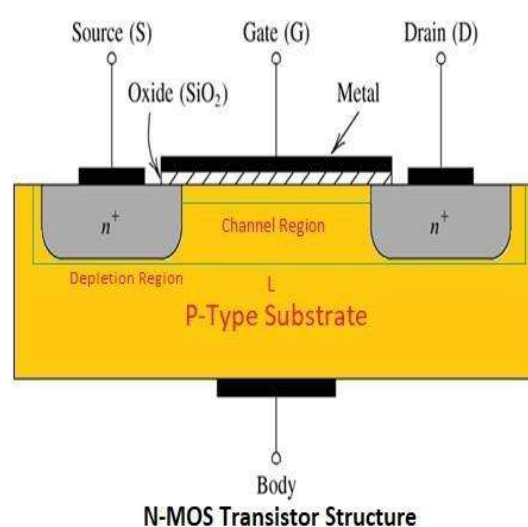
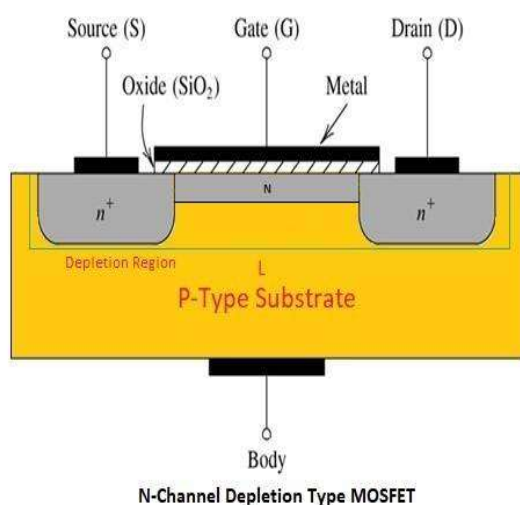
**Signature****Questions**

1. What is a Thyristor? Draw the structure of an SCR?
2. What is Forward break over voltage? Reverse break over voltage?
3. What are modes of working of an SCR?
4. Differentiate between holding and latching currents.
5. Explain reverse current  $I_{rev}$ .
6. Why should the gate signal be removed after turn on?
7. What are applications of SCR?

Date:-

## Theory

## B. MOSFET –



- **MOSFET Characteristics Definition:** MOSFETs are voltage-controlled devices used in various electronic circuits, classified into depletion-type and enhancement-type.
- **Operating Regions:** MOSFETs operate in cut-off, ohmic, and saturation regions, each defining different behaviours in current flow and voltage response.
- **VI Characteristics:** VI characteristics of MOSFETs explain how current ( $I_{DS}$ ) changes with gate-to-source voltage ( $V_{GS}$ ) and drain-to-source voltage ( $V_{DS}$ ).
- **Enhancement-type MOSFETs:** These require a threshold voltage to conduct, with distinct characteristics for n-channel and p-channel types.
- **Depletion-type MOSFETs:** These conduct without gate bias and require negative  $V_{GS}$  to turn off, applicable for both n-channel and p-channel types.

**MOSFETs** are three-terminal, unipolar, voltage-controlled devices with high input impedance, crucial in many electronic circuits.

These devices can be classified into two types viz., depletion-type and enhancement-type, depending on whether they possess a channel in their default state or no, respectively.

## Apparatus

| Sr. No. | Apparatus | Range | Quantity |
|---------|-----------|-------|----------|
| 1.      |           |       |          |
| 2.      |           |       |          |
| 3.      |           |       |          |

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## Procedure

### Procedure for Transfer Characteristics:

1. Connection: Connect the circuit as per circuit diagram. Ensure all power supplies are turned down to zero.
2. Fix Drain Voltage: Set the drain-source voltage ( $V_{DS}$ ) to a constant, stable value (e.g., 60V).
3. Step Gate Voltage: Increase the gate-source voltage ( $V_{GS}$ ) slowly from 0V upward.
4. Record Current: Observe that drain current ( $I_D$ ) stays at zero until  $V_{GS}$  hits the threshold voltage ( $V_{GST}$ ). Record ( $I_D$ ) for every step after.
5. Plot Curve:  $I_D$  on the Y-axis against  $V_{GS}$  on the X-axis.

### Procedure for Output Characteristics:

1. Fix Gate Voltage: Set the gate-source voltage ( $V_{GS}$ ) to a fixed value below threshold (for cutoff) or above threshold (for conduction).
2. Sweep Drain Voltage: Gradually increase the drain-source voltage ( $V_{DS}$ ) from 0V in equal intervals.
3. Record Current: Note the changing drain current ( $I_D$ ) for each voltage step.
4. Repeat Steps: Change ( $V_{GS}$ ) to a higher fixed step and repeat the step 2 & 3.
5. Plot Curves: Graph ( $I_D$ ) vs. ( $V_{DS}$ ) for all values of ( $V_{GS}$ ) to identify the Ohmic, Saturation, and Cutoff regions.

## Circuit Diagram

### Precaution:

1. Handle the MOSFET carefully to avoid electrostatic discharge ( $E_{SD}$ ) damage.
2. Ensure that the drain-to-source voltage ( $V_{DS}$ ) and gate-to-source voltage ( $V_{GS}$ ) do not exceed the maximum ratings specified in the MOSFET's datasheet to avoid damaging the device.
3. Use appropriate resistors to limit current in the circuit.

**Observation Table****A. Transfer Characteristics**

| Sr. No. | $V_{DS} = \quad V$ |            |
|---------|--------------------|------------|
|         | $V_{GS} (V)$       | $I_D (mA)$ |
| 1.      |                    |            |
| 2.      |                    |            |
| 3.      |                    |            |
| 4.      |                    |            |
| 5.      |                    |            |
| 6.      |                    |            |
| 7.      |                    |            |
| 8.      |                    |            |
| 9.      |                    |            |
| 10.     |                    |            |

**B. Output Characteristics**

| Sr. No. | Drain voltage<br>$V_{DS} (V)$ | $V_{GS} =$ | $V_{GS} =$ | $V_{GS} =$ | $V_{GS} =$ |
|---------|-------------------------------|------------|------------|------------|------------|
|         |                               | $I_D (mA)$ | $I_D (mA)$ | $I_D (mA)$ | $I_D (mA)$ |
| 1.      |                               |            |            |            |            |
| 2.      |                               |            |            |            |            |
| 3.      |                               |            |            |            |            |
| 4.      |                               |            |            |            |            |
| 5.      |                               |            |            |            |            |
| 6.      |                               |            |            |            |            |
| 7.      |                               |            |            |            |            |
| 8.      |                               |            |            |            |            |
| 9.      |                               |            |            |            |            |
| 10.     |                               |            |            |            |            |

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**Result and Conclusion: -**

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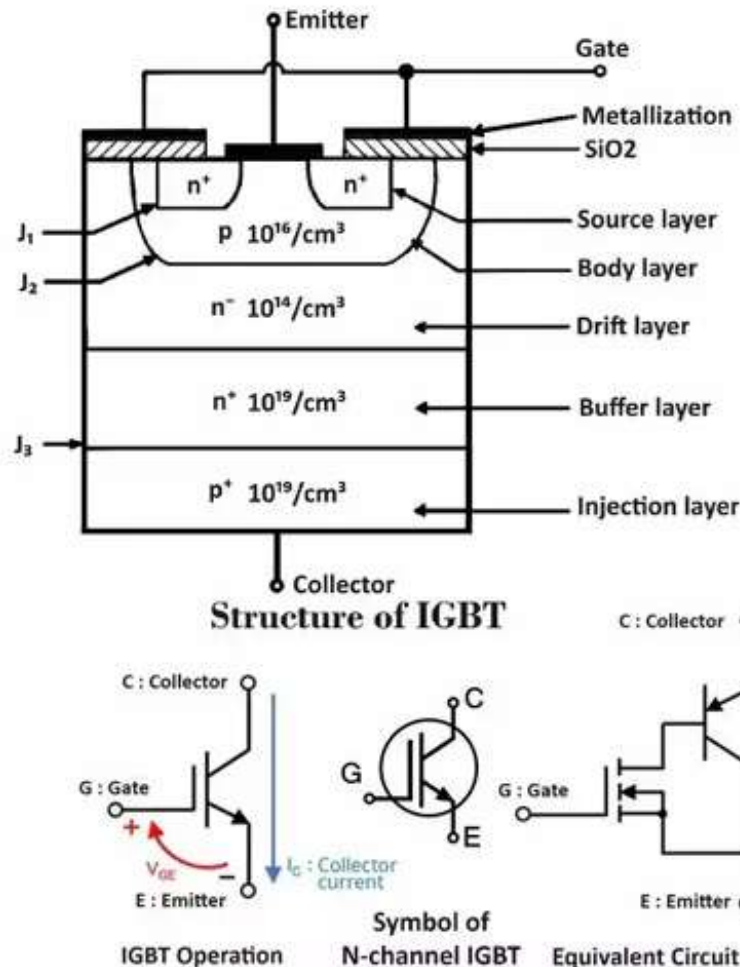
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**Signature****Questions**

1. What are MOSFET's?
2. Draw the symbol of MOSFET.
3. What is the difference between MOSFET and BJT?
4. What are the types of MOSFET?
5. What is the difference between depletion and enhancement MOSFET?
6. Draw the switching model of MOSFET.
7. What is rise time and fall time?
8. In which region does the MOSFET used as a switch?
9. Why are MOSFET's mainly used for low power applications?
10. What are the advantages of vertical structure of MOSFET?

Date: \_\_\_\_\_

### C. IGBT – Insulated Gate Bipolar Transistor



The VI (voltage-current) characteristics of an Insulated Gate Bipolar Transistor (IGBT) are important for understanding its operation and applications. The IGBT combines the advantages of both MOSFETs and BJTs, offering high input impedance and fast switching with high current capability.

#### 1. Output Characteristics ( $I_C$ vs. $V_{CE}$ ):

- **Regions:**
  - **Cutoff Region:** When the gate-emitter voltage  $V_{GE}$  is below the threshold voltage, the IGBT is in the off state, and the collector current  $I_C$  is almost zero regardless of the collector-emitter voltage  $V_{CE}$ .
  - **Active (Saturation) Region:** When  $V_{GE}$  is above the threshold voltage, the IGBT turns on, and the collector current  $I_C$  increases rapidly with an increase in  $V_{CE}$  until it reaches a point where it saturates. In this region, the IGBT acts as a controlled current source.
  - **Ohmic Region:** At higher  $V_{CE}$  values, the device exhibits a slight increase in  $I_C$  with  $V_{CE}$ , indicating a resistive behaviour.
- **Characteristics:**
  - As  $V_{CE}$  increases from zero,  $I_C$  initially remains low until  $V_{GE}$  reaches the threshold voltage.
  - Beyond the threshold voltage, for a constant  $V_{GE}$ , the collector current  $I_C$  increases with increasing  $V_{CE}$  until it reaches saturation.
  - The slope of the  $I_C$  vs.  $V_{CE}$  curve in the active region is influenced by the gate voltage  $V_{GE}$ .

2

#### . Transfer Characteristics ( $I_C$ vs. $V_{GE}$ ):

- **Region:**

- Threshold Voltage: The voltage  $V_{GE}$  at which the IGBT starts to conduct. Below this voltage, the IGBT is off, and  $I_C$  is almost zero.
- Linear Region: As  $V_{GE}$  increases above the threshold, the collector current  $I_C$  increases almost linearly with  $V_{GE}$  until it saturates.

- **Characteristics:**

- $I_C$  is highly sensitive to  $V_{GE}$  in this region.
- For a given  $V_{CE}$ , increasing  $V_{GE}$  increases  $I_C$  exponentially.

### 3. Switching Characteristics:

- IGBTs are used for switching applications, so the switching characteristics, including the turn-on and turn-off times, are crucial.
- **Turn-On Time:** The time taken by the IGBT to turn on completely after the gate voltage exceeds the threshold.
- **Turn-Off Time:** The time taken by the IGBT to turn off completely after the gate voltage drops below the threshold.

### Apparatus

| Sr. No. | Apparatus | Range | Quantity |
|---------|-----------|-------|----------|
| 1.      |           |       |          |
| 2.      |           |       |          |
| 3.      |           |       |          |
| 4.      |           |       |          |
| 5.      |           |       |          |
| 6.      |           |       |          |
| 7.      |           |       |          |

### Procedure

#### Procedure for Transfer Characteristics

1. Make the circuit connections as per circuit diagram with all power supplies set to zero.
2. Set Collector-Emitter Voltage: Fix the collector-emitter voltage ( $V_{CE}$ ) at a constant safe value (e.g., 60V).
3. Vary Gate Voltage: Slowly increase the gate-emitter voltage ( $V_{GE}$ ) in small steps.
4. Record Data: Note the corresponding collector current ( $I_C$ ) once  $V_{GE}$  exceeds the threshold voltage ( $V_{GET}$ ), (typically 3V to 6V).
5. Plot Curve: Graph  $I_C$  on the Y-axis against  $V_{GE}$  on the X-axis.

Pr \_\_\_\_\_

### Procedure for Output (V-I) Characteristics

1. **Fix Gate Voltage:** Set the gate-emitter voltage ( $V_{GE}$ ) to a constant value above the threshold voltage ( $V_{GET}$ ).
2. **Vary Collector Voltage:** Gradually increase the collector-emitter voltage ( $V_{CE}$ ) from zero in regular steps.
3. **Record Data:** Measure the resulting collector current ( $I_C$ ) for each step of ( $V_{CE}$ ).
4. **Repeat for Different Gate Voltages:** Increase ( $V_{GE}$ ) to new higher fixed levels and repeat the sweep of ( $V_{CE}$ ).
5. **Plot Curves:** Graph ( $I_C$ ) versus ( $V_{CE}$ ) for each distinct ( $V_{GE}$ ) value to display the cutoff, active, and saturation regions.

### Circuit Diagram

### Observation Table

#### A. Transfer Characteristic

| Sr. No. | $V_{CC} (V) =$ |            |
|---------|----------------|------------|
|         | $V_{GE} (V)$   | $I_C (mA)$ |
| 1.      |                |            |
| 2.      |                |            |
| 3.      |                |            |
| 4.      |                |            |
| 5.      |                |            |
| 6.      |                |            |
| 7.      |                |            |
| 8.      |                |            |
| 9.      |                |            |
| 10.     |                |            |

#### B. O

### Output Characteristics

| Sr. No. | Collector Voltage $V_{CC}$ (V) | $V_{GE1} =$ | $V_{GE2} =$ | $V_{GE3} =$ | $V_{GE4} =$ |
|---------|--------------------------------|-------------|-------------|-------------|-------------|
|         |                                | $I_C$ (mA)  | $I_C$ (mA)  | $I_C$ (mA)  | $I_C$ (mA)  |
| 1.      |                                |             |             |             |             |
| 2.      |                                |             |             |             |             |
| 3.      |                                |             |             |             |             |
| 4.      |                                |             |             |             |             |
| 5.      |                                |             |             |             |             |
| 6.      |                                |             |             |             |             |
| 7.      |                                |             |             |             |             |
| 8.      |                                |             |             |             |             |
| 9.      |                                |             |             |             |             |
| 10.     |                                |             |             |             |             |

### Result and Conclusion: -

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**Signature**

### Questions

1. What is IGBT? What is the difference between an IGBT and SCR?
2. In what way IGBT is more advantageous than BJT and MOSFET?
4. Draw the equivalent circuit of IGBT.
7. What is switching speed of IGBT?
9. What are merits & demerits of IGBT? Write the applications of IGBT's.
12. Why silicon used in all power semiconductor devices and why not Germanium?
14. What is threshold voltage?

Date:

**Experiment No. 2(A)****Object**

Experimental study of single-phase rectifiers: uncontrolled, half-controlled, and fully controlled converters

**Objectives**

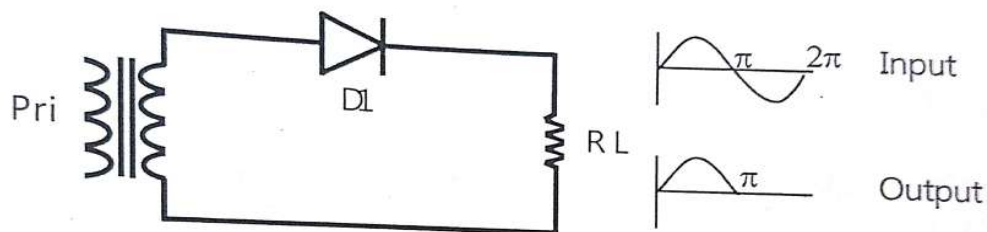
To study the performance of single-phase half and full wave uncontrolled and controlled rectifiers.

**Theory**

A **diode** is a device which conducts in one direction only. It conducts only when anode is more positive than cathode.

**A. Half-Wave Rectifier:**

A **half-wave rectifier** is a simple circuit used in power electronics to convert alternating current (AC) to direct current (DC). It allows only one half of the AC waveform (positive or negative) to pass through, while blocking the other half. Here's an overview of its operation, theory, and equations.

**1. Basic Operation:**

- A half-wave rectifier consists of a single diode connected in series with the load resistor.
- During the positive half-cycle of the AC input voltage, the diode becomes forward-biased (conducts), allowing current to pass through the load resistor.
- During the negative half-cycle, the diode becomes reverse-biased (does not conduct), blocking the current flow. As a result, the output voltage across the load is zero during this half-cycle.
- The output waveform consists of only the positive (or negative) half of the input AC signal.

**2. Output Waveform:**

- The output is a pulsating DC voltage with a frequency equal to the input AC frequency.
- Since only one half of the waveform is utilized, the efficiency and average output voltage are lower compared to a full-wave rectifier.

**Equations**

Let the input AC voltage be represented by:

$$V_{in}(t) = V_m \sin(\omega t)$$

where:

$V_m$  is the peak value of the input AC voltage,

$\omega$  is the angular frequency of the input AC signal.

**1. Output Voltage (V<sub>out</sub>):**

During the positive half-cycle:

$$V_{out}(t) = V_m \sin(\omega t) \quad \text{for } 0 \leq \omega t \leq \pi$$

During the negative half-cycle

$$V_{out}(t) = 0 \quad \text{for } \pi < \omega t \leq 2\pi$$

The output waveform repeats every cycle.

**2. Average (DC) Output Voltage (V<sub>avg</sub>):**

$$V_{avg} = \frac{V_m}{\pi}$$

**3. RMS Value of Output Voltage (V<sub>rms</sub>):**

For a half-wave rectifier:

$$V_{rms} = \sqrt{\frac{1}{2\pi} \int_0^\pi (V_m \sin(\omega t))^2 d(\omega t)}$$

Solving this gives:

$$V_{rms} = \frac{V_m}{2}$$

**4. Form Factor and Ripple Factor:**

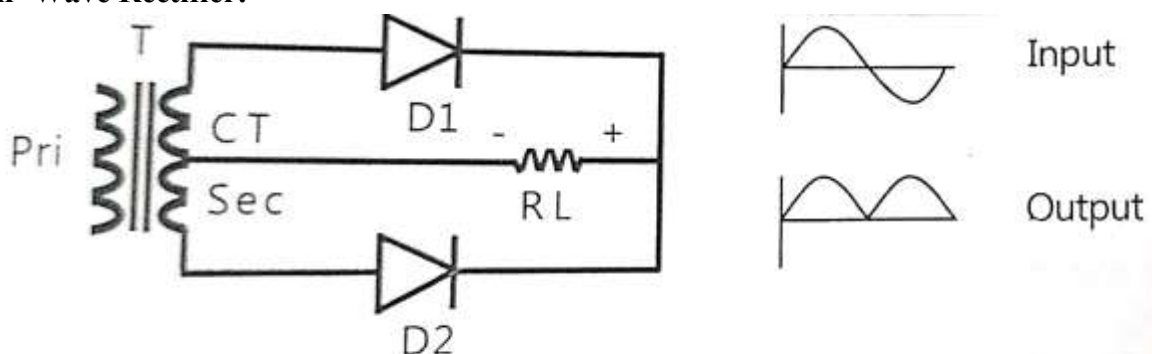
- **Form Factor (F.F):** It is the ratio of the RMS value to the average value

$$F.F = \frac{V_{rms}}{V_{avg}} = \frac{\frac{V_m}{2}}{\frac{V_m}{\pi}} = \frac{\pi}{2} \approx 1.57$$

- **Ripple Factor (γ):** It is a measure of the AC components in the rectified output:

$$\gamma = \sqrt{\left(\frac{V_{rms}}{V_{avg}}\right)^2 - 1} \approx 1.21$$

These equations form the basis of understanding the half-wave rectifier. It's a fundamental building block in power electronics and introduces the principles of rectification and conversion of AC to DC.

**B. Full -Wave Rectifier:**

Full wave rectifier and its input / output waveforms.

A **full-wave rectifier** converts the entire input AC signal into a pulsating DC signal, making it more efficient than a half-wave rectifier. There are two main types of full-wave rectifiers: the center-tap full-

wave rectifier and the bridge full-wave rectifier. Both types provide a DC output by using both halves of the AC input signal.

### 1. Basic Operation:

#### a) Center-Tap Full-Wave Rectifier:

- This rectifier uses a center-tapped transformer and two diodes.
- During the positive half-cycle of the AC input, one diode conducts, and the other is reverse-biased, allowing current to pass through the load in one direction.
- During the negative half-cycle, the roles of the diodes reverse, but the current through the load remains in the same direction, effectively inverting the negative half-cycle.

#### b) Bridge Full-Wave Rectifier:

- This rectifier uses four diodes arranged in a bridge configuration.
- During both the positive and negative half-cycles of the input AC, two diodes conduct while the other two are reverse-biased, ensuring the current through the load is always in the same direction.

### 2. Output Waveform:

- The output voltage of a full-wave rectifier is a pulsating DC waveform with twice the frequency of the input AC signal.
- Since both halves of the AC waveform are used, the output is smoother and has a higher average value compared to a half-wave rectifier.

### Equations

Let the input AC voltage be represented by:

$$V_{in}(t) = V_m \sin(\omega t)$$

where:

$V_m$  is the peak value of the input AC voltage,

$\omega$  is the angular frequency of the input AC signal.

### 1. Output Voltage ( $V_{out}$ ):

For both positive and negative half-cycles

$$\begin{aligned} V_{out}(t) &= V_m \sin(\omega t) & \text{for } 0 \leq \omega t \leq \pi \\ V_{out}(t) &= -V_m \sin(\omega t) & \text{for } \pi < \omega t \leq 2\pi \end{aligned}$$

The output waveform repeats every half cycle, effectively doubling the frequency of the output signal.

### 2. Average (DC) Output Voltage ( $V_{avg}$ ):

$$V_{avg} = \frac{2V_m}{\pi}$$

This value is double that of a half-wave rectifier, which makes the full-wave rectifier more efficient.

### 3. RMS Value of Output Voltage ( $V_{rms}$ ): The RMS value is calculated as:

$$V_{rms} = \frac{V_m}{\sqrt{2}}$$

**4. Form Factor and Ripple Factor:**

**Form Factor (F.F):** It is the ratio of the RMS value to the average value:

$$F.F = \frac{V_{rms}}{V_{avg}} = \frac{\frac{V_m}{\sqrt{2}}}{\frac{2V_m}{\pi}} = \frac{\pi}{2\sqrt{2}} \approx 1.11$$

**Ripple Factor ( $\gamma$ ):** It is a measure of the AC components in the rectified output:

The lower ripple factor of a full-wave rectifier compared to a half-wave rectifier means that the output is smoother.

**5. Frequency of the Output Voltage:**

The output frequency of the full-wave rectifier is twice the input AC frequency:

$$f_{out} = 2f_{in}$$

These concepts and equations are fundamental for understanding the working of a full-wave rectifier and its advantages over a half-wave rectifier in power electronics.

**Apparatus**

| Sr. No. | Apparatus | Range | Quantity |
|---------|-----------|-------|----------|
| 1       |           |       |          |
| 2       |           |       |          |
| 3       |           |       |          |
| 4       |           |       |          |

**Procedure**

1. Keep miniature toggle switch SW towards off side, this will cut diode D2 from the circuit and it becomes a half wave rectifier circuit. Keep miniature toggle switch SW towards on side, this will bring diode D2 from the circuit and it becomes a full wave rectifier circuit.
2. Switch on the power.
3. Measure input AC as  $V_{ac}$  (across the anode of D1 and -ve terminal).
4. Connect DMM with output (across RL). Note the reading of ac ( $V_r$ ) and DC ( $V_{dc}$ ) voltage from it.
5. Connect CRO at input and output. Trace the waveform. Note the output goes to zero as soon as +ve half cycle of input goes zero.
6. Repeat same steps for full wave rectifier circuit.

## Circuit Diagram

### Precaution

1. Before connecting to the supply check the auto transformer and voltmeter reading/dial is at zero position.
2. Care should be taken for the connections to be tightened properly.

### Observation Table

Load Resistance R =

|                                   | Sr.<br>No. | Input $V_{AC}$ | $V_{DC}$<br>across R<br>( $V_{out DC}$ ) | $V_{AC}$<br>across R<br>( $V_{out AC}$ ) |
|-----------------------------------|------------|----------------|------------------------------------------|------------------------------------------|
| For half wave<br>bridge rectifier | 1.         |                |                                          |                                          |
|                                   | 2.         |                |                                          |                                          |
| For full wave<br>bridge rectifier | 1.         |                |                                          |                                          |
|                                   | 2.         |                |                                          |                                          |

### Calculations

A. For half wave rectifier:

$$1. I_{DC} = \frac{V_{DC}}{R}$$

$$2. \text{Ripple Factor} = \frac{V_{out AC}}{V_{out DC}} = \frac{V_{rms}}{V_{DC}}$$

**B. For full wave rectifier:**

$$1. I_{DC} = \frac{V_{DC}}{R}$$

$$2. \text{Ripple Factor} = \frac{V_{out AC}}{V_{out DC}} = \frac{V_{rms}}{V_{DC}}$$

**Result and Conclusion: -**

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**Signature****Questions**

1. What is the use of uncontrolled rectifier?
2. What is uncontrolled rectifier type?
3. Why is a diode called an uncontrolled rectifier?
4. What is 3 phase half wave uncontrolled rectifier?

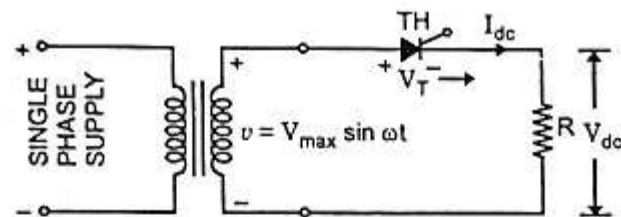
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**Experiment No. 2(B)****Object**

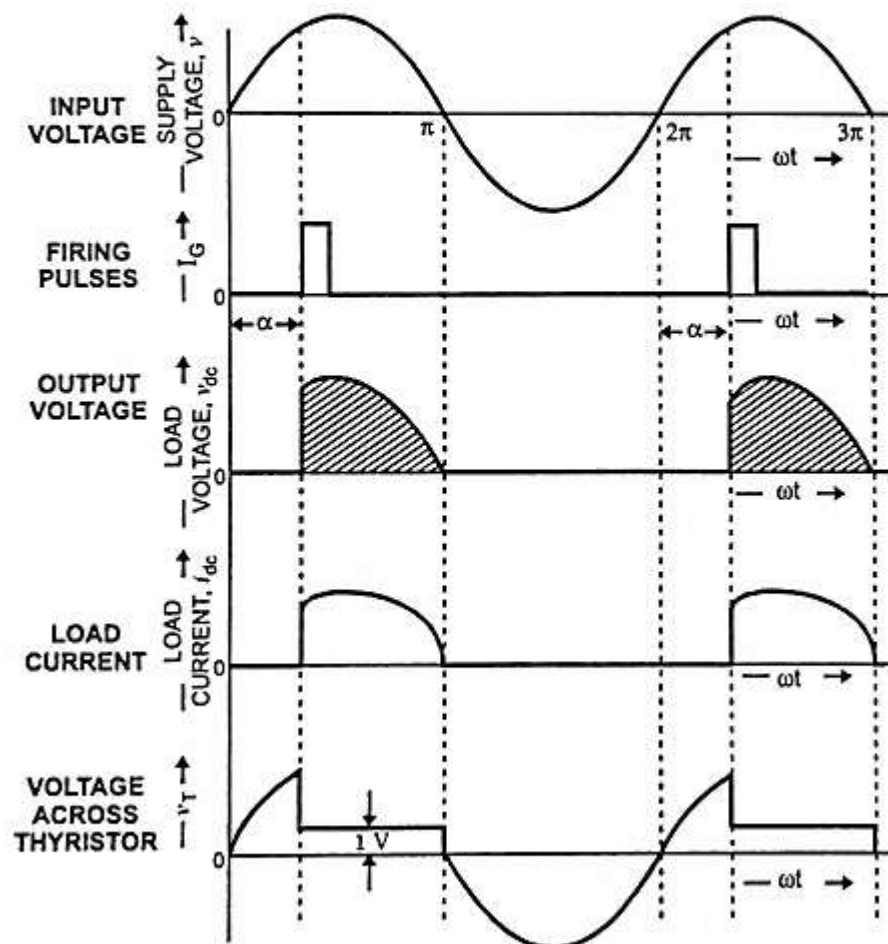
Experimental analysis of Single-Phase Half Controlled Converter

**Objectives**

To study the performance of single-phase half-controlled converter with R Load.

**Theory**

(a) Circuit Diagram



(b) Waveforms of Input Voltage, Firing Pulses, Output Voltage, Current and Voltage Drop Across Thyristor

Figure (a) depicts the circuit diagram of a Single-Phase Half Wave Controlled Rectifier with resistive load (triggering circuit not shown in the figure). The circuit is energized by the line voltage or transformer secondary voltage,  $v = V_{\max} \sin \omega t$ . It is assumed that the peak supply voltage never exceeds the forward and reverse-blocking ratings of the thyristor. The thyristor can be triggered at any angle  $\alpha$  in the positive half cycle and thus the output voltage can be controlled. The thyristor blocks during the negative half cycle. The various voltage and current waveforms for the Single-Phase Half Wave Controlled Rectifier with resistive load circuit are shown in Figure (b).

During the positive half cycle of the supply voltage, the thyristor anode is positive w.r.t, its cathode and until the thyristor is triggered by a proper gate pulse, it blocks the flow of load current in the forward direction. When the thyristor is fired at an angle  $\alpha$ , full supply voltage (ignoring the thyristor drop  $V_T$ ) is applied to the load. Thus, the load is directly connected to the ac supply. With a zero-reactance source and a purely resistive load, the current waveform after the thyristor is triggered will be identical to the applied voltage wave and of a magnitude dependent on the amplitude of the applied voltage and the value of the load resistance  $R$ . At zero crossing, the thyristor is turned off by natural commutation thereby switching off the power to the load.

Average load voltage is given by

$$V_{dc} = \frac{1}{2\pi} \left[ \int_{\alpha}^{\pi} V_{\max} \sin \omega t d(\omega t) + \int_{\pi}^{2\pi} (0) d(\omega t) \right]$$

$$= \frac{1}{2\pi} [-V_{\max} \cos \omega t]_{\alpha}^{\pi} = \frac{V_{\max}}{2\pi} (1 + \cos \alpha)$$

where  $V_{\max}$  is the peak value of the ac input voltage.

Average load current, with resistive load, is directly proportional to the average load voltage and is given by

$$I_{dc} = \frac{V_{dc}}{R} = \frac{V_{\max}}{2\pi R} (1 + \cos \alpha)$$

## Apparatus

| Sr.No. | Apparatus | Range | Quantity |
|--------|-----------|-------|----------|
| 1      |           |       |          |
| 2      |           |       |          |
| 3      |           |       |          |

## Procedure

1. Make the circuit shown in the figure.
2. Rotate the firing control pot in full clockwise direction.
3. Switch 'On' the power.
4. Measure the ac voltage ( $V_{rms}$ ) by voltmeter across secondary side of transformer and calculate  $V_m$  by  $V_m = \sqrt{2} V_{rms}$ .
5. Switch 'Off' the power. Connect the circuit of half-wave rectifier as shown figure.

6. Switch 'On' the power.
7. Connect the Oscilloscope and voltmeter across the load.
8. Vary the firing control pot and set on  $0^\circ$ ,  $54^\circ$ ,  $90^\circ$ ,  $144^\circ$ , and  $180^\circ$  firing angles using  $T = (\alpha \times 10\text{ms}) / 180$ .
9. Observe the output waveforms and note the readings of voltage across load on different firing angles.
10. Observe the waveform across the SCR1 when firing angle is  $90^\circ$ .
11. Calculate the average load  $I_{DC}$  current and  $V_{DC}$ .
12. Plot the input signal, gate pulse, and drop signal across SCR and output waveforms when firing angle is  $90^\circ$ .

### Precaution

1. Ensure that all connections are correctly made according to the circuit diagram.
2. Verify the polarity of components like diodes, SCRs, and the load.
3. Use the correct gate pulse triggering circuit for the thyristor. Ensure the triggering pulse is synchronized with the AC supply and is applied at the correct phase angle.

### Circuit Diagram

### Observation Table

Load Resistance  $R =$

| Sr. No. | Input AC Voltage |                                 | Firing Angle |         | Average Output Voltage Across Load |                                                                                 | Average Load Current ( $I_{DC}$ ) |                                         |
|---------|------------------|---------------------------------|--------------|---------|------------------------------------|---------------------------------------------------------------------------------|-----------------------------------|-----------------------------------------|
|         | $V_{RMS}$        | $V_M = \sqrt{2} \times V_{RMS}$ | In Deg       | In time | Measured Voltage DC ( $V_o$ )      | Calculated Voltage ( $V_{DC}$ )<br>$V_{DC} = \frac{V_m}{2\pi}(1 + \cos \alpha)$ | Measured ( $I_o$ )<br>$V_o / R$   | Calculated ( $I_{DC}$ )<br>$V_{DC} / R$ |
|         |                  |                                 |              |         |                                    |                                                                                 |                                   |                                         |
|         |                  |                                 |              |         |                                    |                                                                                 |                                   |                                         |
|         |                  |                                 |              |         |                                    |                                                                                 |                                   |                                         |
|         |                  |                                 |              |         |                                    |                                                                                 |                                   |                                         |
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|         |                  |                                 |              |         |                                    |                                                                                 |                                   |                                         |

**Result and Conclusion: -**

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**Signature****Questions**

1. Why is it called a 'half controlled' converter?
2. How does the firing angle ( $\alpha$ ) affect the output voltage of a Single-Phase Half Controlled Converter?
3. What is the role of the freewheeling diode in a Single-Phase Half Controlled Converter?
4. What are the typical applications of single-phase half-controlled rectifiers?

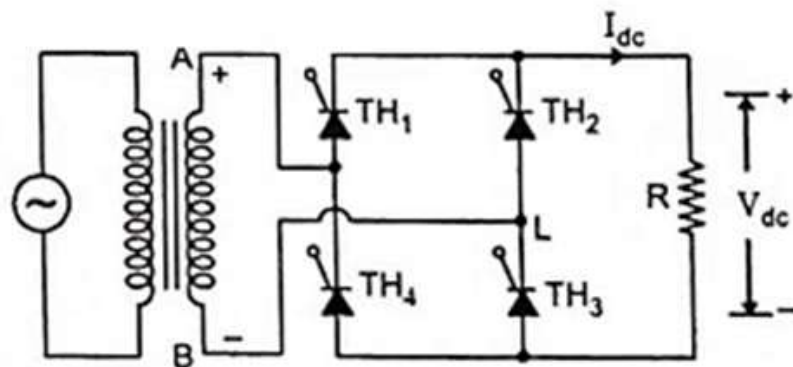
Date:

**Experiment No. 2(C)****Object**

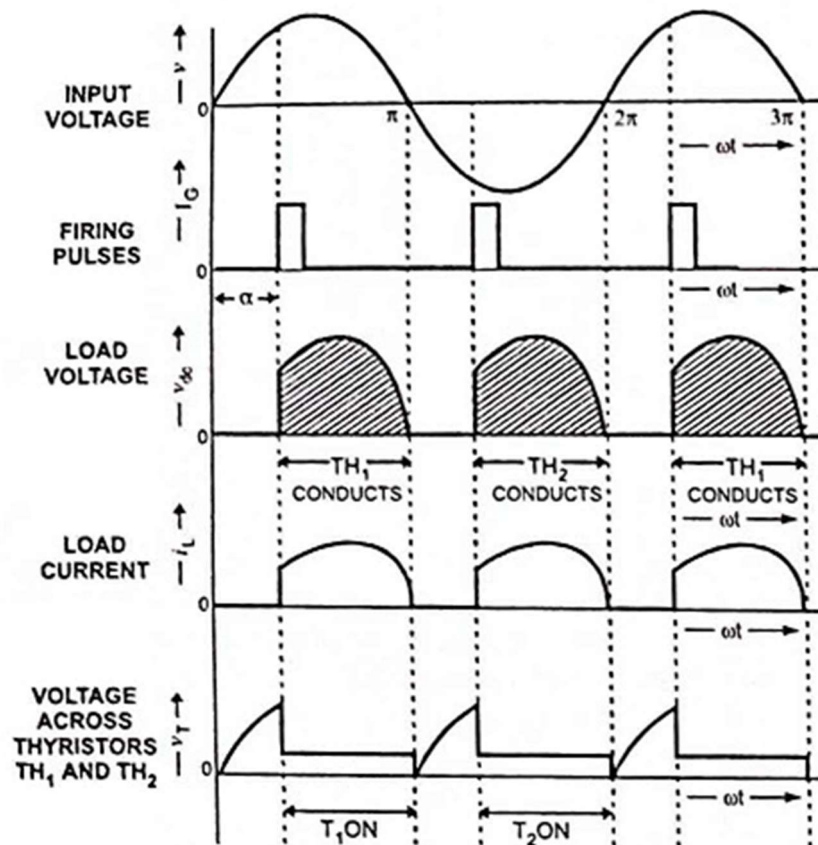
Experimental analysis of Single-Phase Full Controlled Converter

**Objectives**

To study the performance of single-phase full-controlled converter with R Load.

**Theory**

*Single Phase Full-Wave Controlled Rectifier  
With Resistive Load*



*Waveforms With Resistive Load*

A fully controlled full-wave bridge rectifier is shown in Fig. All the four devices used in the circuit are thyristors TH<sub>1</sub>-TH<sub>4</sub> for control of output power. In this circuit, diagonally opposite pair of thyristors are made to conduct, and are commutated, simultaneously. During the first positive half cycle, thyristors TH<sub>1</sub> and TH<sub>3</sub> are forward biased and if they are triggered simultaneously, the current flows through the load via thyristor TH<sub>1</sub>-load-TH<sub>3</sub>-source. Thus, during positive half cycle, thyristors TH<sub>1</sub> and TH<sub>3</sub> are conducting. During the negative half cycle of the ac input, thyristors TH<sub>2</sub> and TH<sub>4</sub> are forward biased and if they are triggered simultaneously, the current flows through the load via thyristor TH<sub>2</sub>-load-TH<sub>4</sub>-source. Thyristors TH<sub>1</sub>, TH<sub>3</sub> and TH<sub>2</sub>, TH<sub>4</sub> are triggered at the same firing angle  $\alpha$  in each positive and negative half cycles of the supply voltage respectively. When the supply voltage falls to zero, the current also becomes zero. Thus, thyristors TH<sub>1</sub>, TH<sub>3</sub> in positive half cycle and TH<sub>2</sub> and TH<sub>4</sub> in negative half cycle turn off by natural commutation. The related voltage and current waveforms for this circuit are depicted in Fig.

Average load voltage is given by

$$V_{dc} = \frac{1}{\pi} \int_{\alpha}^{\pi} V_m \sin \omega t \, d\omega t$$

$$= \frac{V_m}{\pi} (1 + \cos(\alpha))$$

The maximum value of V<sub>dc</sub> is obtained at  $\alpha = 0^\circ$

where V<sub>m</sub> is the peak value of the ac input voltage.

Average load current, with resistive load, is directly proportional to the average load voltage and is given by

$$I_{dc} = \frac{V_{dc}}{R} = \frac{V_m}{R\pi} (1 + \cos(\alpha))$$

### Apparatus

| S.No. | Apparatus | Range | Quantity |
|-------|-----------|-------|----------|
| 1     |           |       |          |
| 2     |           |       |          |
| 3     |           |       |          |

### Procedure

1. Connect the circuit of fully-controlled bridge rectifier as shown in figure. Rotate the firing control Potentiometer in full clockwise direction.
2. Switch 'On' the power.
3. Measure the ac voltage (V<sub>rms</sub>) by voltmeter between secondary terminal of transformer and calculate E<sub>m</sub>.
4. Connect the Oscilloscope and voltmeter across the load.

5. Vary the firing control pot and set on  $0^\circ$ ,  $54^\circ$ ,  $90^\circ$ ,  $144^\circ$ , and  $180^\circ$  firing angles using  $T = (\alpha \times 10\text{ms}) / 180$ .
6. Observe the output waveforms and note the readings of voltage across load on different firing angle.
7. Measure and calculate the load current  $I_{DC}$  and power  $P_{DC}$  from measured load voltage  $V_o$ .
8. Plot the input signal, gate pulse and drop signal across SCR and output waveforms when firing angle is  $90^\circ$  with resistive and resistive-inductive load.

### Precaution

1. Ensure that all connections are correctly made according to the circuit diagram.
2. Verify the polarity of components like diodes, SCRs, and the load.
3. Use the correct gate pulse triggering circuit for the thyristor. Ensure the triggering pulse is synchronized with the AC supply and is applied at the correct phase angle.

### Circuit Diagram

### Observation Table

Load Resistance  $R =$

| Sr. No. | Input AC Voltage |                                 | Firing Angle |         | Average Output Voltage Across Load |                                                                                | Average Load Current (IDC)      |                                         |
|---------|------------------|---------------------------------|--------------|---------|------------------------------------|--------------------------------------------------------------------------------|---------------------------------|-----------------------------------------|
|         | $V_{RMS}$        | $V_M = \sqrt{2} \times V_{RMS}$ | In Deg       | In time | Measured Voltage DC ( $V_o$ )      | Calculated Voltage ( $V_{DC}$ )<br>$V_{DC} = \frac{V_m}{\pi}(1 + \cos \alpha)$ | Measured ( $I_o$ )<br>$V_o / R$ | Calculated ( $I_{DC}$ )<br>$V_{DC} / R$ |
|         |                  |                                 |              |         |                                    |                                                                                |                                 |                                         |
|         |                  |                                 |              |         |                                    |                                                                                |                                 |                                         |
|         |                  |                                 |              |         |                                    |                                                                                |                                 |                                         |
|         |                  |                                 |              |         |                                    |                                                                                |                                 |                                         |
|         |                  |                                 |              |         |                                    |                                                                                |                                 |                                         |
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**Result and Conclusion: -**

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**Signature****Questions**

1. What is the difference between half wave and full wave rectifier?
2. What is the effect of the firing angle on the output voltage of a full-wave bridge rectifier?
3. Describe the conduction pattern of thyristors in a full-wave bridge rectifier during one complete cycle.
4. What are the advantages of using a full-wave bridge rectifier over a half-wave rectifier?
5. What is the typical application of a single-phase full-wave bridge-controlled rectifier?

**Date:****Experiment No. 3****Object**

Simulation of single phase semi controlled converter

**Objectives**

To build and simulate single phase semi controlled converter

**Software Needed:** MATLAB R2013a.**Theory**

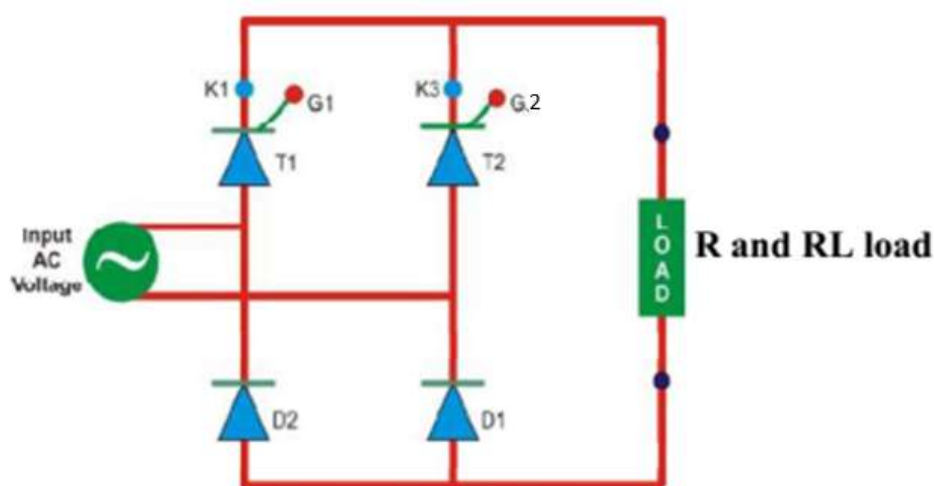
In this configuration two thyristors are replaced by power diodes and can be connected in either arm of the bridge. Depending on the connections, these are further classified as

1. Symmetrical
2. Asymmetrical

Symmetrical configuration is in two types

1. Common cathode
2. Common anode

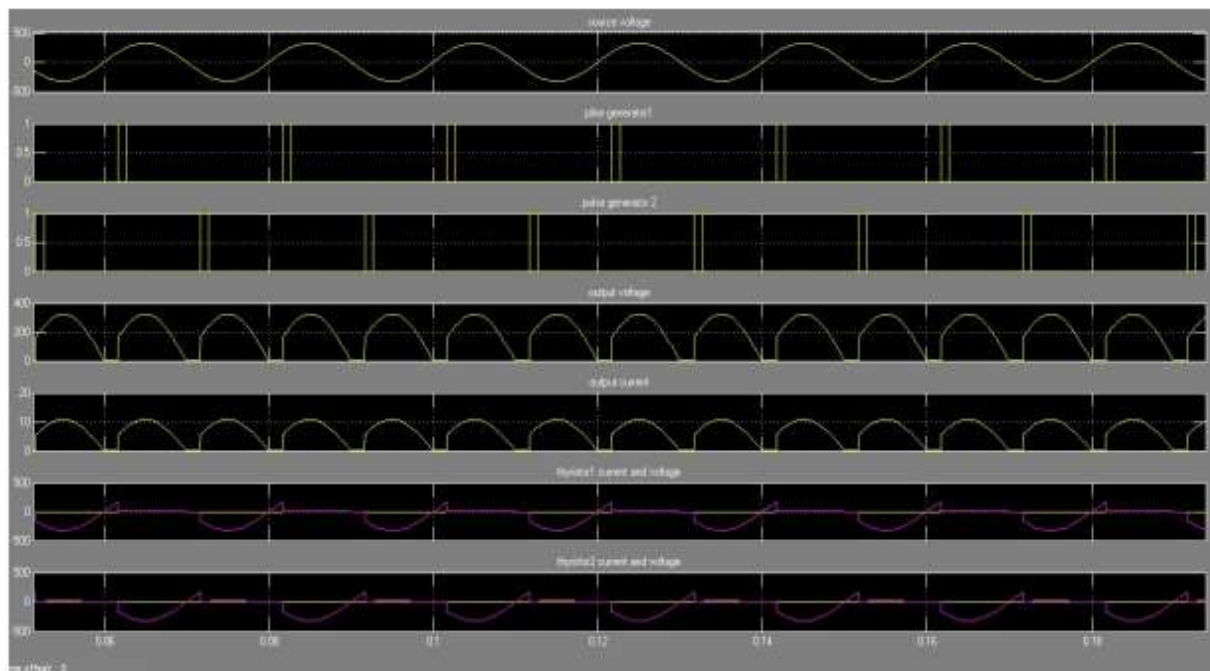
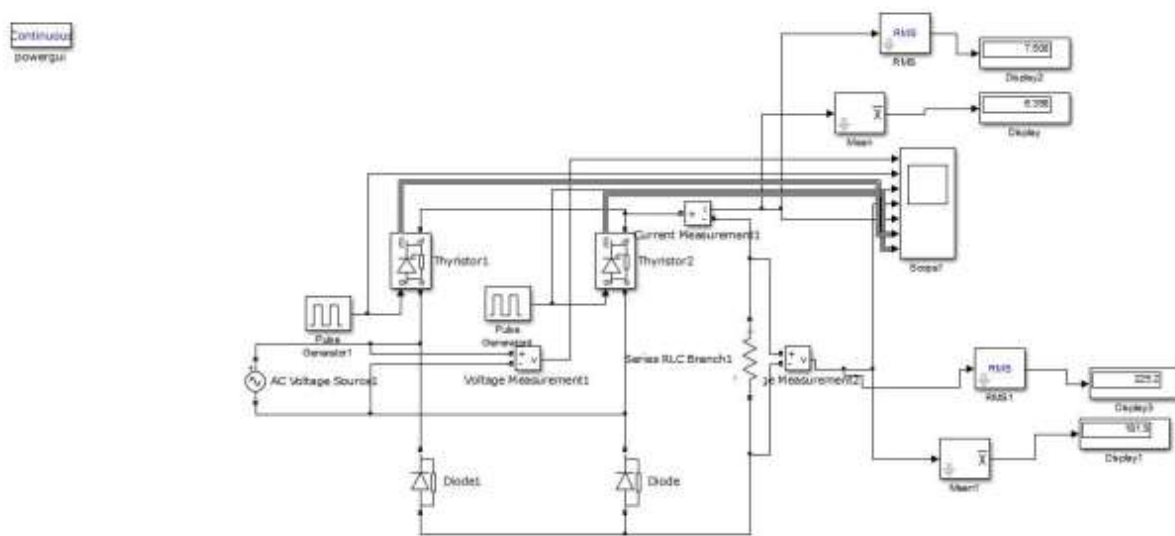
Out of these configurations, the common cathode symmetrical configuration is the most commonly used configuration, because a single trigger can be used to fire both thyristors without any electrically isolation. During the positive half cycle, when thyristor T1 is triggered, the load current flows through T1 and the diode D2 in the circuit shown in figure. During the negative half cycle, the thyristor T2 and the diode D1 constitute the load current.

**Single Phase semi converter with R and RL Load****Procedure:**

1. Connect the Circuit as shown in circuit diagram.
2. Give the firing angle from pulse generator to generate suitable pulses.
3. Observe output voltage, current and thyristor voltages from the Simulink model.
4. From display values note down the average and rms values of voltage and current.

## Experimental Mat lab Model and Waveforms:

### Single Phase Half Wave Controlled Rectifier R load model and waveform for $\alpha=30^\circ$ :



### Result and Conclusion:

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Signature

**Date:****Experiment No. 4****Object**

Simulation of Single Phase Bridge Controlled Rectifier with R and RL load

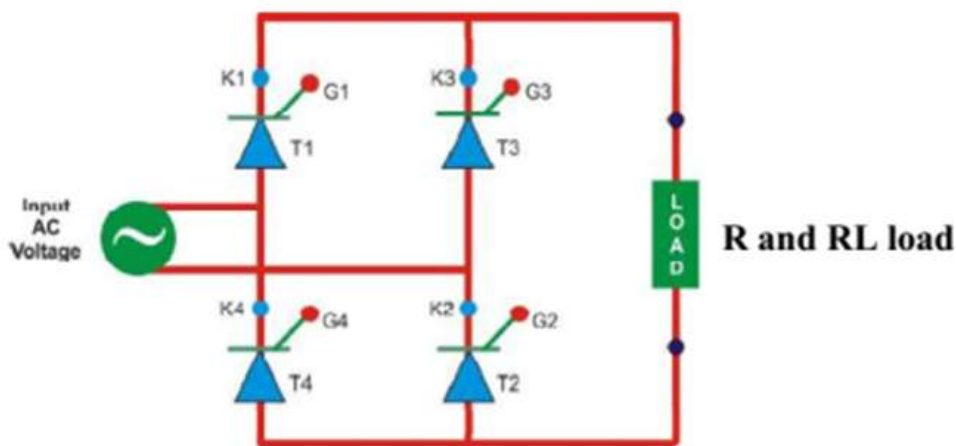
**Objectives**

To Study the simulation of Single-Phase Bridge Controlled Rectifier with R and RL Load using Simulink.

**Software Needed:** Matlab R2013a.

**Theory**

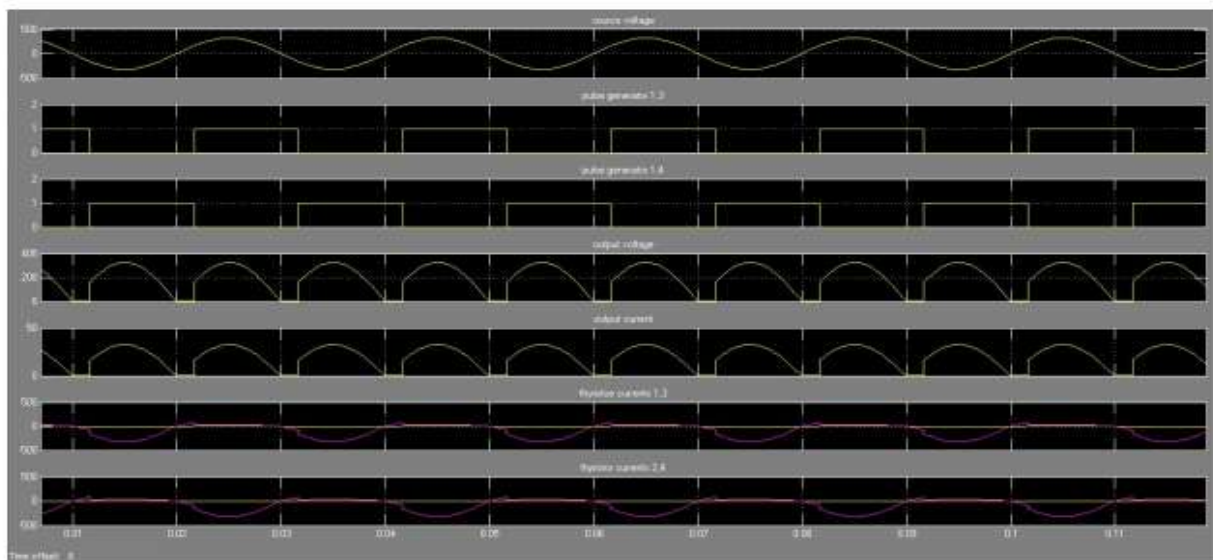
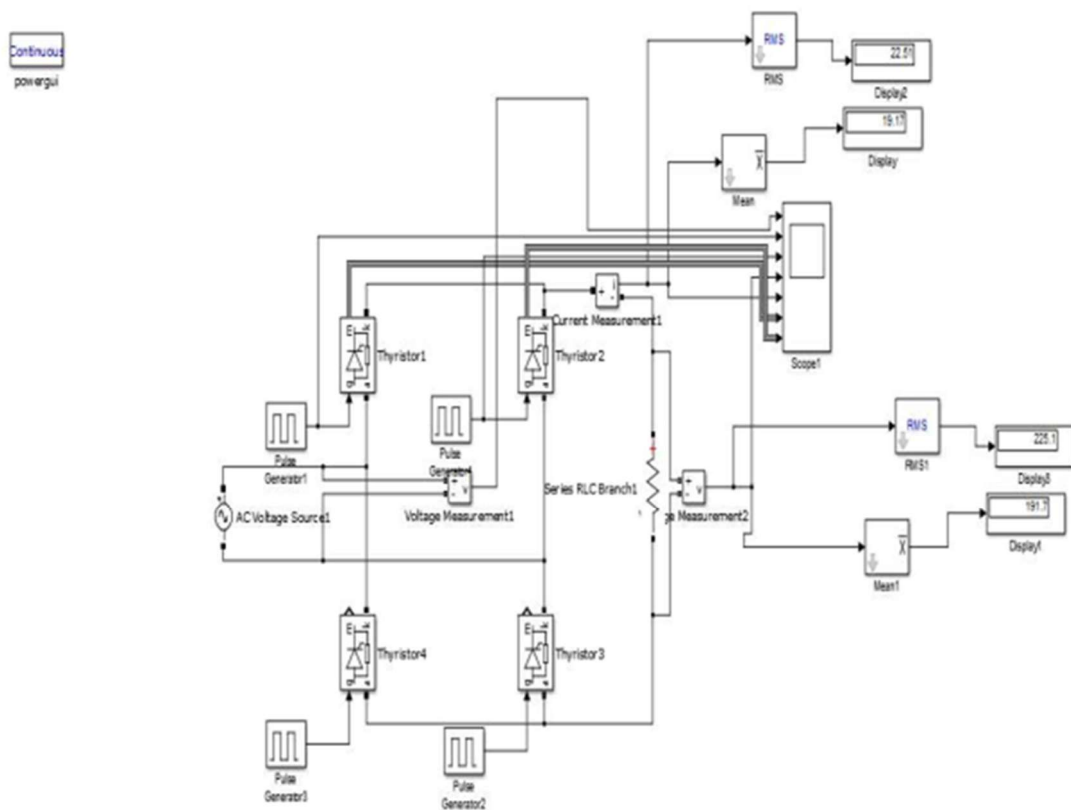
A single-phase fully controlled bridge circuit consists of four thyristor as shown in figure, with a resistive load. During the positive half cycle thyristors T1 and T2 are in the forward blocking state and when these thyristors fire simultaneously at  $\omega t = \alpha$ , the load is connected to the input through T1 and T2. During negative half cycle i.e., after  $\omega t = \pi$ , thyristor T3 and T4 are in the forward blocking state, and simultaneous firing of these thyristors reverse biases the previously conducting thyristors T1 and T2. These reverse biased thyristors turn off due to line or natural commutation and the load current transfers from T1 and T2 to T3 and T4.



**Single Phase Bridge Controlled Rectifier with R and RL load**

**Procedure:**

1. Connect the Circuit as shown in circuit diagram.
2. Give the firing angle from pulse generator to generate suitable pulses.
3. Observe output voltage, current and thyristor voltages from the Simulink model.
4. From display values note down the average and rms values of voltage and current
5. Compare theoretical and practical values where both calculated and theoretical values must be same.

**Experimental Mat lab Model and Waveforms:****Single Phase Bridge Controlled Rectifier R load model and waveform for  $\alpha=30^\circ$ :****Result and Conclusion:**


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**Signature**

**Date:****Experiment No. 5****Object**

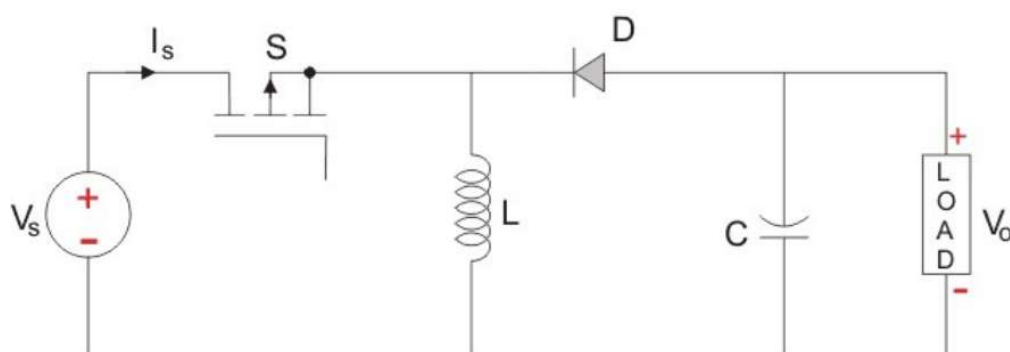
Experimental study of DC-DC converters (Buck, Boost, and Buck-Boost converters).

**Objectives**

To study the performance of Buck- Boost Converters.

**Theory**

In buck-boost converters, the output voltage is either higher or lower than the input voltage; but the polarity of the output voltage is reversed with respect to the input voltage. When the switch is ON, the diode is reverse biased and input provides energy to the inductor. When the switch is OFF, the energy stored in the inductor is transferred to the output. No energy is supplied by the input during this interval. Buck-Boost Converter which can operate as a DC-DC Step-Down converter or a DC-DC Step-Up converter depending upon the duty cycle, D. Buck-Boost Converter is shown below



Mode I : Switch is ON, Diode is OFF When the switch S1 is ON as it represents a short circuit ideally offering zero resistance to the flow of current, the current will flow through the switch, through the inductor and back to the DC input source. The inductor stores charge during the time the switch is ON and when the solid-state switch is OFF the polarity of the Inductor reverses so that current flows through the load and through the diode and back to the inductor. So, the direction of current through the inductor remains the same.

Mode II : Switch S1 is OFF, Diode D is ON In this mode as the switch S1 is OFF, the diode D becomes conductive. Thus, the polarity of the inductor voltage is reversed and the energy stored in the inductor is released, which is ultimately dissipated in the load resistance. This helps to maintain the flow of current in the same direction through the load and also step-up the output voltage as the inductor is now also acting as a source in addition to the input source.

**Apparatus**

| S.No. | Apparatus | Range | Quantity |
|-------|-----------|-------|----------|
| 1     |           |       |          |
| 2     |           |       |          |
| 3     |           |       |          |

### Procedure

1. Connect the circuit as shown in figure
2. Initially keep all the switches in off position.
3. Initially keep Duty cycle Pot in minimum position.
4. Switch on the main supply.
5. Check the test point waveforms with respect to ground.
6. Measure the output voltage and observe the duty cycle. Note down  $T_{ON}$ ,  $T_{OFF}$ , and  $T$ .
7. Vary the duty ratio from 10% to 70% (in steps of 10%). Measure the average DC load voltage for the corresponding values of duty ratio.
8. Observe the inductor voltage waveform across 3 and Ground, inductor current during switching across 1-2 and diode current waveform across 3-4.
9. Calculate the average theoretical DC output voltage for the corresponding duty ratios.
10. Compare the observed average output voltage results with the calculated ones.
11. Draw the graph output voltage Vs duty cycle ratio.

### Precaution

1. Ensure that all connections are correctly made according to the circuit diagram.
2. Verify the polarity of components like diodes, switch and the load.
3. The duty cycle is adjustable, start at a low value and gradually increase it while monitoring the output. Sudden changes can lead to voltage spikes or stress on the components.

### Circuit Diagram

### Observation Table

| Sr. No. | Input DC voltage | $T_{ON}$ | $T_{OFF}$ | $T$ | Duty ratio<br>$D = T_{ON}/T_{OFF}$ | Output voltage measured | Output voltage Calculated |
|---------|------------------|----------|-----------|-----|------------------------------------|-------------------------|---------------------------|
|         |                  |          |           |     |                                    |                         |                           |
|         |                  |          |           |     |                                    |                         |                           |
|         |                  |          |           |     |                                    |                         |                           |
|         |                  |          |           |     |                                    |                         |                           |
|         |                  |          |           |     |                                    |                         |                           |

**Result and Conclusion: -**

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**Signature****Questions**

1. What is the purpose of a buck-boost converter?
2. How does a buck-boost converter differ from a buck converter and a boost converter?
3. What are the applications of buck-boost converters in real-world electronics?
4. What is the effect of increasing the duty cycle on the output voltage of a buck-boost converter?

Date:

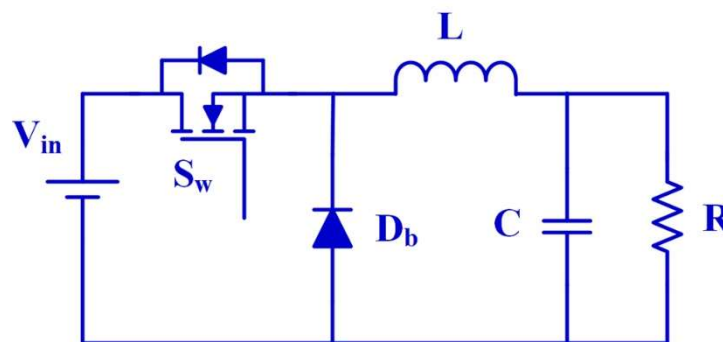
**Experiment No. 6****Object**

Simulation of BUCK /BOOST/BUCK -BOOST converter

**Objectives**

To Study the simulation of Single-Phase Bridge Controlled Rectifier with R and RL Load using Simulink.

**Software Needed:** Matlab R2013a.

**Theory****Buck Converter:**

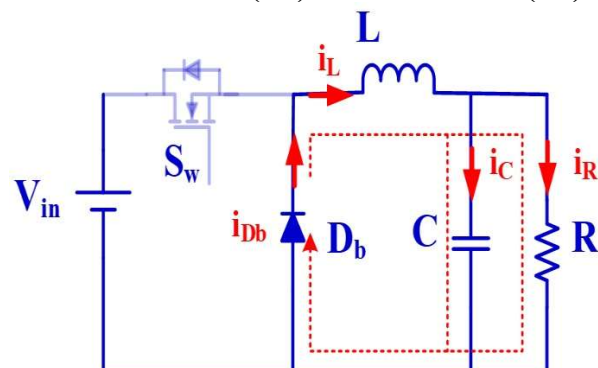
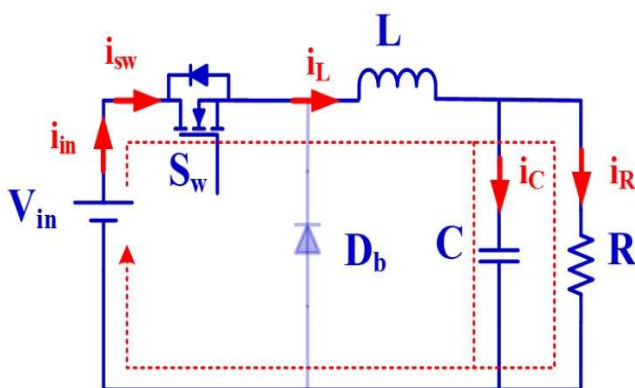
Based on the operation of switch ( $S_w$ : ON/OFF-state) the operating principle of the converter is explained below briefly.

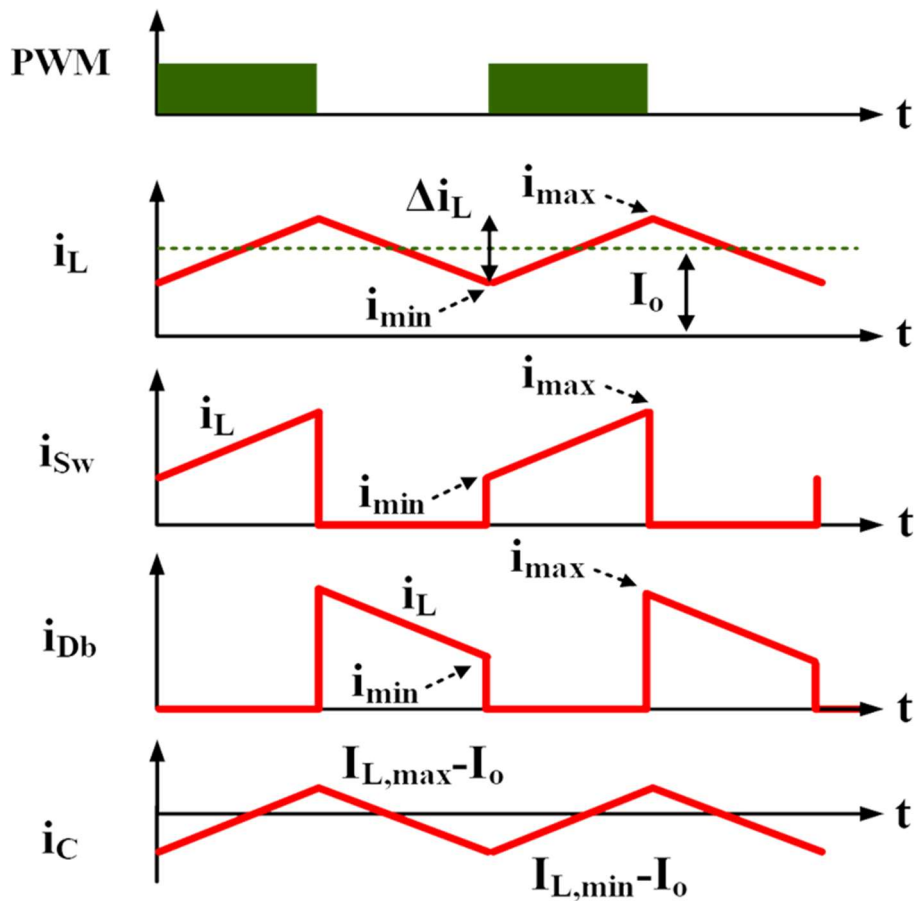
**Switch ON:** Current flows from the input source through the closed switch and the inductor to the load. The inductor stores energy in its magnetic field, and its current rises linearly. The diode is reverse-biased (blocking).

**Switch OFF:** The switch opens. The inductor resists the sudden drop in current by collapsing its magnetic field, which reverses its voltage polarity. This forward-biases the diode (called a free-wheeling diode), allowing the inductor current to loop back around to continue powering the load. Current decreases linearly.

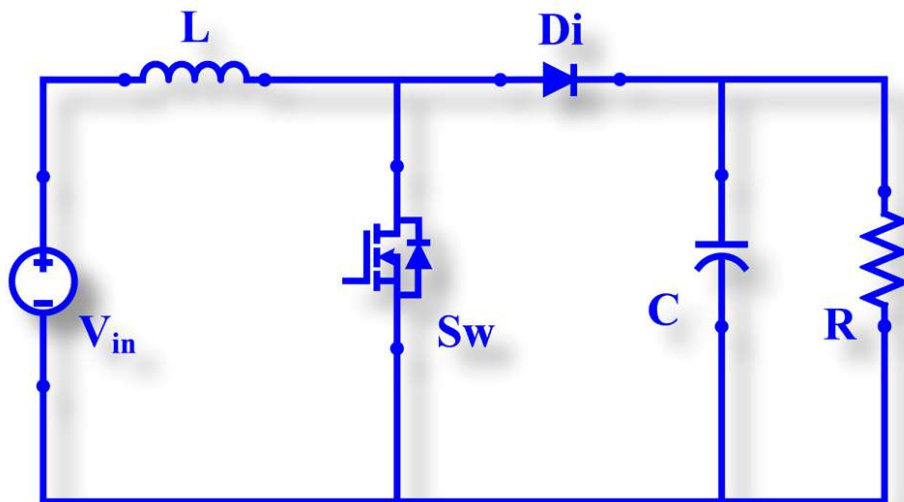
**Mode – I : Switch ( $S_w$ ): ON and Diode ( $D_b$ ): OFF**

**Mode – II : Switch ( $S_w$ ): OFF and Diode ( $D_b$ ): ON**





### Boost Converter:



The average output voltage is more than the input voltage  $V_d$ .

The filter capacitor is assumed to be high so that the output voltage is more or less constant.

**Switch ON:** The switch closes, routing current straight from the source through the inductor to ground. The inductor stores energy, and its current rises linearly. The diode prevents the output capacitor from discharging back into the ground loop.

**Switch OFF:** The switch opens. The inductor's current cannot instantly drop to zero, so its voltage spikes up. This forces the voltage at the node before the diode to rise above the input voltage. The diode becomes forward-biased, dumping the combined energy of the source and inductor together into the output capacitor and load.

$$V_{dc} = \text{Supply Voltage,}$$

$$V_0 = \text{Output Voltage,}$$

$$V_{ind} = V_s - V_0, \text{ (S1 is OFF)}$$

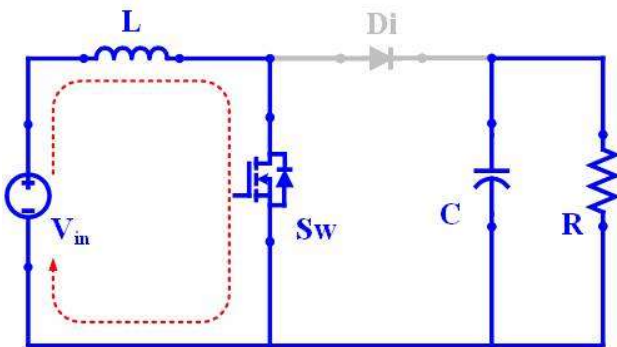
$$V_{ind} = V_s, \text{ (S1 is ON)}$$

The average voltage across inductor in a cycle is zero.

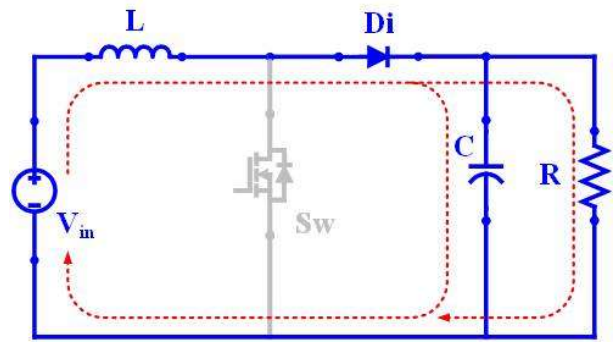
$$V_0 = \frac{T_s}{T_{off}} V_d$$

$$V_0 = \frac{1}{1-D} V_d$$

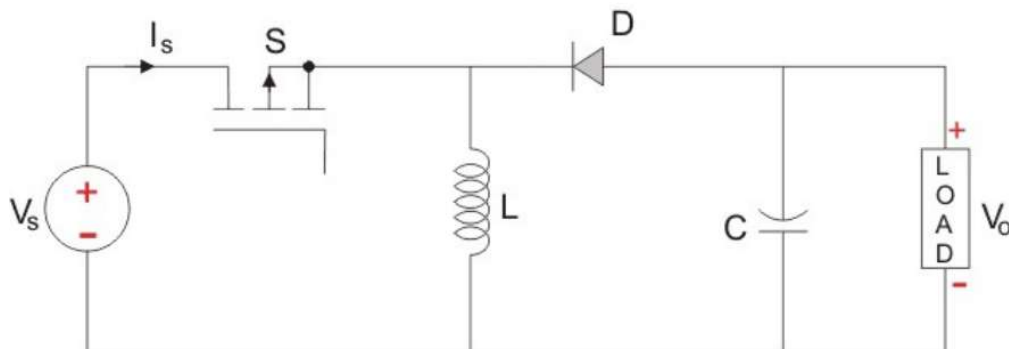
Mode – I : Switch S:ON-state, Diode: OFF-state



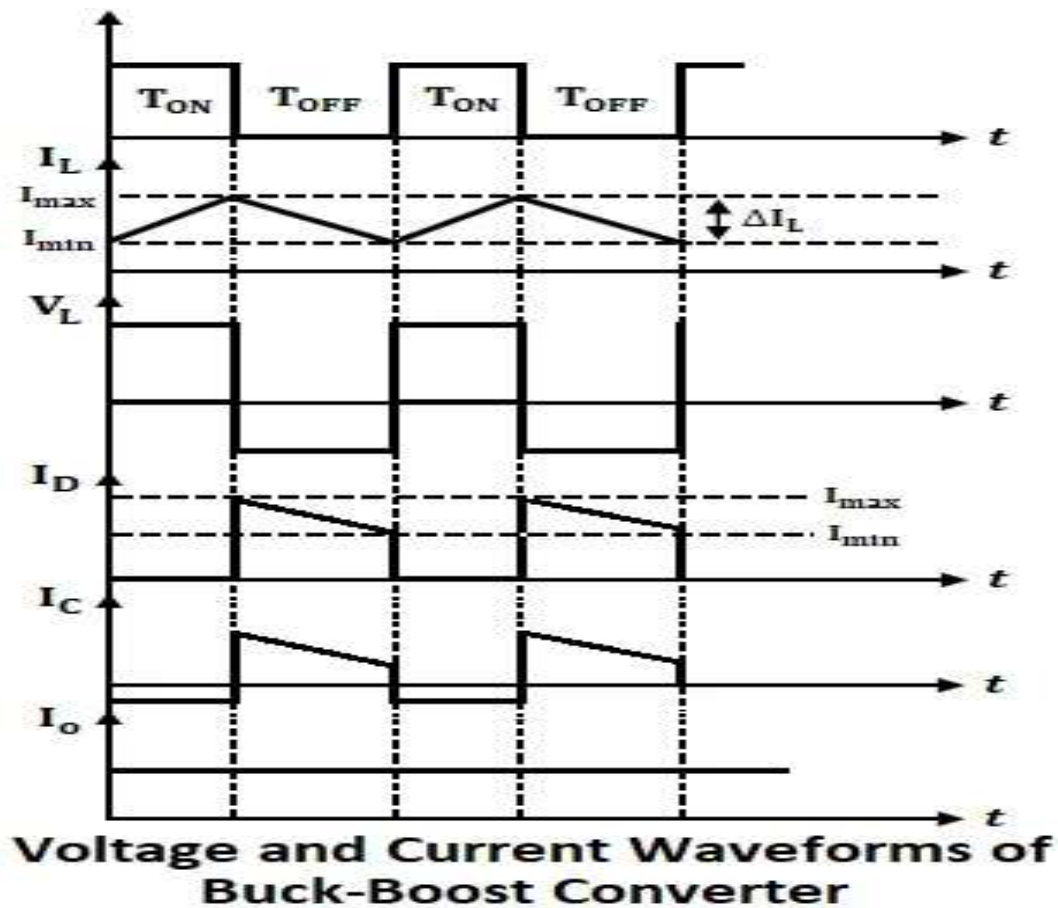
Mode – II : Switch S:OFF-state, Diode: ON-state



### Buck Boost Converter:



- **Switch ON:** The switch closes, connecting the inductor directly across the input source. Current flows through the inductor to ground, storing energy. The diode is reverse-biased, completely isolating the input side from the load. The load is supported entirely by the output capacitor.
- **Switch OFF:** The switch opens. The inductor reverses its polarity to maintain current flow. This pulls the diode node below ground, forward-biasing the diode. Current is forced out of the ground node, through the load and capacitor, and back into the inductor. This creates a negative (inverted) output voltage relative to the source ground.



### Procedure

1. Make the connections as per circuit diagram with elements taken from the MATLAB library for both R & RL load.
2. Simulate them.
3. Observe the waveform carefully on scope.

### Precaution

1. Ensure that all connections are correctly made according to the circuit diagram.
2. Verify the polarity of components like diodes, switch and the load.
3. The duty cycle is adjustable, start at a low value and gradually increase it while monitoring the output. Sudden changes can lead to voltage spikes or stress on the components.

### Result and Conclusion: -

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Signature

Date:

**Experiment No. 7****Object**

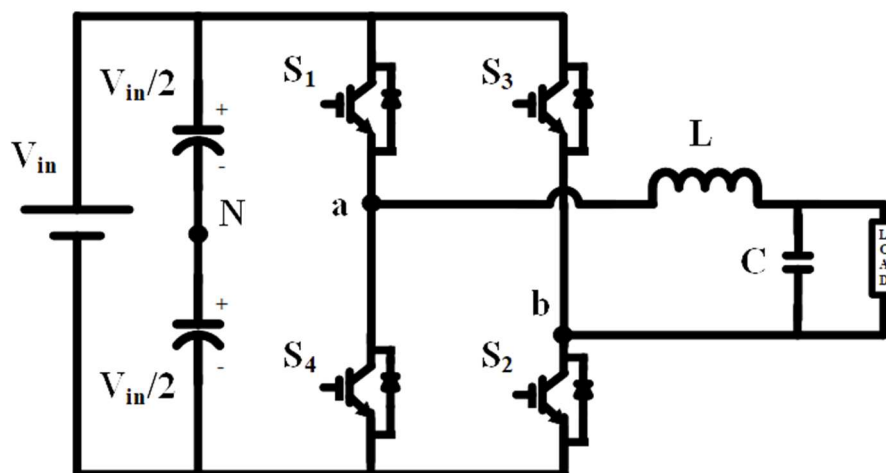
Experimental analysis of single-phase inverters, including bridge inverter configurations.

**Objectives**

Study the performance of a single-phase inverter under sinusoidal PWM control

**Theory**

A single-phase IGBT inverter is a power electronic circuit that converts a DC voltage into a single-phase AC voltage using Insulated Gate Bipolar Transistors (IGBTs) as switching devices. Pulse Width Modulation (PWM) is used to control the output voltage and reduce harmonic distortion. The circuit configuration of single-phase bridge inverter is shown in Fig. 1.



The inverter converts DC into AC by switching the IGBTs at high frequency according to the PWM signals.

For a full-bridge inverter:

| Switching condition | Output voltage |
|---------------------|----------------|
| S1 and S2 ON        | $+V_{in}$ dc   |
| S3 and S4 ON        | $-V_{in}$ dc   |
| S1 and S3 ON        | 0              |
| S2 and S4 ON        | 0              |

S1 and S2 are switched together to produce the positive output voltage, while S3 and S4 are switched together to produce the negative output voltage.

Important: S1 and S4 in the same leg must never be turned ON simultaneously, and similarly S3 and S2 must not be ON simultaneously. Otherwise, a short circuit of the DC source can occur.

**PWM Technique**

In **Sinusoidal Pulse Width Modulation (SPWM)**, a sinusoidal reference signal is compared with a high-frequency triangular carrier signal.

- **Reference signal:** Determines the desired output frequency.
- **Carrier signal:** Determines the switching frequency.
- When the reference signal is greater than the carrier signal, the corresponding IGBT is turned ON.
- When the reference signal is lower than the carrier signal, the IGBT is turned OFF.

The resulting output consists of a series of voltage pulses whose widths vary according to the sinusoidal reference waveform.

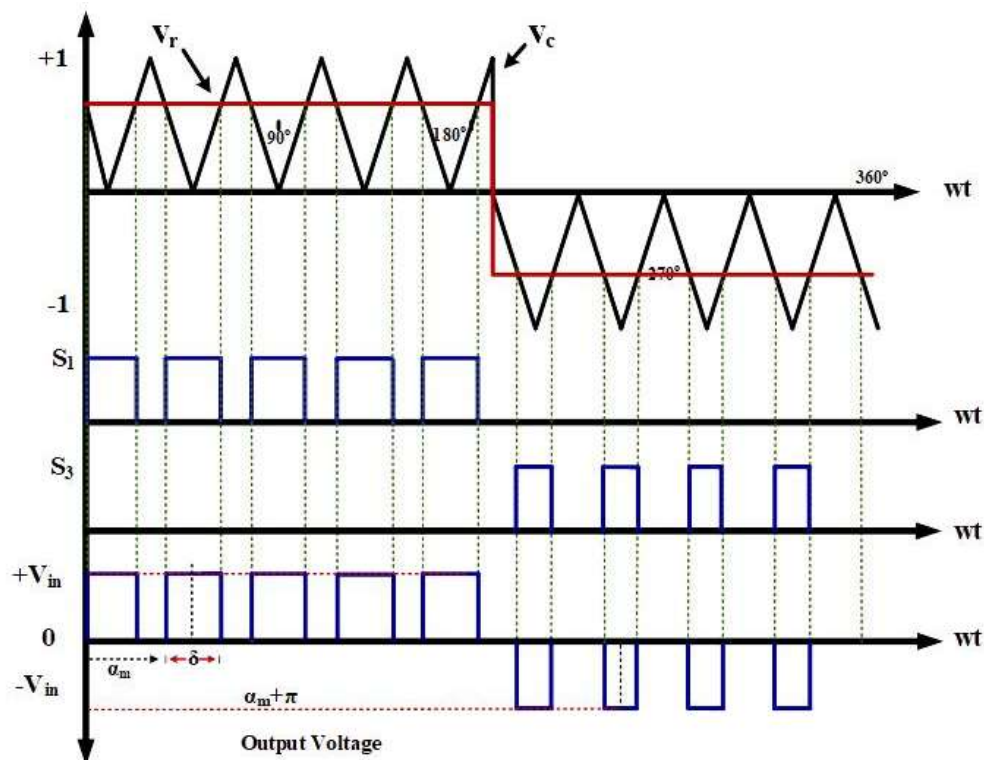
The number of pulses (p) per half-cycle is:

$$p = \frac{f_c}{2f_o} = \frac{m_f}{2}$$

where  $m_f = \frac{f_c}{f_o}$

Fourier series expression for the output voltage waveform is:

$$V_o = \sum_{n=1,2,\dots}^k (a_n \cos(n\omega t) + b_n \sin(n\omega t))$$



### Apparatus

| S.No. | Apparatus | Range | Quantity |
|-------|-----------|-------|----------|
| 1     |           |       |          |
| 2     |           |       |          |
| 3     |           |       |          |

### Procedure

1. Connect the appropriate component to its position by connecting wires.
2. Set the values of DC input voltage ( $V_{in}$ ) and modulation index ( $M$ )
3. Press “RECORD” button to simulate the circuit and observe various waveforms.
4. Change “ $V_{in}$  and  $M$ ” to observe the waveforms at different operating conditions.
5. Press “Download” button to download the files.

## Circuit Diagram

## Observation Table

### A. Single Pulse Width Modulation

| Sr. No. | Vin(V) | M<br>(Modulation<br>Index) | V0(V)<br>(RMS) | V01(V)<br>(Fundamental) | Harmonic Component |     |     | THD<br>(%) |
|---------|--------|----------------------------|----------------|-------------------------|--------------------|-----|-----|------------|
|         |        |                            |                |                         | 3rd                | 5th | 7th |            |
|         |        |                            |                |                         |                    |     |     |            |
|         |        |                            |                |                         |                    |     |     |            |
|         |        |                            |                |                         |                    |     |     |            |
|         |        |                            |                |                         |                    |     |     |            |
|         |        |                            |                |                         |                    |     |     |            |
|         |        |                            |                |                         |                    |     |     |            |
|         |        |                            |                |                         |                    |     |     |            |
|         |        |                            |                |                         |                    |     |     |            |

### B. Sinusoidal Pulse Width Modulation

| Sr. No. | Vin(V) | M<br>(Modulation<br>Index) | V0(V)<br>(RMS) | V01(V)<br>(Fundamental) | Harmonic Component |     |     | THD<br>(%) |
|---------|--------|----------------------------|----------------|-------------------------|--------------------|-----|-----|------------|
|         |        |                            |                |                         | 3rd                | 5th | 7th |            |
|         |        |                            |                |                         |                    |     |     |            |
|         |        |                            |                |                         |                    |     |     |            |
|         |        |                            |                |                         |                    |     |     |            |
|         |        |                            |                |                         |                    |     |     |            |
|         |        |                            |                |                         |                    |     |     |            |
|         |        |                            |                |                         |                    |     |     |            |
|         |        |                            |                |                         |                    |     |     |            |
|         |        |                            |                |                         |                    |     |     |            |

**Result and Conclusion: -**

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**Signature****Questions**

1. What is a single-phase inverter?
2. What are the basic types of single-phase inverters?
3. What is the difference between half-bridge and full-bridge inverters?
4. Why is PWM used in an inverter?
5. How does PWM control the output voltage?
6. What are harmonics in an inverter output?
7. What is the difference between single phase and sinusoidal PWM?

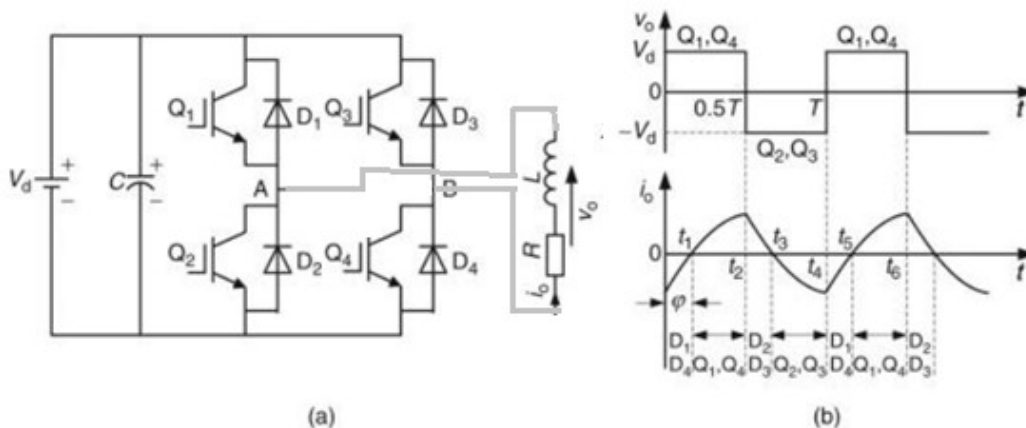
Date:

**Experiment No. 8****Object**

Simulation of Single-phase inverter

**Objectives**

To Study the simulation of Single-Phase inverter using Simulink.

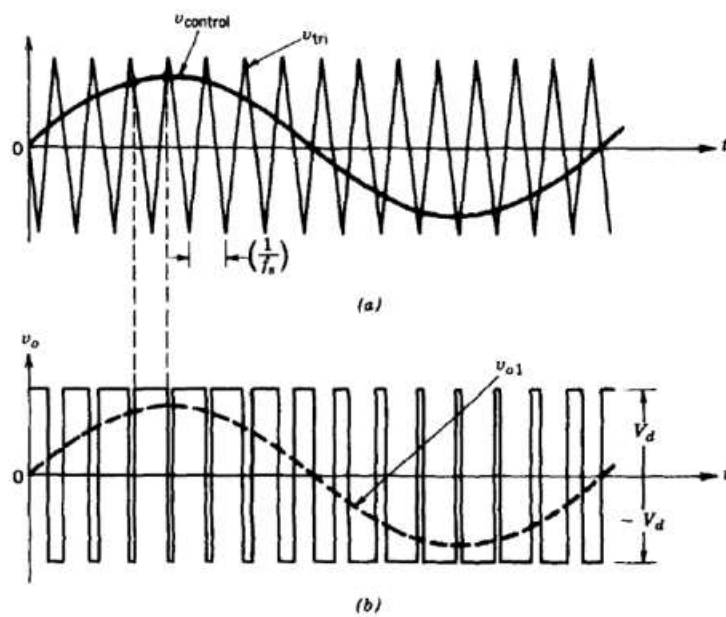
**Software Needed:** Matlab R2013a.**Theory**

**Fig. 1. (a) The full-bridge inverter and (b) sample output voltage and output current waveforms.**

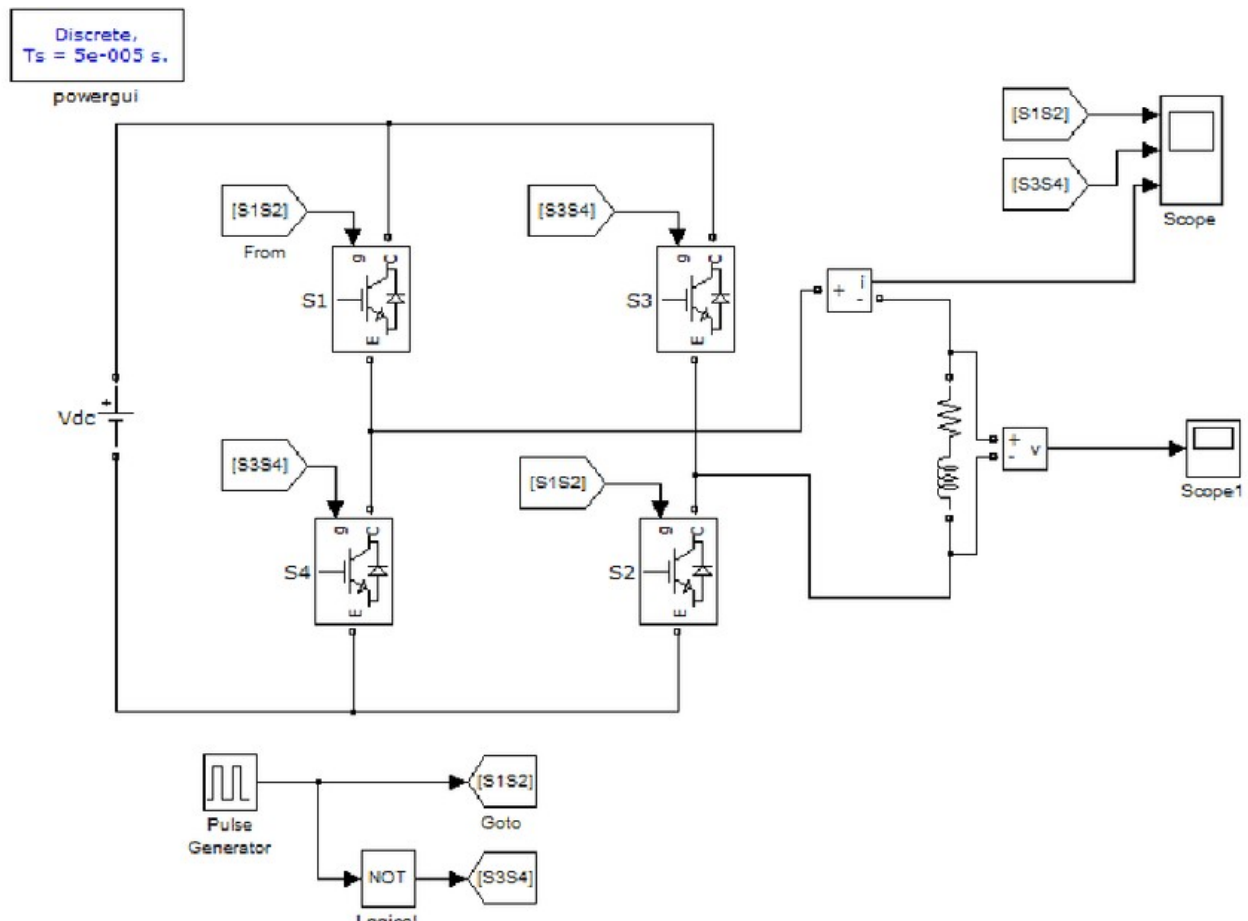
The inverter is a power electronic converter that converts direct power to alternating power.

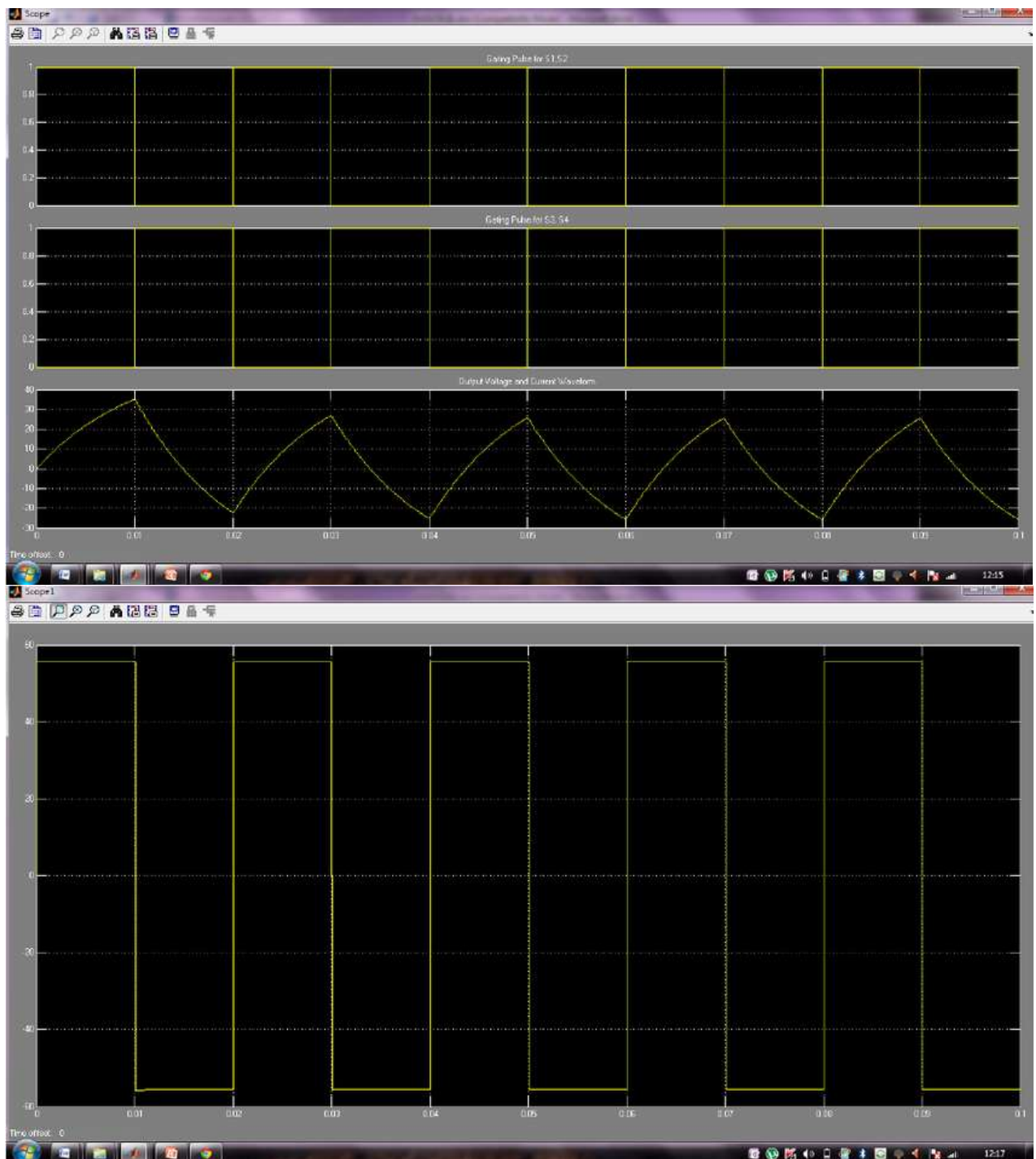
- By using this inverter device, we can convert fixed dc into variable ac power which as a variable frequency and voltage.
- Secondly from this inverter, we can vary the frequency i.e we will be able to generate the 40HZ, 50HZ, 60HZ frequencies as of our requirement.
- If the dc input is a voltage source, then the inverter is known as VSI (Voltage Source Inverter).
- The bridge inverters are of two types they are half-bridge inverter and full-bridge inverter.
- The full bridge inverters need four switching devices whereas half bridge inverter needs two switching devices.

In Figure 1(a) the full bridge inverter circuit has two switch legs where each leg has two switches. Each leg of the switch has two separate power controllers and has a diode connected to the load. Points a and b are the link between the inverter and the load. The inverter works by changing the conditions of each switch with a certain frequency. In the inverter circuit, the switches  $S_{1+}$  and  $S_{2+}$  or  $S_{1-}$  and  $S_{2-}$  cannot be turned on simultaneously because there will be a short circuit in the voltage source  $V_i$ .



**Fig. 3.** (a) Sinusoidal PWM reference and carrier waveforms and (b) resulting output voltage.





### Result and Conclusion: -

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**Signature**

**Date:****Experiment No. 9****Object**

Three-Phase Voltage Source Inverter With 120° &amp; 180° Conduction Mode (Virtual Lab)

**Objectives**

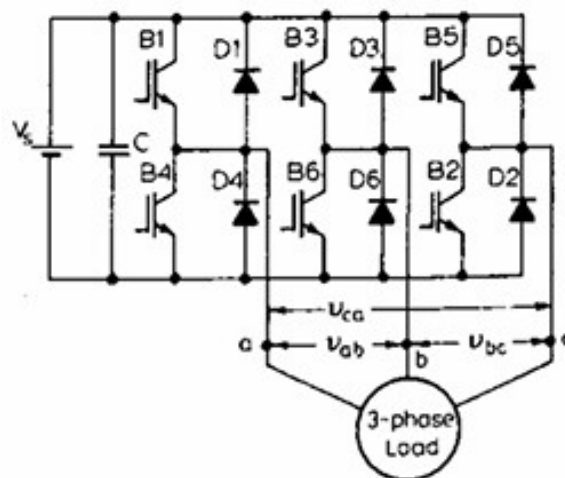
To study the performance of three phase bridge inverter with R Load.

**Theory****Three Phase Bridge Inverter**

A 3-phase inverter is a power electronic device that converts DC input into a 3-phase AC output. It's commonly used in industrial applications for variable speed drives, UPS systems, and renewable energy systems. The basic principle of a 3-phase inverter involves switching three sets of semiconductor devices (typically MOSFETs or IGBTs) to generate a three-phase AC waveform.

The 3-phase inverter operates in three modes:

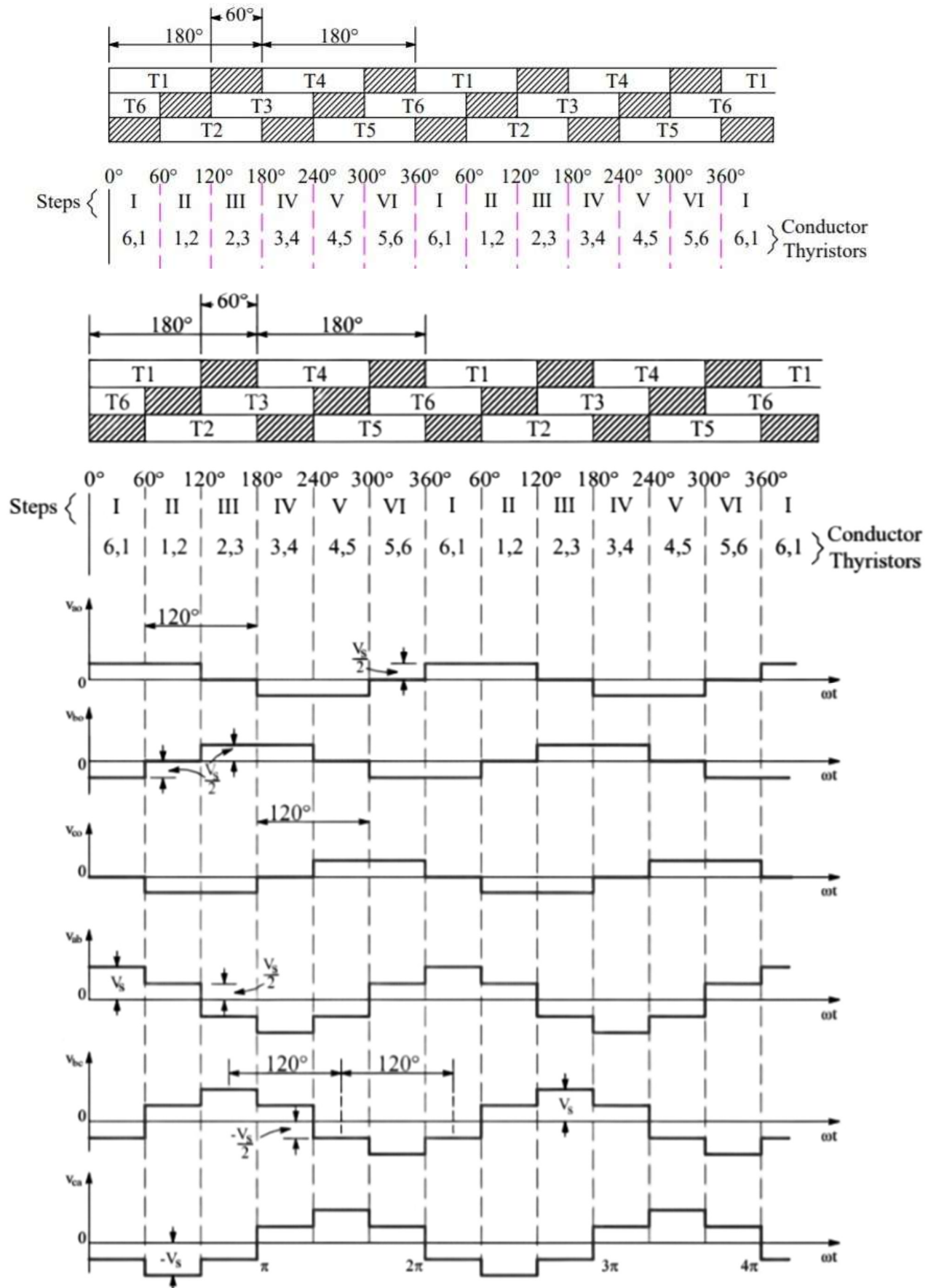
1. **180° Conduction Mode:** Each transistor conducts for 180° of the 360° cycle, providing a balanced 3-phase output.
2. **120° Conduction Mode:** Each transistor conducts for 120°, resulting in a reduced harmonic distortion.
3. **PWM (Pulse Width Modulation):** Provides precise control over output voltage and frequency.



A 3-phase inverter in 120° conduction mode is a power electronic device that converts DC input into a 3-phase AC output, with each switch in the inverter conducting for 120° of the electrical cycle. This results in each phase conducting for 120°, which ensures that at any point, only two switches are on, and one phase is left open, producing a more sinusoidal output with reduced harmonic distortion compared to 180° conduction mode.

In 120° conduction:

1. Each switch conducts for 120° out of a full 360° cycle.
2. At any time, only two transistors are conducting, and one phase remains open.
3. This conduction mode reduces harmonic content and creates a distinct waveform with a phase shift of 120° between each output phase.



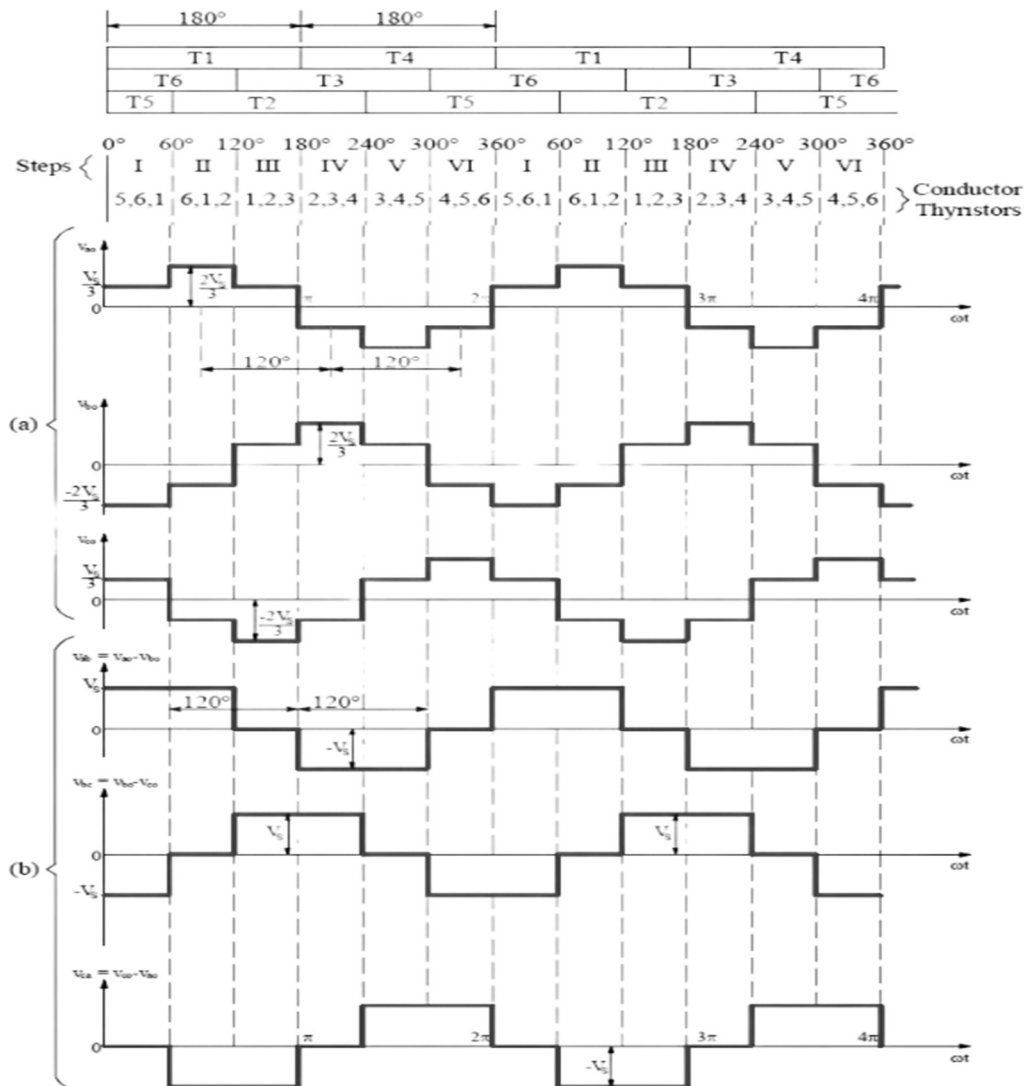
**Fig: Waveform for 120° Conduction Mode**

It can be seen from the above table that each of the thyristor conducts for 120° duration only and it remains off for the next 60°. This is different from 180° operation mode where each thyristor conducts for 180° duration.

In

the first row of table, T1 is shown to be conducting for  $120^\circ$  and for the next  $60^\circ$  neither T1 nor T4 conducts. T4 is turned ON at  $\omega t = 180^\circ$  and it further conducts for next  $120^\circ$  i.e. up to  $\omega t = 300^\circ$ . This simply means that for  $60^\circ$  interval i.e. from  $\omega t = 300^\circ$  to  $360^\circ$ , neither T1 nor T4 conducts. In fact, at  $\omega t = 300^\circ$ , T4 is turned OFF and at  $\omega t = 360^\circ$ , T1 is turned ON again.

In the second row of table, T3 is turned ON at  $\omega t = 120^\circ$  and it conducts for next  $120^\circ$ . Then  $60^\circ$  interval elapses during which neither T3 nor T6 conducts. At  $\omega t = 300^\circ$ , T6 is turned ON. It also conducts for next  $120^\circ$  and then  $60^\circ$  interval elapses after which T3 is turned ON again. The third row is also completed in the same manner.



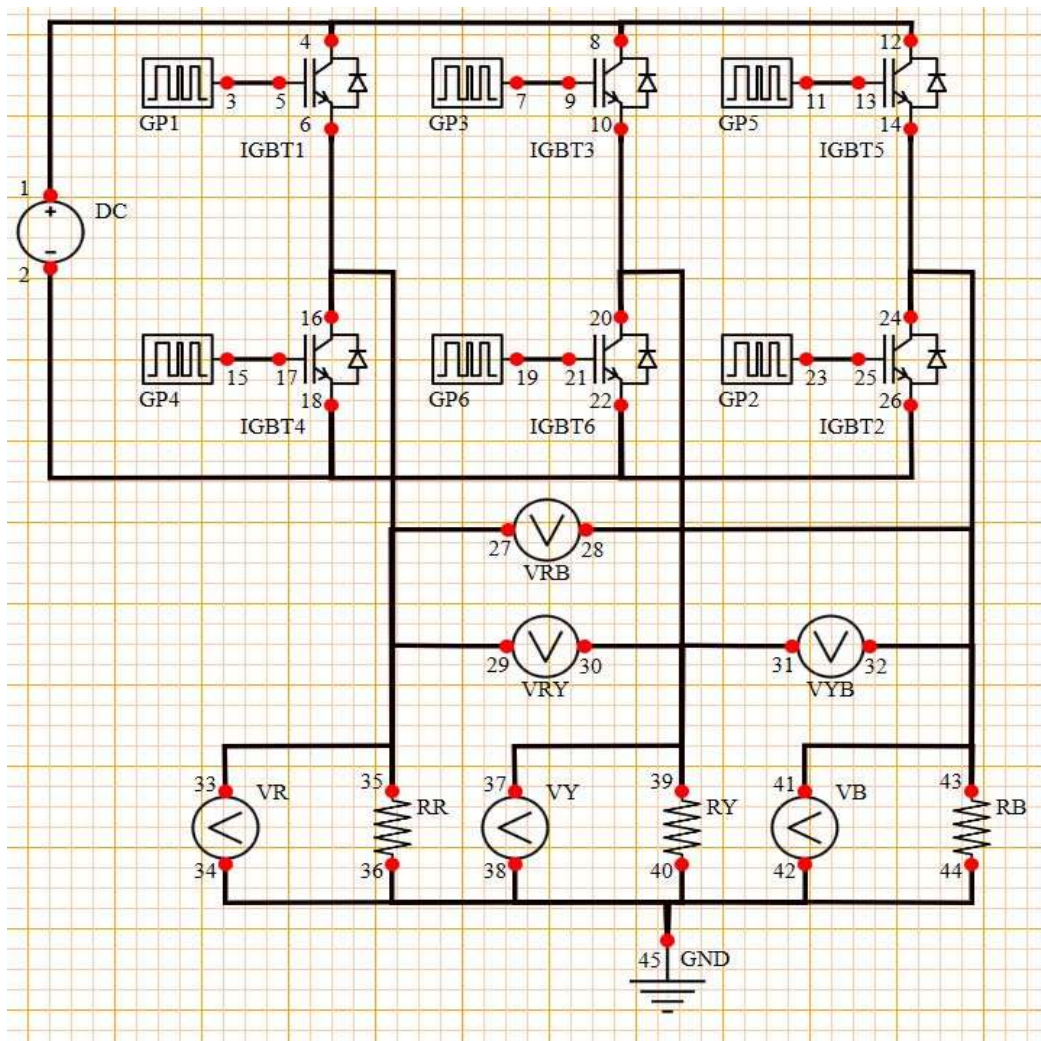
**Fig: Waveform for 180° Conduction Mode**

### Procedure

**STEP 1:** Drag and drop the components in the workspace to create the circuit.

Nos of required components:

DC Source – 1, IGBT – 6, Gate Pulse - 6, Resistor - 3, Voltmeter - 6, Ground – 1



**STEP 2:** Make the connections as per the instructions given below:

- (a) (01-04, 03-05, 06-16, 04-08, 07-09, 10-20, 08-12)
- (b) (11-13, 14-24, 02-18, 15-17, 18-22, 19-21, 22-26)
- (c) (23-25, 16-35, 20-39, 24-43, 35-27, 28-43, 35-29)
- (d) (30-39, 39-31, 32-43, 33-35, 34-45, 36-45, 37-39)
- (e) (41-43, 38-45, 40-45, 42-45, 44-45)

**Note:** Click on the wire to delete the connection.

**STEP 3:** Click on the **CHECK** button to check the connections.

**Note:** Right click on the component to open the dialog box to edit the properties of the component.

**STEP 4:** For **120° Conduction mode** Input the values for all the required components (**DC Source and Gate Pulses**) and the waveform will get plot automatically.

**GP1** - 0° to 120°, **GP3** - 120° to 240°, **GP5** - 240° to 360°, **GP4** - 180° to 300°, **GP6** - 300° to 420°, **GP2** - 60° to 180°.

**STEP 5:** Now, Click on the **ADD** button to insert the reading into the observation table.

**STEP 6:** Now, you can input different values as per your requirement to get the desired waveform.

**STEP 7:** Repeat **Step 5** to again insert the reading into the table and now repeat **Steps 6 to 7** to take more readings.

**STEP 8: For 180° Conduction mode** Input the values for all the required components (**DC Source and GatePulses**) and the waveform will get plot automatically.

**GP1** - 0° to 180°, **GP3** - 120° to 300°, **GP5** - 240° to 420°, **GP4** - 180° to 360°, **GP6** - 300° to 480°, **GP2** - 60° to 240°.

**STEP 9:** Now, Repeat **Steps 5 to 7**.

**STEP 10:** Click on the **PRINT** button to take out the print of the webpage.

**STEP 11:** Click on the **RESET** button to reload the webpage.

**Result and Conclusion: -**

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**Signature**

### Questions

1. What are the different modes of operation for a 3-phase inverter?
2. What is the difference between 180° conduction mode and 120° conduction mode?
3. What are the applications of a 3-phase inverter?
4. What are the advantages, disadvantages and applications of 3 phase inverter with 120° conduction mode?