



Ahsanullah University of Science and Technology

Department of Electrical and Electronic Engineering

**LABORATORY MANUAL
FOR
ELECTRICAL AND ELECTRONIC SESSIONAL COURSES**

Course no: - EEE 4228
Course title: - Power Electronics Lab
1st Edition

For the students of
Department of Electrical and Electronic Engineering
4th Year, 2nd Semester

Student Name: _____

Student ID: _____

Lab section: _____

Table of contents

Lab Experiments

| Exp. | Name of the Experiments | Page |
|------|--|------|
| 1. | Characterizing and Measurement of SCR, TRIAC, Power MOSFET, IGBT | 03 |
| 2. | Study of Thyristor firing circuit and isolation | 14 |
| 3. | Study of Single-phase Full wave controlled rectifier | 18 |
| 4. | Study of AC voltage controller | 21 |
| 5. | Study of Switching Mode power Supply (SMPS) | 23 |
| 6. | Study of Single-Phase SPWM inverter | 28 |
| 7. | Study of Stepper Motor and motor driver | 38 |
| 8. | Study of Three-Phase Full-Wave Full-Controlled Rectifier | 42 |

Simulation/Assignment

- Simulation of three phase Full wave controlled and uncontrolled rectifier 47

Data Sheet

| | | |
|---|---|----|
| A | Motorola® TL 494 (Part: Application Information) | 50 |
| B | Texas Instruments ULN 2003 V12 (Part: Unipolar Stepper Motor Driver) | 52 |

Reference & Acknowledgement:

53

Experiment No : 1
Name of the Experiment: Characterizing and Measurement of SCR, TRIAC, Power MOSFET, IGBT

(a)Objective

1. To measure the static characteristics of SCR.
2. To measure the V-I characteristic curve of SCR.
3. To measure the static characteristics of TRIAC.
4. To measure the V-I characteristic curve of TRIAC.

(b)Theory

SCR

Silicon Controlled Rectifier or simply SCR is a four-layer semiconductor device which has three terminals Anode (A), Cathode (K) and Gate (G), as shown in Fig. 1.1

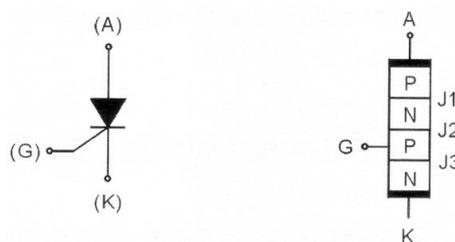


Figure 1.1:- SCR Symbol and structure

The SCR has the property of unidirectional conduction. Fig. 1.2 shows the V-I characteristic when an SCR is forward-biased, the reverse-biased characteristic is the same as that of general diodes. When the SCR is forward-biased ($V_{AK} > 0V$), the magnitude of gate current I_G will change the forward breakover voltage V_{BO} . When I_G increases, the V_{BO} will decrease and the load voltage increases. Consequently, varying the magnitude of I_G controls the triggering angle of SCR and the power delivered to the load circuit.

When an SCR is in conduction state (on state), it is not turned off by varying I_G . To turn off an SCR in on state, the voltage across A and K terminals must be reverse-biased ($V_{AK} < 0V$) or the anode current I_A is reduced to a level below the holding current I_H .

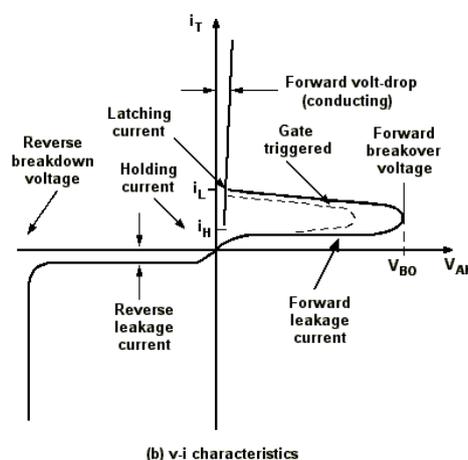


Figure1.2:- SCR V-I characteristics

TRIAC

TRIAC is the abbreviation of Triode AC Thyristor. It is a three-terminal device which can conduct in either positive or negative half cycle of ac source by applying the triggering pulse to the gate of TRIAC.

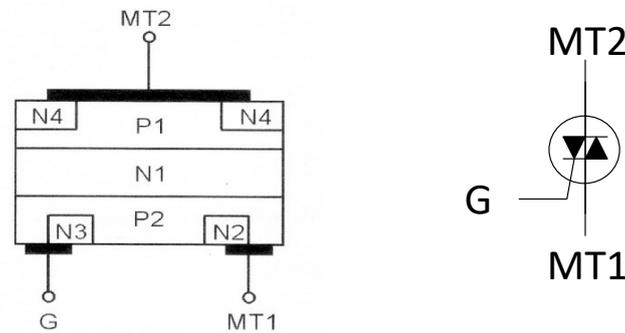
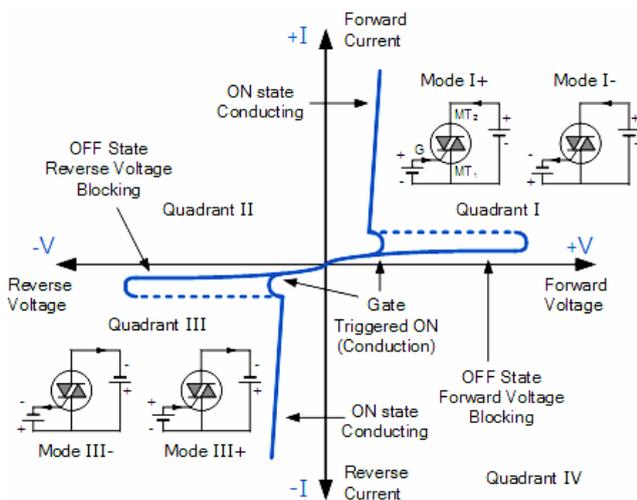


Figure 1.3 :-TRIAC structure and symbol

Fig. 1.3 shows the symbol and structure of TRIAC. Its structure is equivalent to inverse parallel connection of two SCRs, so it can conduct in both the positive and negative half cycles of ac power source. Three terminals are designated as the first anode MT1 (labeled A2 on module panel), second anode MT2 (labeled A1 on module panel), and the gate G Terminals MT2 and MT1 cannot be reversed in use.

The characteristic of TRIAC is equivalent to that of two SCRs in inverse parallel operation. Its characteristic curve in first quadrant is identical to that of Fig. 1.2 and the characteristic curve in third quadrant is similar but reverse polarity.



1. I+ MT2 Positive, V_G Positive
2. I- MT2 Positive, V_G negative
3. III+ MT2 negative, V_G Positive
4. III- MT2 negative, V_G negative

The SCR is triggered by applying a positive gate signal when the anode voltage is positive. The TRIAC can be triggered under four gate conditions

Power MOSFET

The power Metal-Oxide-Semiconductor FET (power MOSFET) is a unipolar and voltage-controlled device. The power MOSFET has the features of fast switching speed, good high-frequency characteristic, high input impedance, small drive power, excellent thermal stability, no second breakdown, wide Safe Operating Area (SOA), and high operating linearity, etc. Since the key advantages of small size and lightweight, the power MOSFET provides a high speed, high power, high voltage, and high gain device. The power MOSFET is widely used in high-power switching applications such as power supplies, converters and PWM drives.

Power MOSFET is an integrated power device which contains tens of thousands small MOSFETs interconnected in parallel. Fig. 1.3 shows the typical structure and circuit symbol of an n-channel power MOSFET. Two higher-doped n+ regions are constructed as source and drain terminals. An insulating layer (SiO₂) exists between gate and channel.

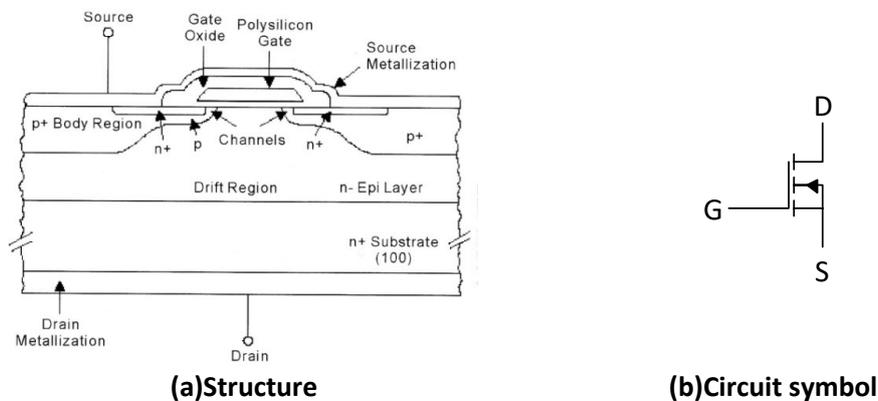


Figure 1.4:- N-Channel power MOSFET

The power MOSFET shown in Fig. 1.4 is a 4-layer sandwich configuration of n+ (n-) pn+. The lower-doped n-region is a drift region which increases the device voltage rating. In the device, two back-to-back pn junctions exist between drain and source. If no gate voltage is applied, the device is always in off state whenever the drain-source voltage is either positive or negative.

Characteristics of Power MOSFET

Power MOSFET's output characteristic curves have two distinct operating regions: a constant-resistance region and a constant-current region. In the constant-resistance region, the drain current is direct proportion to the increase in the drain-source voltage until the drain-source voltage reaches at its pinch-off voltage. Beyond this point, the drain current remains constant and the device operates in the constant-current region.

Fig 1.5 shows the characteristics of N-channel enhancement power MOSFET. When the power MOSFET is used as an electronic switch, the drain-source voltage drop V_{DS} is proportional to the drain current I_D , that is, the MOSFET operates in the constant resistance region and it can be considered as a resistive component. The on-state drain-source resistance $R_{DS(on)}$ is the key parameter which determines the power losses at a given drain current. The drain current starts to flow at the applied gate-source voltage V_{GS} over the threshold voltage V_T (typically 2 to 4 V). Once the gate-source voltage is over the threshold voltage, the relationship between drain current and gate voltage is approximately linear.

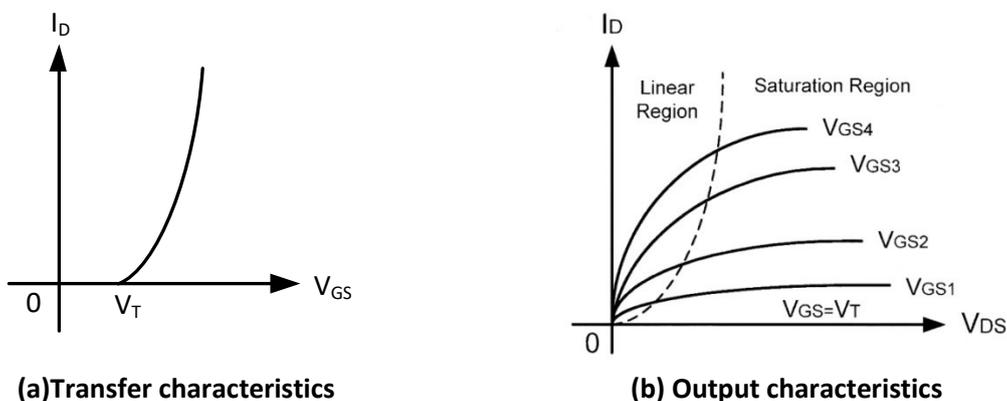


Figure 1.5:- Characteristics of N-channel enhancement power MOSFET

Insulated Gate Bipolar Transistor (IGBT)

An Insulated Gate Bipolar Transistor (IGBT) recently received attention is a MOS gate turn on/off bipolar transistor which combines the attributes of the MOSFET. The IGBT device has the high input impedance of a MOSFET but a low on-state conduction drop similar to a bipolar transistor. The switching speed and safe operating area (SOA) of bipolar transistor are retained. The storage time of the bipolar tends to be long because of its incapability to drive negative base current. However, the device has thyristor-like reverse voltage blocking capability.

The IGBT plays an important role in the field of power electronics and is widely used in many applications such as the Uninterruptable Power Supplies (UPS), variable-speed motor control in air conditioning systems, and robot control in factory automation.

The BJT has the highest current rating and lowest operating frequency. The MOSFET has the lowest current and voltage ratings, but highest operating frequency. The IGBT current capability is close to the BJT and has highest voltage rating, but operating frequency is lower than MOSFET. However, the operating frequency of the IGBT is high enough to use in the power stage of an audio amplifier. The advantages of high voltage rating, high current rating and low saturation voltage drop make the IGBT an excellent power device particularly suited for use in power amplifiers for higher reliability

This overcomes some of the limitations of enabling high voltages to be switched and high currents to be controlled with the use of relatively simple gate drive circuitry.

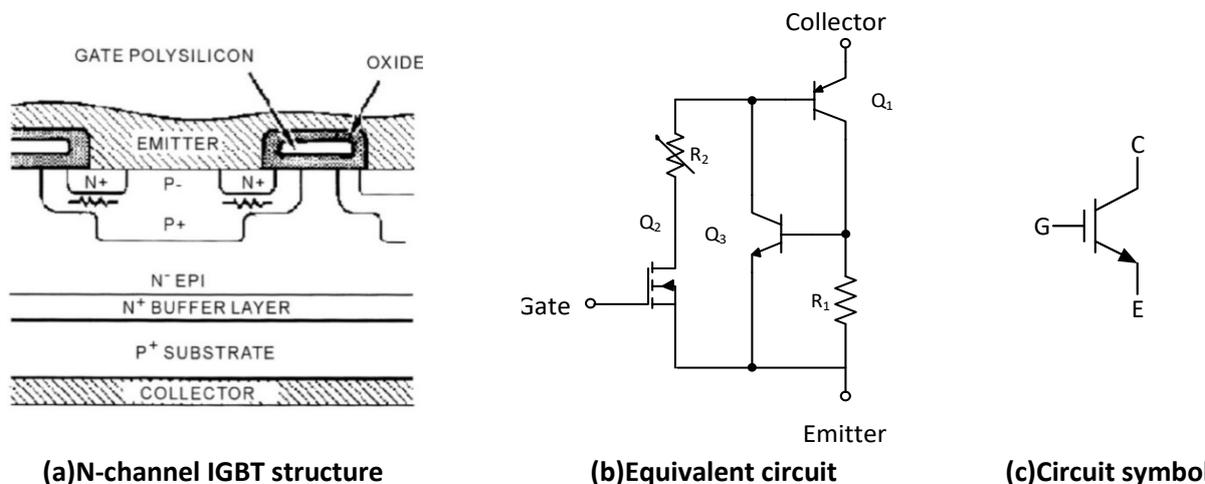


Figure 1.6:- IGBT Structure, equivalent circuit and circuit symbol

Unfortunately a parasitic thyristor exists in the typical IGBT structure. When the parasitic thyristor conducts, latch-up effect is thus triggered. For examining the operation of latch-effect mechanism, review the IGBT structure and the equivalent circuit of Fig. 1.6. The parasitic NPN transistor Q3 is formed by the n+ type MOSFET source, the p type body region and the n- type drift region. Also shown is the lateral resistance of the p-type region. If the current flowing through the resistor R1 is high enough, it will produce a voltage drop that will forward bias the junction with the n+ region turning on the parasitic transistor Q3 which forms part of a parasitic thyristor. Once this happens there is a high injection of electrons from the n+ region into the p region and all gate control is lost. This phenomenon is known as latch up and usually leads to device destruction. According to the results of experimentation and simulation, the wider the polysilicon gate area, the smaller

the latching current becomes. The IGBT transfer characteristic and output characteristic are illustrated in Fig. 1.8

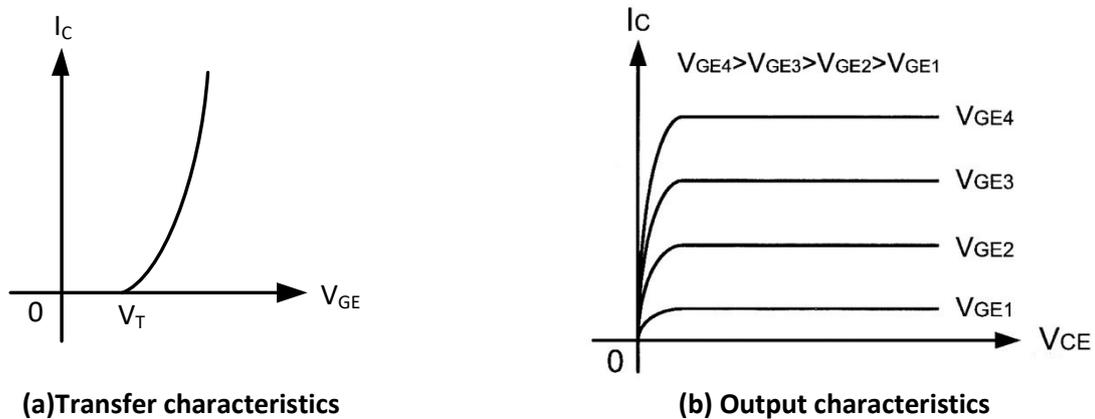


Figure 1.8:-IGBT characteristics

(c)Equipment required

- | | |
|----------------------------------|----|
| 1. SCR/TRIAC Set | x1 |
| 2. MOSFET/IGBT Set | x1 |
| 3. DC power supply | x1 |
| 4. Differential Amplifier Module | x1 |
| 5. Oscilloscope | x1 |
| 6. Multimeter | x1 |
| 7. Connecting wires | |

(d)Procedure

SCR CHARACTERISTICS AND MEASUREMENT PROCEDURE:

1. Turn off the power of SCR/TRIAC Set module. Follow the steps to identify the three terminals of the SCR:
 - i. Measure and record the resistance between A and K terminals. $R_{AK} = \text{_____} \Omega$. Measure and record the resistance between G and K terminals. $R_{GK} = \text{_____} \Omega$. Measure and record the resistance between A and G terminals. $R_{AG} = \text{_____} \Omega$.
2. SCR Characteristic Curve Measurement
 - i. Complete the connections by referring to the wiring diagram in Fig. 1.9. **Set the S2 switch of SCR/TRIAC set to ON, S1 and S3 to OFF.** The anode to cathode voltage V_{AK} of SCR is connect to the CH1 input of oscilloscope via the Differential Amplifier Ch.A, the load voltage (the voltage across lamp E1 stands for anode current I_{AK}) is connected to CH2 input of oscilloscope via Differential Amplifier Ch.C. Set the V Range selector (SWA.SWC) switches of Differential Amplifiers Ch.A and Ch.C to 100V position.

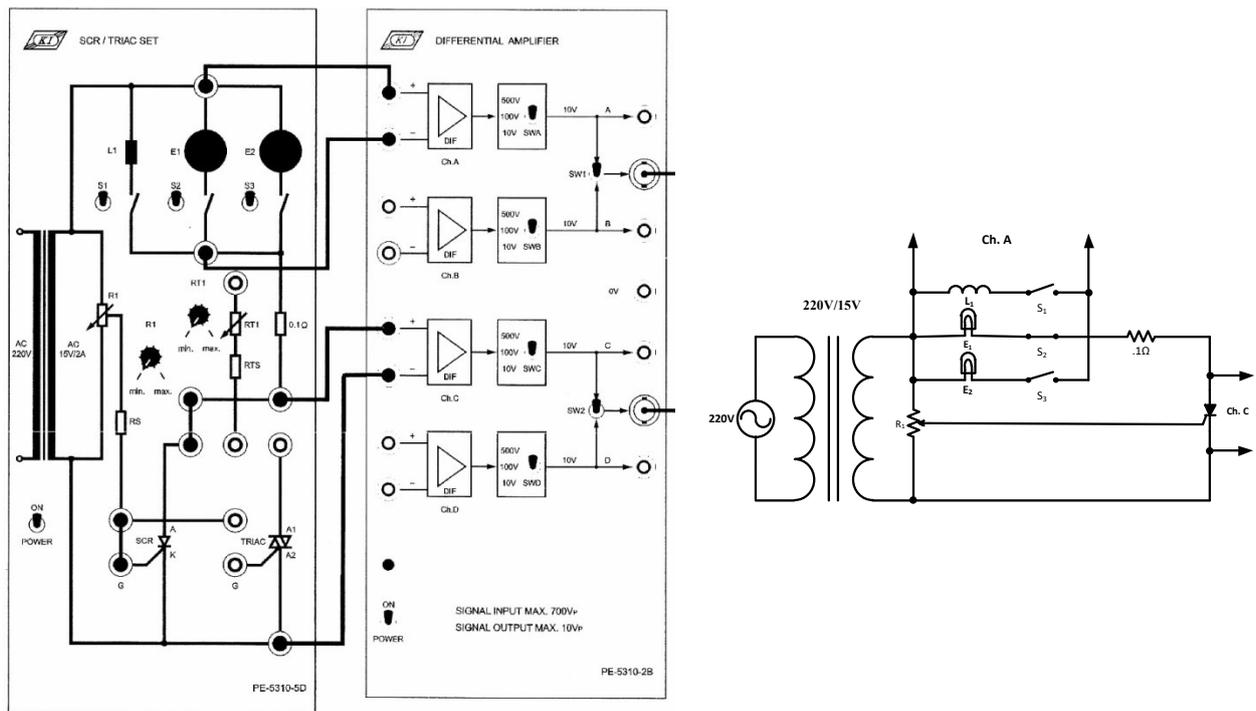
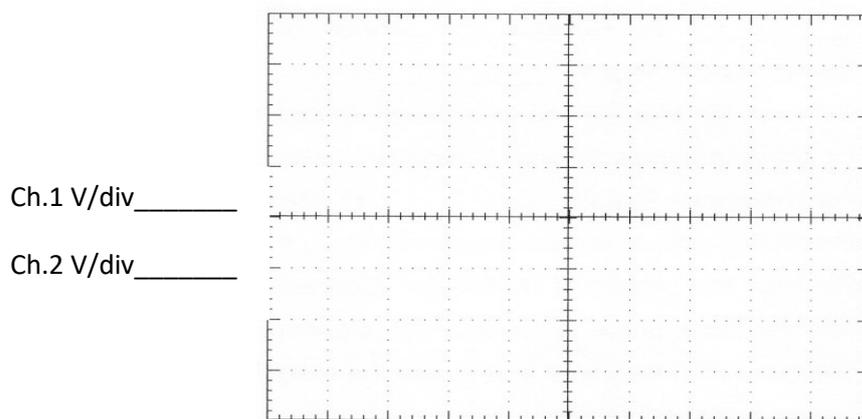


Figure 1.9:- Wiring/circuit diagram for SCR characteristic curve measurement
 L1:150mH/1A, Lamp 24V/10W each, SCR: 600V/12A

- ii. Adjust VOLTS/DIV control knobs of CH1 and CH2 so that the amplitudes of two waveforms are nearly the same.
- iii. Select “XY” option to display the Lissajous chart (X-Y display) and select CH2 in oscilloscope.
- iv. If a straight line is displayed, adjust the R1 control knob to trigger the SCR on.
- v. Adjust the VOLTS/DIV control knobs (CH1=X, CH2=Y in X-Y mode) for a clear curve.
- vi. Draw the measured SCR characteristic curve in Graph 1.1



Graph 1.1:-Measured SCR characteristics curve

3. SCR Triggering Control

- i. Complete the connections by referring to the wiring diagram in Fig. 1.10. Set the V Range selector(SWA,SWC) switches of Differential Amplifiers Ch.A and Ch.C to the 100V position. On SCR/TRIAC Set Module, set S2 to ON, S1 and S3 to OFF.

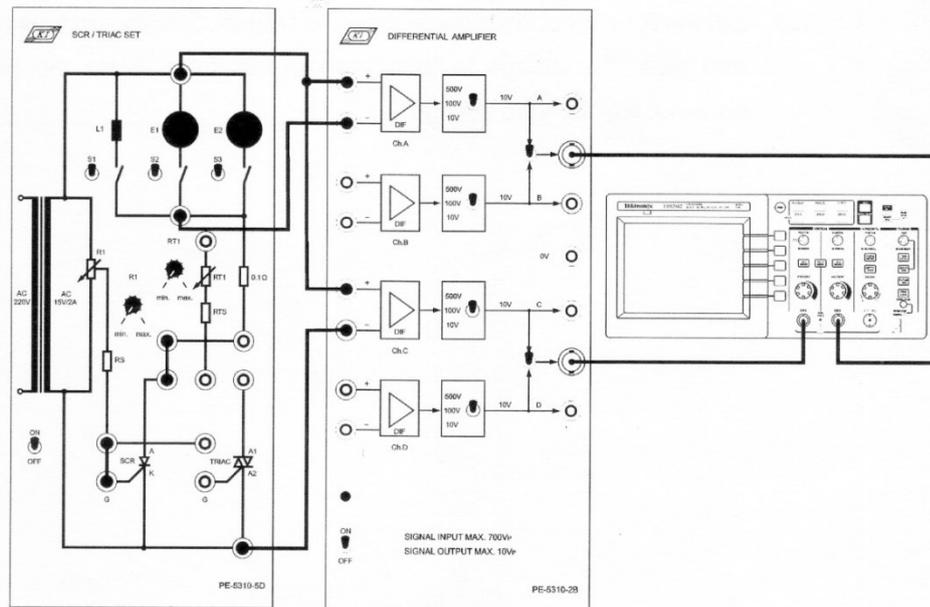


Figure 1.10:- Wiring diagram for SCR Triggering control

- ii. Turn all power on. During the negative half cycle of AC 15V, SCR is reverse-biased and turned off, there is no voltage on the load. During the positive half cycle of AC 15V, adjust the R1 control knob to increase the gate current I_G and turn on the SCR. Draw the waveform.
- iii. Set the R1 control knob respectively to 1/2max, 2/3max, and max positions, and view the change in load voltage waveform. State the relationship between R1 and load voltage_____.

TRIAC CHARACTERISTICS AND MEASUREMENT PROCEDURE:

1. Place the power switch of SCR/TRIAC set in the OFF position. Follow the steps to identify the three terminals of TRIAC.
 - i. Measure and record the resistance between A1 and A2 terminals. $R_{A1-A2} = \text{_____} \Omega$. Measure and record the resistance between A1 and G terminals. $R_{A1-G} = \text{_____} \Omega$. Measure and record the resistance between A2 and G terminals. $R_{A2-G} = \text{_____} \Omega$.
 - ii. Connect the black probe to terminal A1 and the red probe to terminal A2. Connect terminals A1 and G together using a connecting wire and record the resistance $R_{A2-(A1+G)} = \text{_____} \Omega$.
 - iii. Connect terminals A1 and G together using a connecting wire and record the resistance $R_{A2-(A1+G)} = \text{_____} \Omega$.
2. TRIAC Characteristic Curve Measurement
 - i. Complete the connections by referring to the wiring diagram in Fig. 1.11.

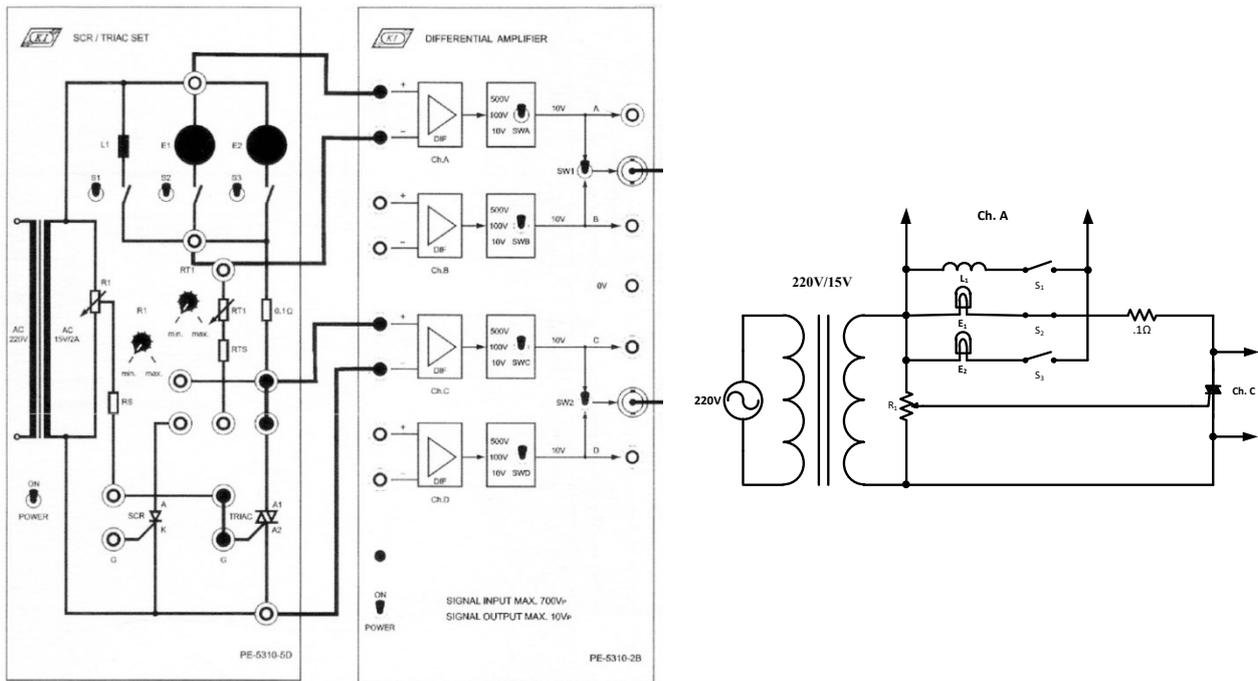
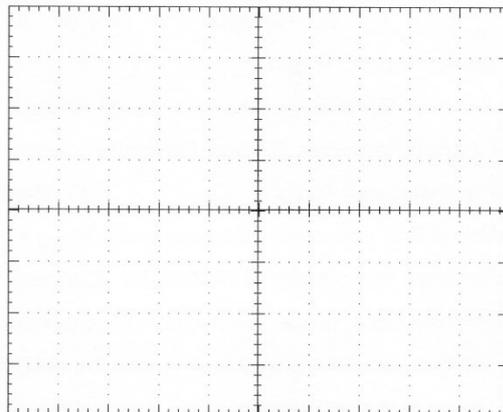


Figure 1.11:- Wiring/circuit diagram for TRIAC characteristic curve measurement
 L1:150mH/1A, Lamp 24V/10W each, TRIAC: 800V/16A

ii. Turn all power on. Measure and draw the TRIAC characteristics curve

Ch.1 V/div _____

Ch.2 V/div _____



Graph 1.2:-Measured TRIAC characteristics curve

3. TRIAC Triggering Control

- i. Complete the connections by referring to the wiring diagram in Fig. 1.12.
- ii. Adjust the R1 control knob to make the TRIAC conduct. Compare the waveforms between SCR and TRIAC.

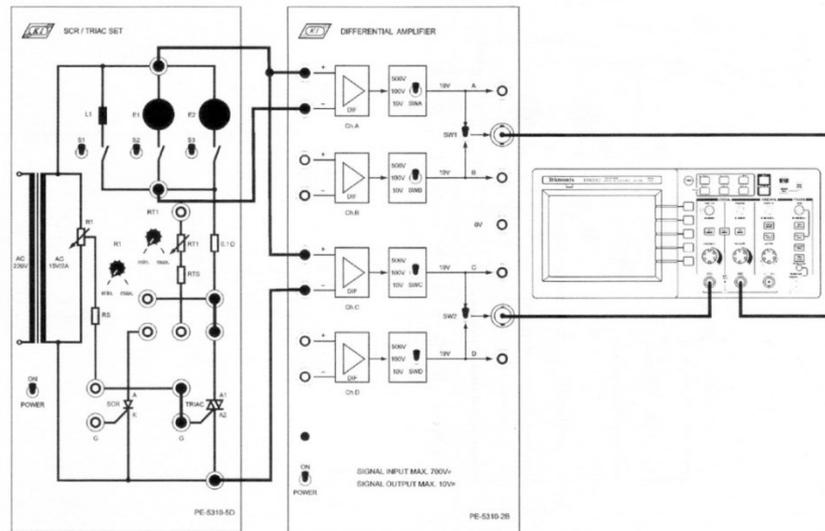


Figure 1.12:- Wiring diagram for TRIAC triggering control

MOSFET CHARACTERISTICS AND MEASUREMENT PROCEDURE:

1. Complete the connections by referring to the wiring diagram in Fig. 1.13 using bridging plugs (curved lines) and connecting wires. Connect 220V AC supply to DC Power Supply and Differential Amplifier modules by plugging in the grounded 3-prong outlets.

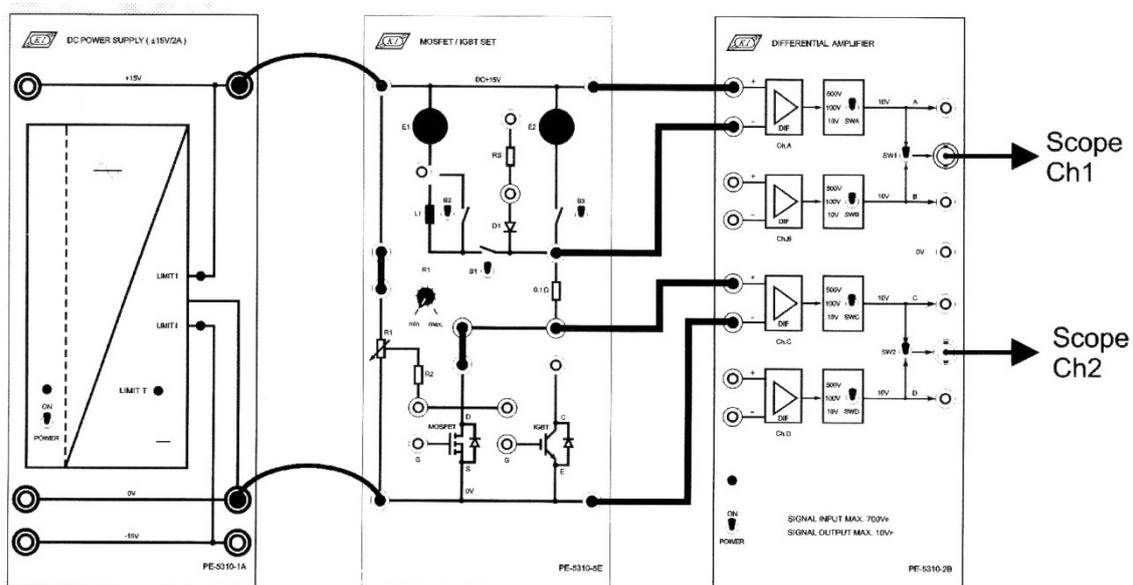
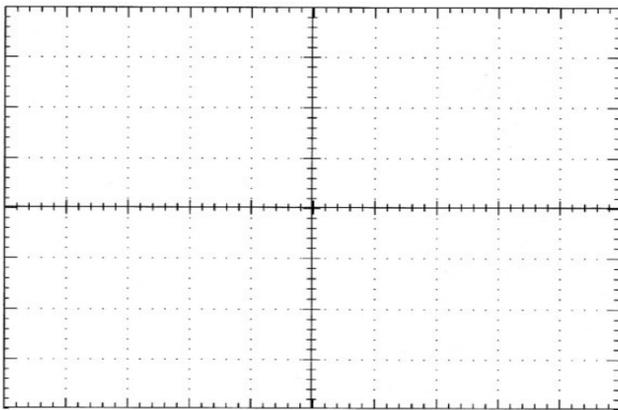


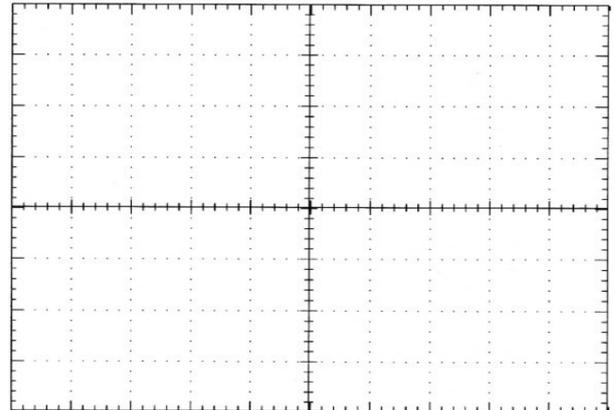
Figure 1.13:- Wiring diagram MOSFET control

2. The CH1 input of DSO is connected to measure the load voltage V_L of the power MOSFET via the Differential Amplifier Ch.A, whereas the CH2 input is connected to measure the D-S voltage V_{DS} of the power MOSFET via the Differential Amplifier Ch.C.
3. On Differential Amplifier, place the V Range selector(SWA,SWC) switches of Differential Amplifiers Ch.A and Ch.C in 100V position (the V_i/V_o ratio = $100/10=10$) and place Ch Selector(SW1,SW2) switches in A and C, respectively.

4. On MOSFET/IGBT Set, switch on S1 (left position), S2 (up position) and S3 (up position) to connect load lamps E1 and E2 in parallel. Set the R1 knob to min position. This set the gate voltage V_G of MOSFET to zero.
5. Turn all power on.
6. Slowly turn the R1 knob toward max to increase the gate voltage V_G until the MOSFET is turned on. The measured load voltage V_L (CH1) and D-S voltage V_{DS} (CH2). Measure and record the gate voltage $V_G = \underline{\hspace{2cm}}$ V using a multimeter. The measured V_G is the gate threshold voltage V_T of the MOSFET.



Graph 1.3:- Measured load voltage V_L (CH1) and V_{DS} (CH2)
 CH1 V/div _____ Ch2 V/div _____



Graph 1.4:- Measured load voltage V_L (CH1) and V_{DS} (CH2)
 CH1 V/div _____ Ch2 V/div _____

7. Turn the R1 knob to max position (V_G maximum). Measure and record the load voltage V_L and D-S voltage V_{DS} in Graph 1.3
8. Turn the R1 knob to min position (minimum V_G). Measure and record the load voltage V_L and D-S voltage V_{DS} in Graph 1.4

IGBT CHARACTERISTICS AND MEASUREMENT PROCEDURE:

1. Complete the connections by referring to the wiring diagram in Fig. 1.14 using bridging plugs (curved lines) and connecting wires. Connect 220V AC supply to DC Power Supply and Differential Amplifier modules by plugging in the grounded 3-prong outlets.

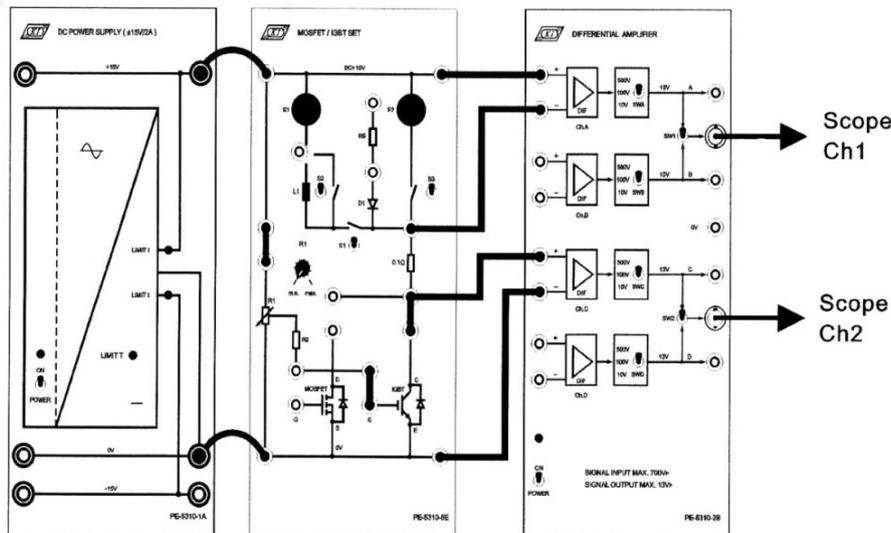
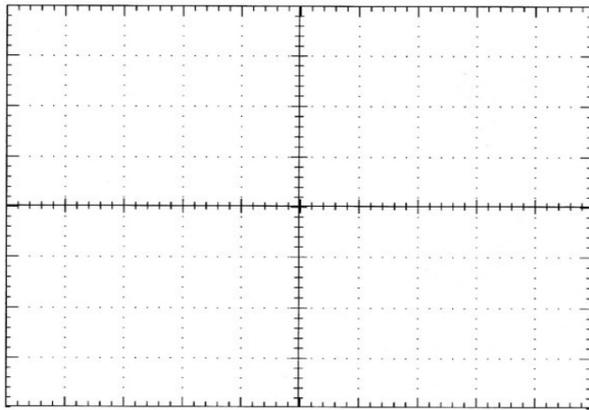
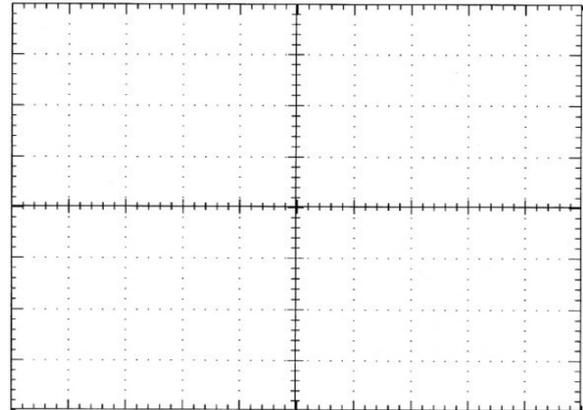


Figure 1.14:- Wiring diagram for IGBT control

- The CH1 input of DSO is connected to measure the load voltage V_L of the IGBT via the Differential Amplifier Ch.A, whereas the CH2 input is connected to measure the C-E voltage V_{CE} of the IGBT via the Differential Amplifier Ch.C.
- On Differential Amplifier, place the V Range selector(SWA.SWC) switches of DIF Ch.A and Ch.C in 100V position (the V_i/V_o ratio =100/10=10) and place Ch Selector (SW1 ,SW2) switches in A and C, respectively.
- On MOSFET/IGBT Set, switch on S1 (left position), S2 (up position) and S3 (up position) to connect load lamps E1 and E2 in parallel. Set the R1 knob to min position. This set the gate voltage V_G of IGBT to zero.
- Turn all power on.
- Slowly turn the R1 knob toward max to increase the gate voltage V_G until the IGBT is turned on. The point the IGBT turns on measure and record the gate voltage $V_G = \underline{\hspace{2cm}}$ V using a multimeter. The measured V_G is the gate threshold voltage V_T of the IGBT



Graph 1.5:- Measured load voltage V_L (CH1) and V_{CE} (CH2)



Graph 1.6:- Measured load voltage V_L (CH1) and V_{CE} (CH2)

- Turn the R1 knob to max position (maximum V_G). Measure and record the load voltage V_L and C-E voltage V_{CE} of IGBT in Graph 1.5.
- Turn the R1 knob to min position (minimum V_G). Measure and record the load voltage V_L and C-E voltage V_{CE} of IGBT as shown in Graph 1.6.

(e)Report

- Draw SCR and TRIAC characteristics curve and compare them.
- Sketch how SCR and TRIAC are constructed and with that explain the reason for different value of resistance measured during the experiment
- Draw MOSFET and IGBT characteristics curve indicating the values obtained during the experiment.
- Draw the circuit diagram of Fig. 1.13 and Fig.1.14 from the wiring diagram.
- What are the advantages of IGBT over MOSFET
- Attach Graphs 1.3-1.6 obtained during the experiment

| | |
|---|-----|
| Experiment No | : 2 |
| Name of the Experiment: Study of Thyristor firing circuit and isolation | |

(a)Objective:

The objective of this experiment is to observe the output wave shapes of the thyristor's triggering circuit and the isolation circuit. Also how the UJT can be used as a triggering circuit.

(b)Theory:

Thyristor triggering circuit:

Thyristor will begin conduct

- If it is forward biased and
- The gate is triggered /fired with appropriate pulse

Thyristor can be triggered (gated on) by simple divider circuit consisting of resistors or capacitors across the ac line. One of the divider components can be made adjustable to produce earlier or later firing to accomplish the conduction angle control. Such simple divider circuits are seldom used. They have the disadvantage of temperature instability and efficiency. Negative resistance devices are used to establish a more predictable and stable trigger behavior.

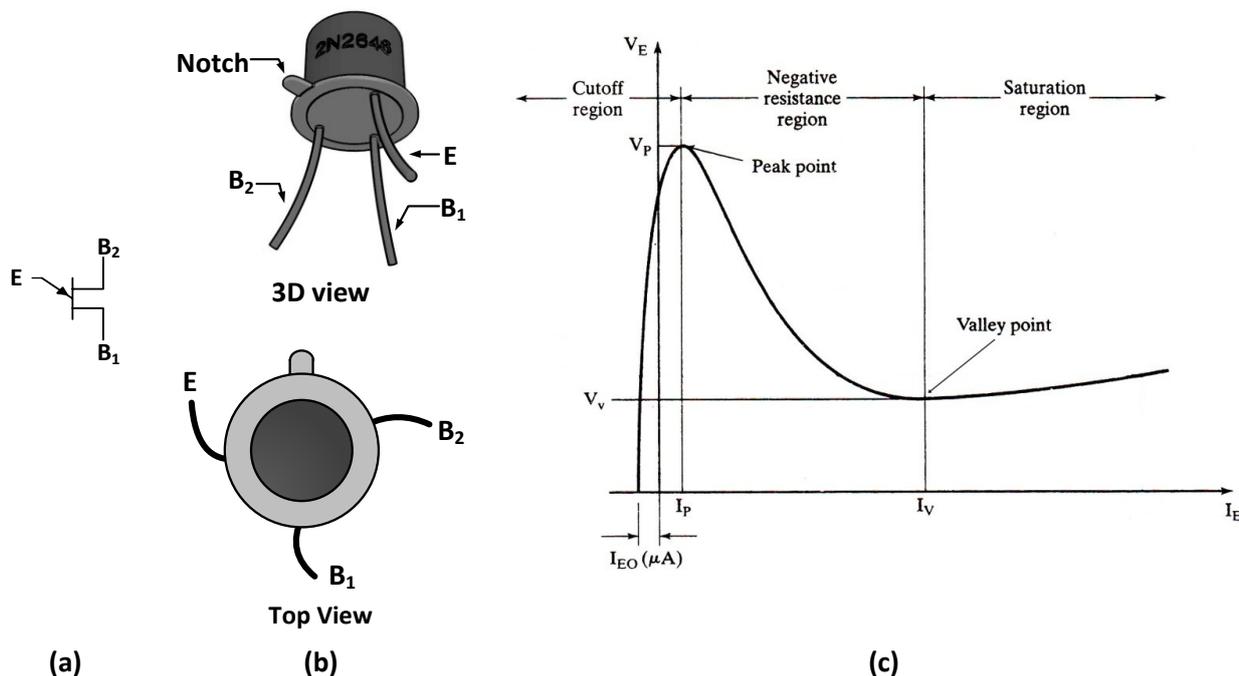


Figure 2.1:- (a)Circuit symbol of UJT (b) Pin out of TO-18 packaged 2N2646 UJT (c) V_E vs I_E curve of UJT

The UJT exhibits negative resistance and is commonly used for generating triggering signals for SCRs. UJT has the three terminals: emitter E, base-one B₁, base-two B₂ as shown in Fig 2.1(a,b) Between B₁ and B₂ UJT have the characteristics of an ordinary resistance. The B₁ resistor is variable. This is where the negative resistance effects occur. It is called negative resistance because it decreases abruptly when the UJT emitter diode becomes forward-biased with respect to B₁.

A basic UJT triggering circuit is shown in Fig-2.2. When supplied voltage is applied, capacitor is charged through the resistor and the potentiometer since the emitter circuit of the UJT is in open state. When emitter voltage V_E reaches the peak value V_P , the UJT turns on and capacitor discharges through 33Ω resistor. The emitter voltage V_E decays to the valley point V_V , the emitter ceases to conduct, the UJT turns off, and the charging cycle is repeated.

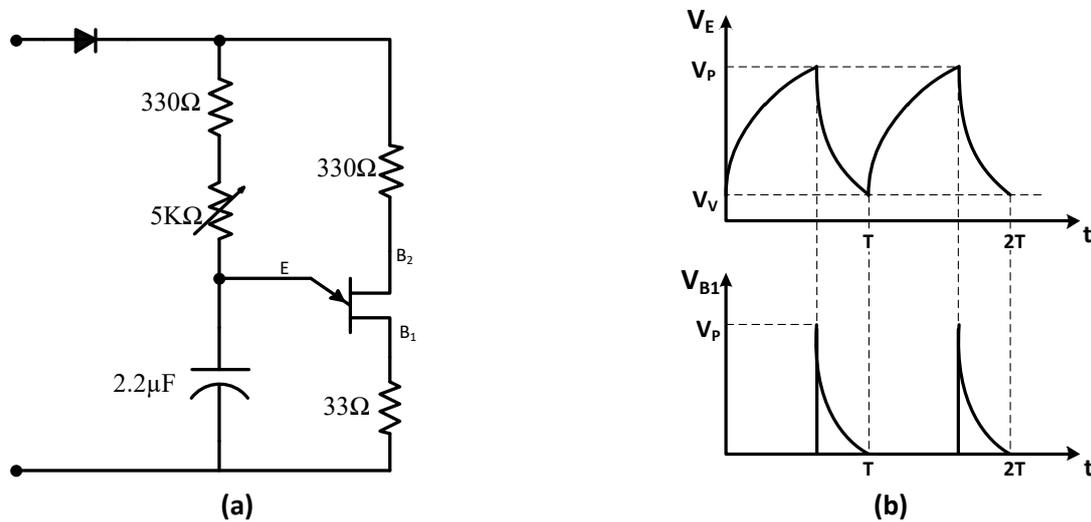


Figure 2.2:- (a) Thyristor Triggering circuit (b) waveform of the triggering circuit

Thyristors can also be triggered using RC circuit in conjunction with BJT/MOSFET, digital circuit/IC purposefully built to trigger/control controlled rectifier (Ex. TCA 785, U490B)

Isolation:

There are many situations where signals and data need to be transferred from one subsystem to another within a piece of electronics equipment, or from one piece of equipment to another, without making a direct 'ohmic' electrical connection. Often this is because the source and destination are (or may be at times) at very different voltage levels or for safety purpose. In such situations the link between the two must be an isolated one, to protect the device from over voltage damage.

Type of isolation

- Galvanic isolation
- Optical Isolation

In thyristor converters, different potential exist at various terminals. The power circuit is subjected to a high voltage, usually greater than 100V, and the gate circuit is held at low voltage, typically 12V to 30V. An isolation circuit is required between an individual thyristor and its gate pulse generating circuit. The isolation can be accomplished by either pulse transformer or optocouplers.

Optocouplers typically comes in a small 6-pin or 8-pin IC package, but are essentially a combination of two distinct devices: an optical transmitter, typically a gallium arsenide LED and an optical receiver such as a phototransistor or light-triggered DIAC (shown in Fig 2.3). It use a beam of light to transmit the signals or data across an electrical barrier, and achieve excellent isolation.

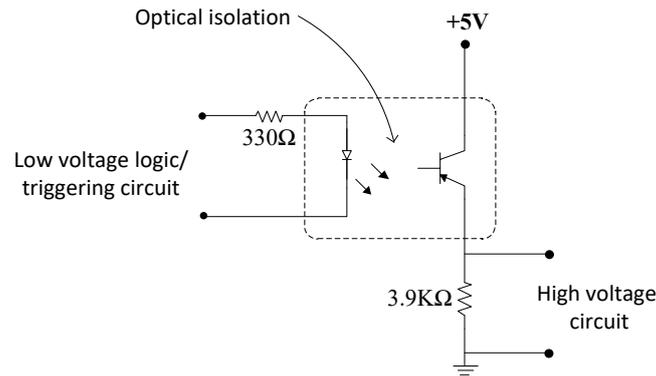


Figure 2.3:- Optical Isolation (Dotted line indicate inside circuitry of PC 101 Opt coupler)

(c)Apparatus:

| | | | |
|-----|-------------------------|------------------|----|
| 1. | Transformer | 220V/12-0-12V | x1 |
| 2. | Diode | 1N4007 | x1 |
| 3. | Resistors | 33Ω, 3.9 KΩ, 10K | x1 |
| | | 330Ω | x3 |
| 4. | Variable resistor (POT) | 5KΩ | x1 |
| 5. | Capacitor | 2.2μF | x1 |
| 6. | SCR | 2P4M | x1 |
| 7. | UJT | 2N2646 | x1 |
| 8. | Optocoupler | PC 101 | x1 |
| 9. | Multimeter | | x1 |
| 10. | Oscilloscope | | x1 |

(d)Procedures:

1. Build the triggering part of the circuit in Fig 2.4 and observe waveform at point A, V_E and B in oscilloscope and draw them in **same time base**.
2. Build the Isolation part of the circuit and connect it with point B.
3. Observe how the waveform change from point B to C
4. Build the rectifier circuit and observe the output waveform at D point.

(e)Reports:

1. Draw all the wave shapes of the experiment in same time base
2. How can opto-coupler provide isolation?
3. Give Example of different type of isolation device and its working principle.
4. What is the necessity of firing circuit for SCRs.

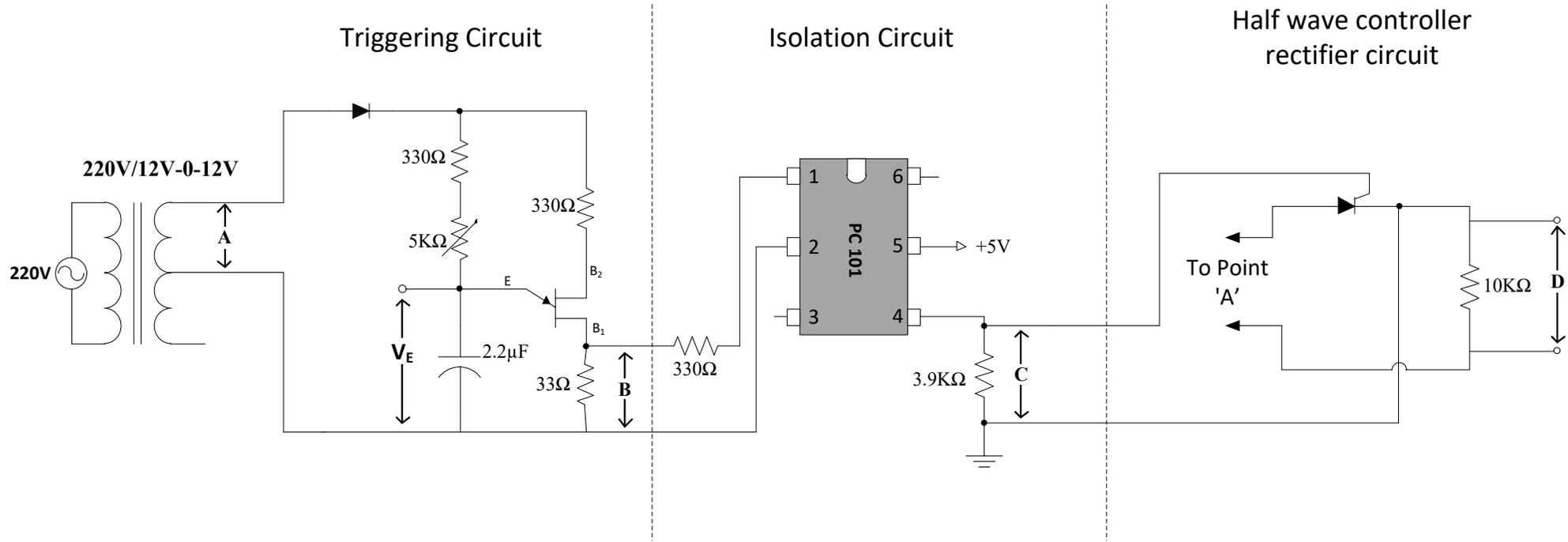


Figure 2.4:- Circuit diagram of half wave controlled rectifier with triggering and isolation circuit

Experiment No : 3

Name of the Experiment: Study of Single-phase Full Converter (Controlled Full-wave Rectifier)

(a)Objective

The objective of this experiment is to observe the output of a single-phase full converter (controlled full-wave rectifier) with a highly inductive load.

(b)Theory

The single-phase full converter (full-wave rectifier) is diagrammed in fig-3.1. During the positive half-cycle, thyristors T1 and T2 are forward biased. When T1 and T2 are fired simultaneously at $\omega t = \alpha$, the load is connected to the input supply through T1 and T2. During the negative half-cycle of the input voltage, thyristor T3 and T4 are forward biased. The firing of thyristors T3 and T4 will apply the supply voltage across thyristors T1 and T2 as reverse blocking voltages. T1 and T2 will be turned off due to line (natural) commutation and the load current will be transferred from T1 and T2 to T3 and T4. Fig.-3.1 shows the waveforms for input voltage, output voltage and input currents.

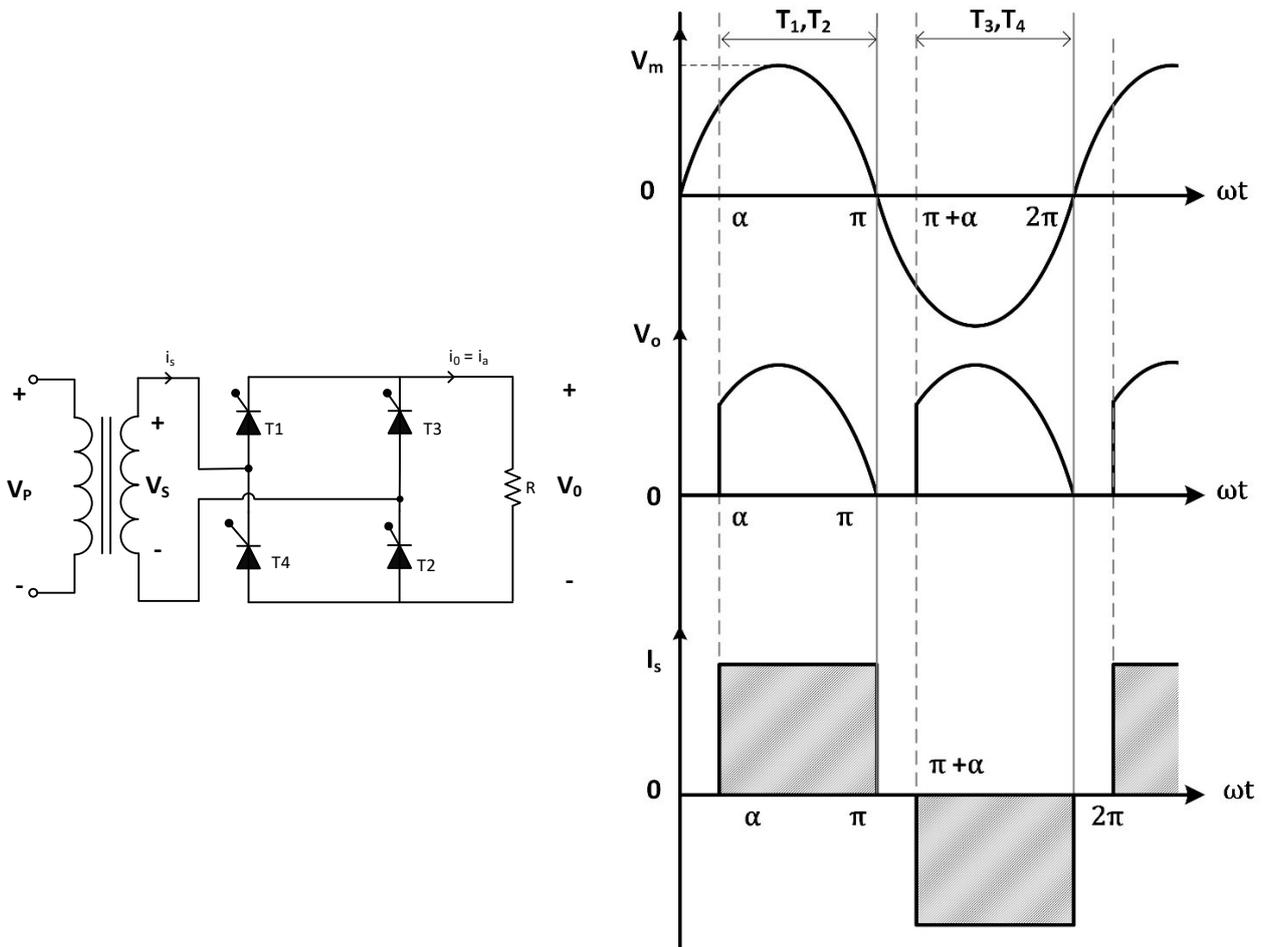


Figure 3.1: Single phase full converter circuit and the output waveform

(c)Apparatus:

| | | | |
|-----|-------------------------|------------------------------|----------------|
| 1. | Transformer | 220V/12-0-12V | x1 |
| 2. | Diode | 1N4007 | x2 |
| 3. | Resistors | 33Ω, 3.9 KΩ, 330Ω 10KΩ | x2 x4 x1 |
| 4. | Variable resistor (POT) | 5KΩ | x2 |
| 5. | Capacitor | 2.2μF | x2 |
| 6. | SCR | 2P4M | x2 |
| 7. | UJT | 2N2646 | x2 |
| 8. | Optocoupler | PC 101 | x2 |
| 9. | Multimeter | | x1 |
| 10. | Oscilloscope | | x1 |

(d)Procedure:

1. Build the triggering circuit of fig-3.3 and observe the waveform.
2. Build the isolation circuit as and observe the waveform.
3. Build the Full wave rectifier circuit.
4. Connect gate pulse to the thyristor circuit as in fig-3.3and observe the waveform.
5. Vary the pot and observe the output wave shape and also with multi meter measure the output DC (avg.) and R.M.S. voltage.

(e)Report:

1. Draw all the wave shapes you observe in the experiment.
2. Write the advantages of controlled rectifier over diode rectifier.
3. Why did we used center taped rectifier instead of bridge rectifier in the lab? Explain.

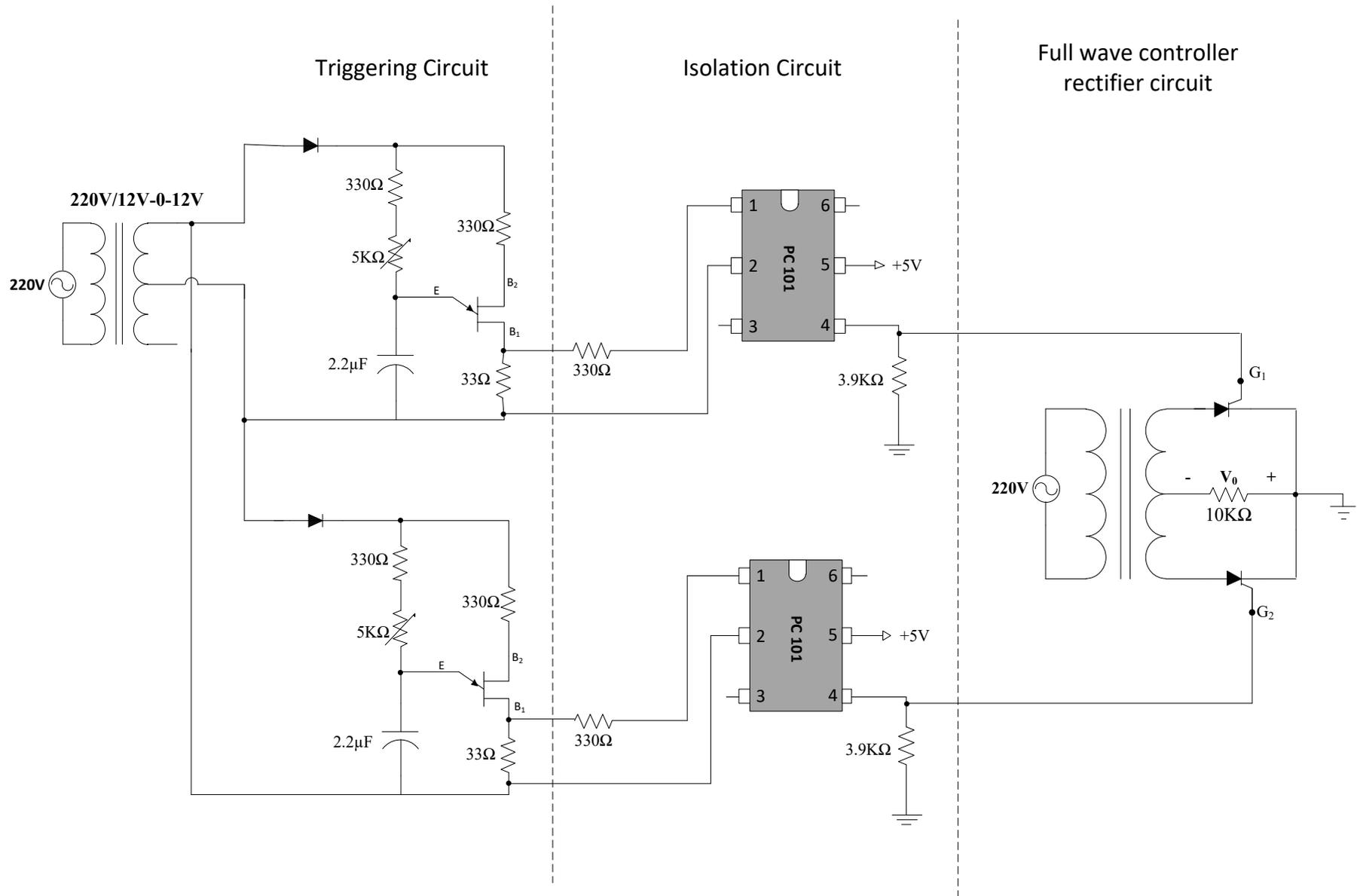


Figure 3.3:- Circuit diagram of single phase full wave controlled rectifier with triggering and isolation circuit

Experiment No : 4
Name of the Experiment: Study of Single-phase Full-Wave AC voltage Controller

(a)Objective

The objective of this experiment is to observe the output of a single-phase full-wave AC voltage controller with a resistive load.

(b)Theory

A single-phase full-wave AC voltage controller with a resistive load is diagrammed in fig-4.1. During the positive half cycle of input voltage, the power flow is controlled by varying the delay angle of thyristor T1 and thyristor T2 controls the power flow during the negative half cycle of input voltage. The firing pulses of T1 and T2 are kept 180° apart.

(c)Apparatus

| | | | |
|-----|-------------------------|------------------------------|----------------|
| 1. | Transformer | 220V/12-0-12V | x1 |
| 2. | Diode | 1N4007 | x2 |
| 3. | Resistors | 33Ω, 3.9 KΩ, 330Ω 10KΩ | x2 x4 x1 |
| 4. | Variable resistor (POT) | 5KΩ | x2 |
| 5. | Capacitor | 2.2μF | x2 |
| 6. | SCR | 2P4M | x2 |
| 7. | UJT | 2N2646 | x2 |
| 8. | Optocoupler | PC 101 | x2 |
| 9. | Multimeter | | x1 |
| 10. | Oscilloscope | | x1 |

(d)Procedure:

1. Set up the circuit as in Fig 4.1. Observe and draw the wave shape at different point.
2. Vary the pot and observe the output wave shape and also with multi meter measure the output DC (avg.) and R.M.S. voltage.
3. Measure the secondary side of the transformer peak voltage using oscilloscope (not multi meter) and change the pot in such a way the delay angle is approximately 90°. Measure the output RMS and DC voltage using multimeter.
4. Add a large inductor in series with the resistive load and observe the wave shape.

(e)Report:

1. Why can control be lost in a full-wave AC voltage controller if the load is highly inductive and how can you regain control?
2. Why did we use two different 5 Volt DC power supply?
3. Using the equation $V_{RMS} = V_S \left[\frac{1}{2\pi} \left(2\pi - \alpha + \frac{\sin 2\alpha}{2} \right) \right]^{1/2}$ and $V_{DC} = \frac{\sqrt{2}V_S}{2\pi} (\cos \alpha - 1)$ and the data from procedure 3 calculate the RMS and DC voltage of the output. What are the possible reasons for the different values?

Experiment No : 5
Name of the Experiment: Study of Switch-Mode Power Supplies (SMPS) (DC-DC Converters)

(a)Objective

The objective of this experiment is to observe the variation in output of switch-mode power supplies for different configurations.

(b)Theory

Switch-mode power supplies or DC-DC converters may be classified into two different categories: (a) choppers operated (Non-isolated) and (b) Inverter linked (Isolated) DC-DC converters. The chopper type (Non Isolated) SMPS are again classified as (i) Buck regulators, (ii) Boost regulators, (iii) Buck-Boost regulators, (iv) Cúk regulators v) SEPIC etc. The inverter coupled (Isolated) DC-DC converters may be classified as i) Fly-back type, ii) Half bridge inverter, iii) Full bridge inverter, iv) Resonant inverter type etc.

In this experiment various chopper type SMPS will be studied. In continuous conduction mode Buck, Boost, Buck-Boost converters operate by inductive energy transfer principle and the Cúk converter operates by capacitive energy transfer principle.

The chopper type SMPS are made out of three important parts (fig -5.1). The chopper circuit, feedback mechanism and logic circuit. The input DC voltage is put through the chopper circuit. The output voltage is then compared with the desired voltage (V_{ref}) and a control voltage, V_c is created. The control voltage is prepared for the next stage by putting it to the amplifier. Using the V_{cr} the duty cycle of the gate pulse is adjusted by the logic circuit so that the DC chopper output is the same as desired voltage and good regulation can be achieved.

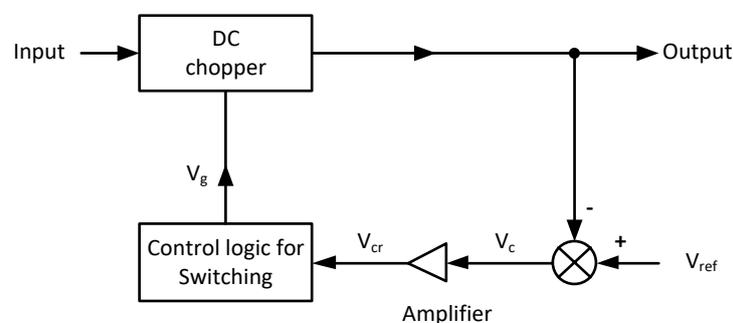


Fig 5.1: Block diagram of chopper type (non-isolated) SMPS

Duty cycle, k of a Square pulse can have a value from 0 to 1. So from the voltage gain, $G(k)$ of different SMPS it is easy to see Buck is a step down converter, Boost is a step up converter and Buck-Boost can work as both.

| | |
|------------|---|
| | Voltage Gain, $G(k) = \frac{V_0}{V_{in}}$ |
| Buck | $k \times V_{in}$ |
| Boost | $\frac{1}{1 - k} \times V_{in}$ |
| Buck-Boost | $\frac{-k}{1 - k} \times V_{in}$ |

Relative comparison of 3 type of non-isolated SMPS

(c)Apparatus:

- | | | | |
|----|-------------------------|----------------------------|----|
| 1. | Diode | 1N4007 | x1 |
| 2. | Resistors | 10K Ω ,22K Ω | x1 |
| | | 470 Ω | x2 |
| 3. | Variable resistor (POT) | 1K Ω | x1 |
| 4. | Capacitor | 22 μ F (50V rated) | x1 |
| | | 0.022 μ F | x2 |
| 5. | MOSFET | IRF 540 | x1 |
| 6. | Magnetic ballasts | .7H | x1 |
| 7. | Multimeter | | |
| 8. | Oscilloscope | | |

(d)Procedures:

Set up the circuit as in Fig. 5.1 and observe the outputs from pins 9. Vary the potentiometer and observe how the output changes at the output.

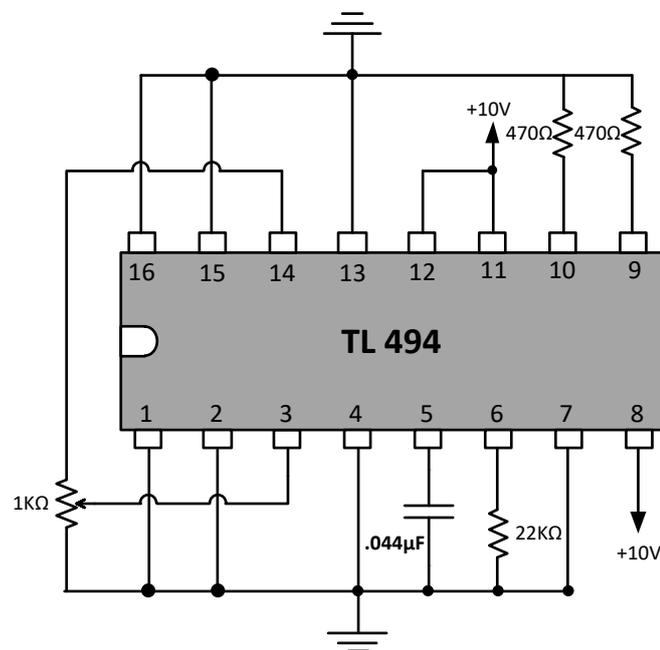


Fig 5.2: Square Wave generator circuit

Buck regulator:

1. Set up the circuit as in Fig. 5.3(d) and observe the output, V_o .
2. Disconnect the 22 μF capacitor and observe the output wave shape in oscilloscope.
3. Vary the potentiometer and observe how the output changes.
4. Note down the on time and the period of the square pulse generator circuit, and the corresponding output.
5. Calculate the duty cycle ($k=T_{\text{ON}}/T$) and the ratio V_o/V_{in} .

During the **BOOST AND BUCK-BOOST** experiment set the potentiometer to the value that gives **MINIMUM** V_o . Do not increase the duty cycle abruptly since it is a step up converter and the output voltage may go beyond the ratings of the capacitor and it might **EXPLODE** also ballast's insulation can fail due to excess current flow. This situation is hazardous and may injure you during the experiment. **SO DO NOT SET THE POT IN SUCH WAY SO THAT THE OUTPUT EXCEEDS 40V (IF THE RATING IS 50V).**

**Boost regulator:**

1. Set up the circuit as in Fig. 5.4(b) and observe V_o .
2. Vary the potentiometer and observe V_o . *Maintain V_o well below the rated voltage of the 22 μF capacitor.*
3. Note down the on time and the period of the square pulse generator circuit, and the corresponding V_o .
4. Calculate the duty cycle and the ratio V_o/V_{in}

Buck-Boost regulator:

1. Set up the circuit as in Fig. 5.5(b) and observe V_o .
2. Vary the potentiometer and observe V_o . *Maintain V_o well below the rated voltage of the 22 μF capacitor.*
3. Note down the on time and the period of the square pulse generator circuit and the corresponding V_o . Calculate the duty cycle and the ratio V_o/V_{in}

(e)Report

1. Why is the position of the MOSFET different in Fig. 5.3 (c) from that in Fig. 5.3 (b)?
2. Does this change alter the operation of the circuit from that of the ideal circuit in Fig. 5.3(a)?
3. Does operation of each regulator correspond to theory?
4. Does our circuit use feedback mechanism? Why do we need feedback in SMPS?

Buck Converter

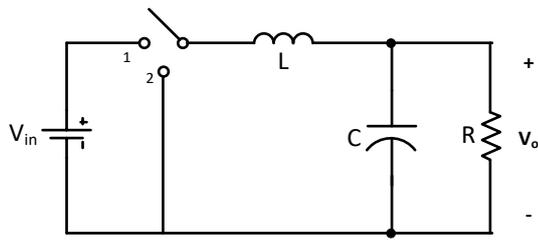


Fig 5.3(a): The ideal circuit

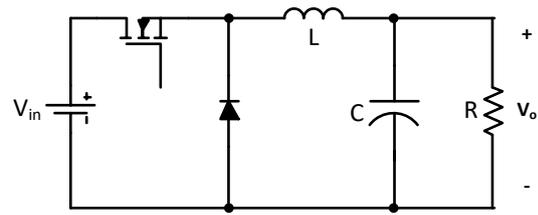


Fig 5.3 (b): With the solid state realization of the SPDT

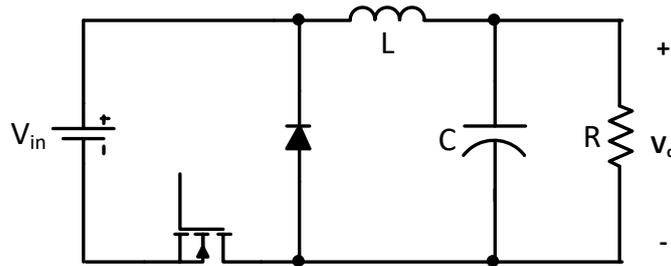


Fig 5.3 (c): Practical realization

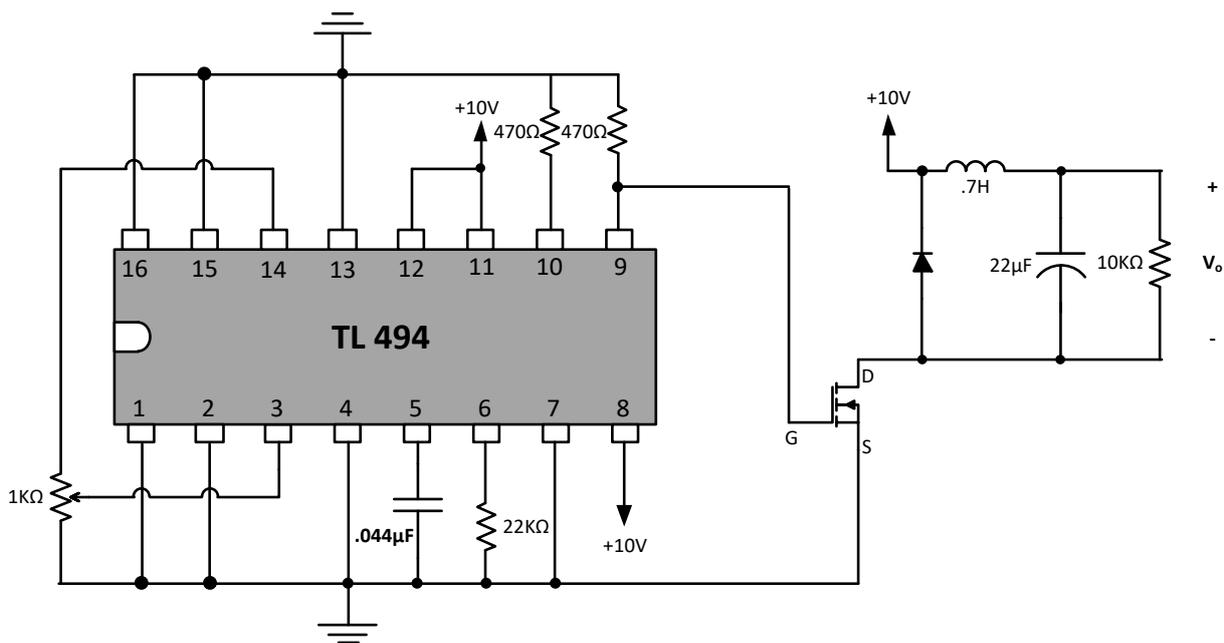


Fig 5.3 (d): Full Buck converter circuit

Boost Converter

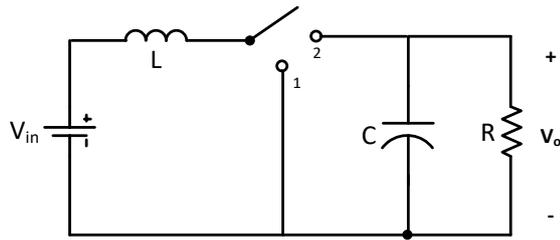


Fig 5.4(a): The ideal circuit

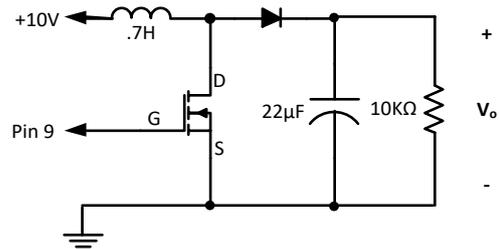


Fig 5.4 (b): Practical realization

Buck-Boost Converter

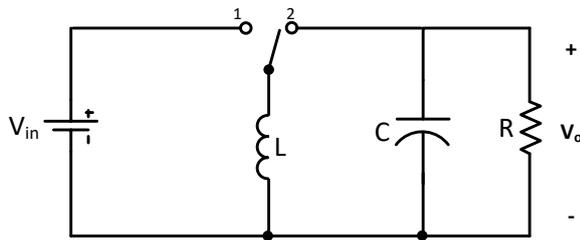


Fig 5.5 (a): The ideal circuit

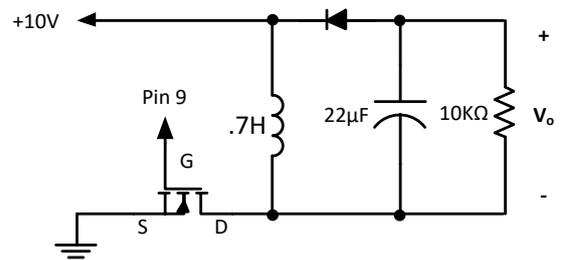


Fig 5.5 (b): Practical realization

Experiment No : 6

Name of the Experiment: Study of Single-Phase PWM inverter

(a)Objective

1. To understand the operating principle of a single-phase full-bridge inverter.
2. To understand gating signals and output voltage of a single-phase inverter.
3. To measure the gating signals and output voltage of a single-phase inverter.
4. To measure the output voltage and output current of a single-phase inverter with a purely resistive load.
5. To measure the output voltage and output current of a single-phase inverter with an RL load.

(b)Discussion

Inverters are also called as dc-to-ac converters. An inverter converts a fixed dc voltage to a symmetrical ac voltage of desired frequency and amplitude. Inverters are widely used in industrial applications such as uninterruptible power supplies (UPS), Variable Frequency Drive (VFD), Air conditioner etc.

Inverters convert dc power to ac power at some desired output voltage and frequency. Inverters can be classified into two types: 1) single-phase inverters, and 2) three-phase inverters. The basic circuits of single-phase and three inverters are shown in Figs 6.1(a) and 6.1(b), respectively. The dc input voltage is fixed and may be a battery, solar cell, fuel cell, or other dc source. The switching device can use each type of controlled turn-on and turn-off devices such as thyristors, BJTs, MOSFETs, and IGBTs.

The output of a single-phase inverter is a symmetrical ac voltage either square or sinusoidal wave. A three-phase inverter may be considered as three single-phase inverters and the output of each single-phase inverter is shifted by 120 degrees.

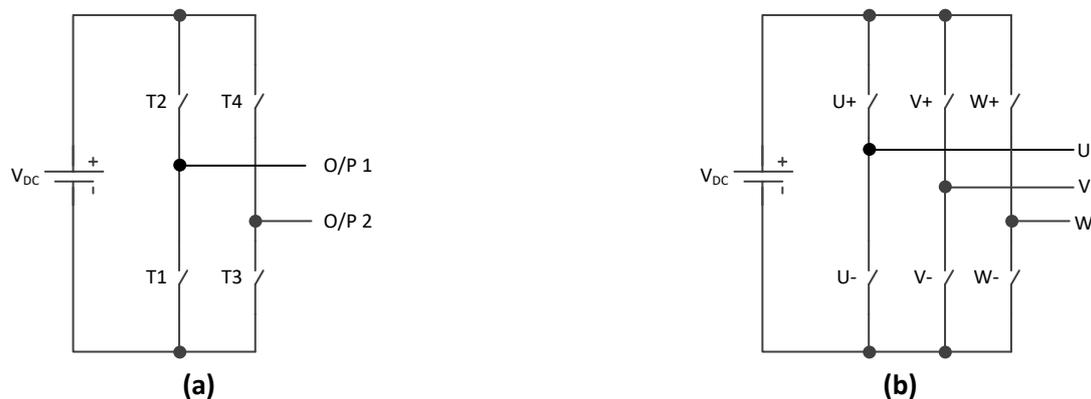


Fig 6.1:-(a)Single Phase Inverter (b)Three phase Inverter

The switching devices of the same arm (e.g., T1 and T2, U+ and U-) cannot conduct at the same time. Since the turn-off time of power switching devices is greater than turn-on time, therefore a delay called the dead time must be introduced to avoid a short circuit. The dead time depending on the turn-off time of power devices is usually specified as 2~3 times the turn-on time.

To control the on- and off-time of each switching device, a gating signal should be applied at an appropriate time. The gating signal may be square or PWM voltage. Generally the inverters are controlled by using Sinusoidal Pulse-Width Modulation (SPWM) technique. A SPWM wave is produced by comparing a sinusoidal reference signal to a higher frequency triangular carrier wave. The frequency of reference signal determines the output frequency of inverter, the peak value of reference signal controls the average output voltage, and the number of pulses per half-cycle is determined by the carrier frequency. SPWM can be divided into two types: 1) unidirectional SPWM control, and 2) bidirectional SPWM control. Fig 6.2(a) shows the operation of unidirectional SPWM control. During the positive half cycle of sinusoidal reference wave, triangular carrier wave can only be positive. When the amplitude of sinusoidal reference wave is higher than that of triangular carrier wave, the output is high; inversely, when the amplitude of sinusoidal reference wave is lower than that of triangular carrier wave, the output is low.

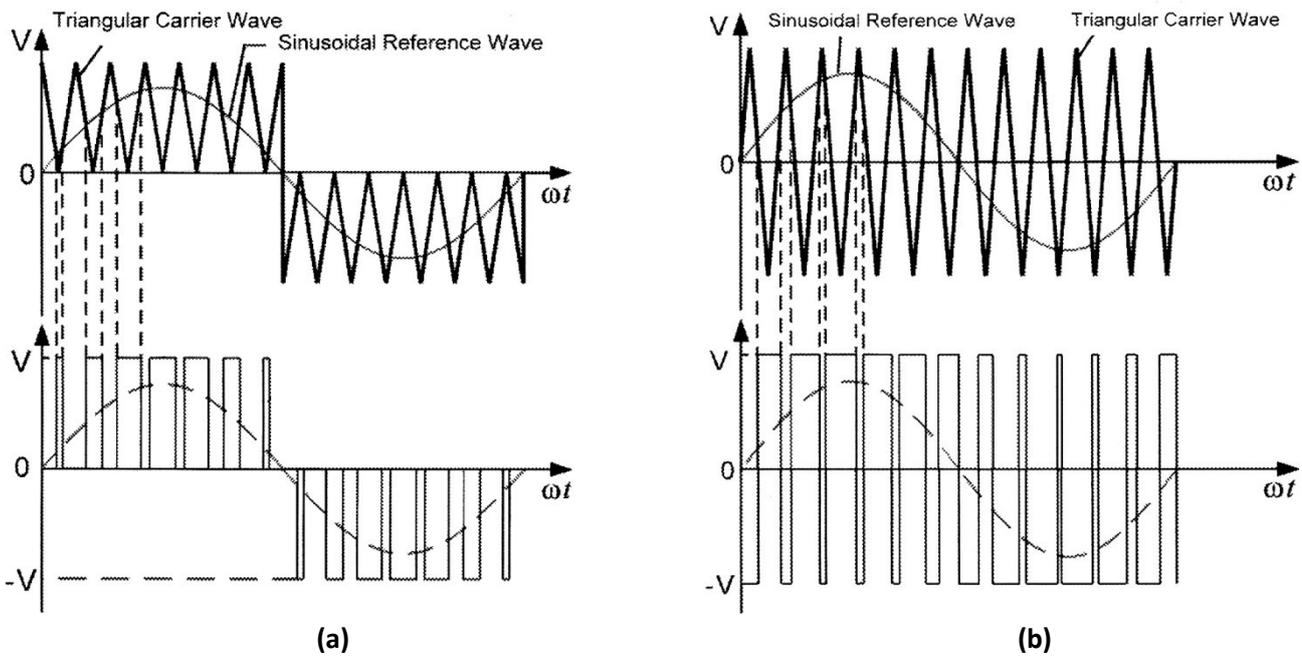


Fig 6.2:- (a)Unidirectional SPWM control (b)Bidirectional SPWM control

The operation of bidirectional SPWM control is illustrated in Fig. 6.2(b). In bidirectional SPWM control, triangular carrier wave may be positive and negative and the output PWM wave has positive and negative voltages.

The power circuit of single-phase full-bridge inverter, as shown in Fig:-6.3(a), is the same as the four-quadrant chopper. When IGBTs T2 and T3 are turned on at the same time, the supply voltage V_s appears across the load. When IGBTs T1 and T4 are turned on simultaneously, the output voltage across the load is reversed and is $-V_s$.

The square gating signals and the output voltage of the single-phase inverter are shown in Fig:-6.3(b). If the gating signals are PWM signals, the output voltage is therefore a PWM wave. With an inductive load, the output current is a sinusoidal waveform. The output frequency of the single-phase inverter is determined by the frequency of the gating signal. The peak-to-peak output voltage is equal to $2V_s$.

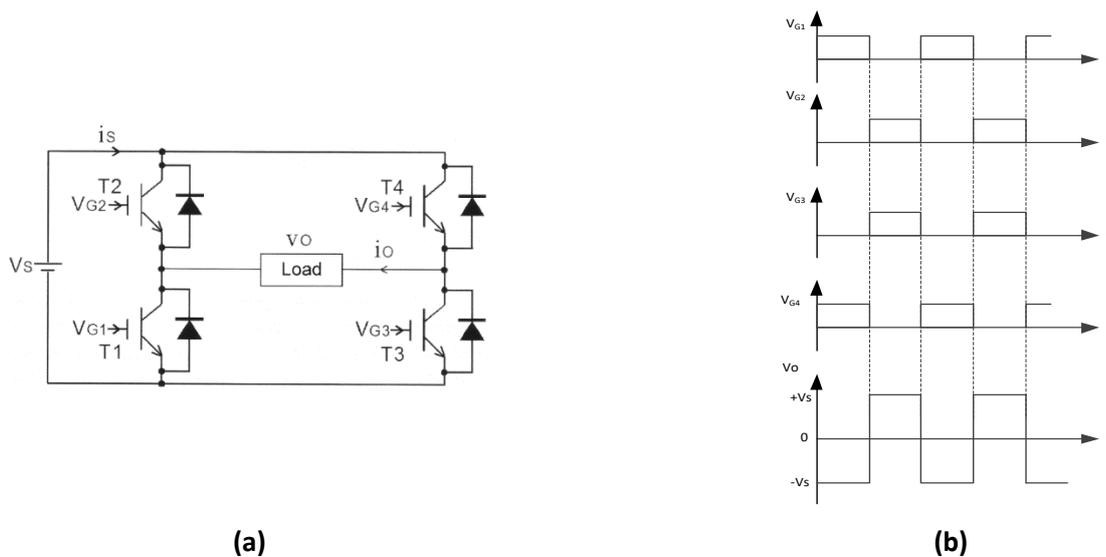
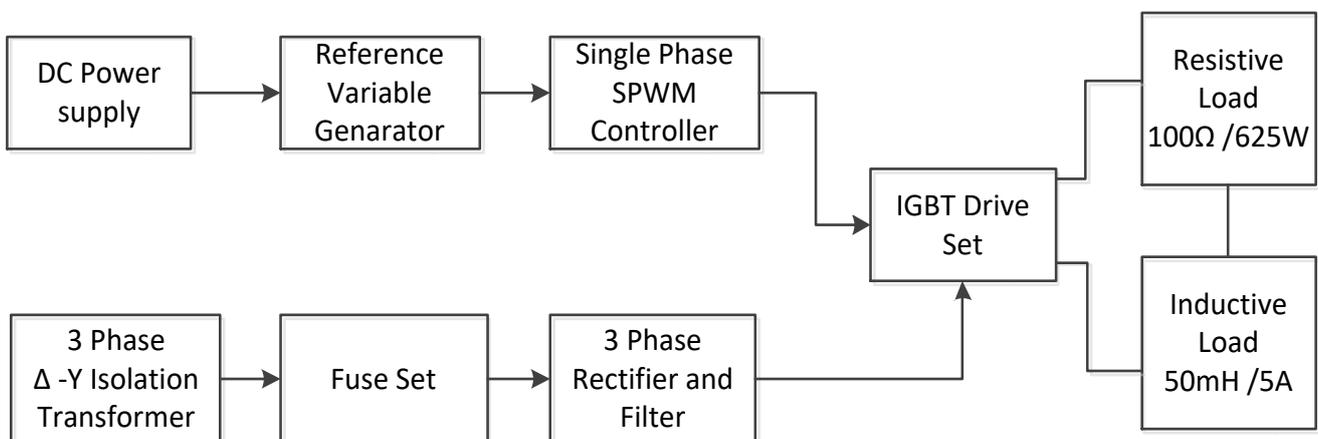


Fig 6.3:- Single phase full bridge inverter (a)Power circuit (b)Gating signals and output voltage

(c)Equipment required

| | | |
|-----|------------------------------------|----|
| 1. | DC Power Supply | x1 |
| 2. | Reference Variable generator | x1 |
| 3. | Differential Amplifier | x1 |
| 4. | Current Transducer | X1 |
| 5. | Resistor Load Unit | x1 |
| 6. | Inductive Load Unit | x1 |
| 7. | IGBT Drive Set | x1 |
| 8. | Single Phase SPWM Generator | x1 |
| 9. | Three Phase Rectifier & Filter | x1 |
| 10. | Fuse Set | x1 |
| 11. | Isolating Transformer | x1 |
| 12. | Digital Storage Oscilloscope (DSO) | x1 |
| 13. | Connecting Wires | |
| 14. | Bridging Plugs | |

(d)Procedure**Fig 6.4:-Block Diagram of the experimental setup**

1. With power off, complete the connections shown in Fig:-6.3 using bridging plugs (curved lines) and connecting wires.
2. Turn on the DC Power Supply. On Reference variable Generator, set V_c Range Selector (SW1) switch to 0 ~ +10V and turn V Control knob to set $V_c=5V$ approximately.

Observation of the Square gate pulse

3. On Single Phase PWM Generator, set PWM/CLK Selector (SW2) switch to CLK (clock) and set the F(KHz) Frequency Selector(SW1) switch of triangular wave to x1 (1KHz).

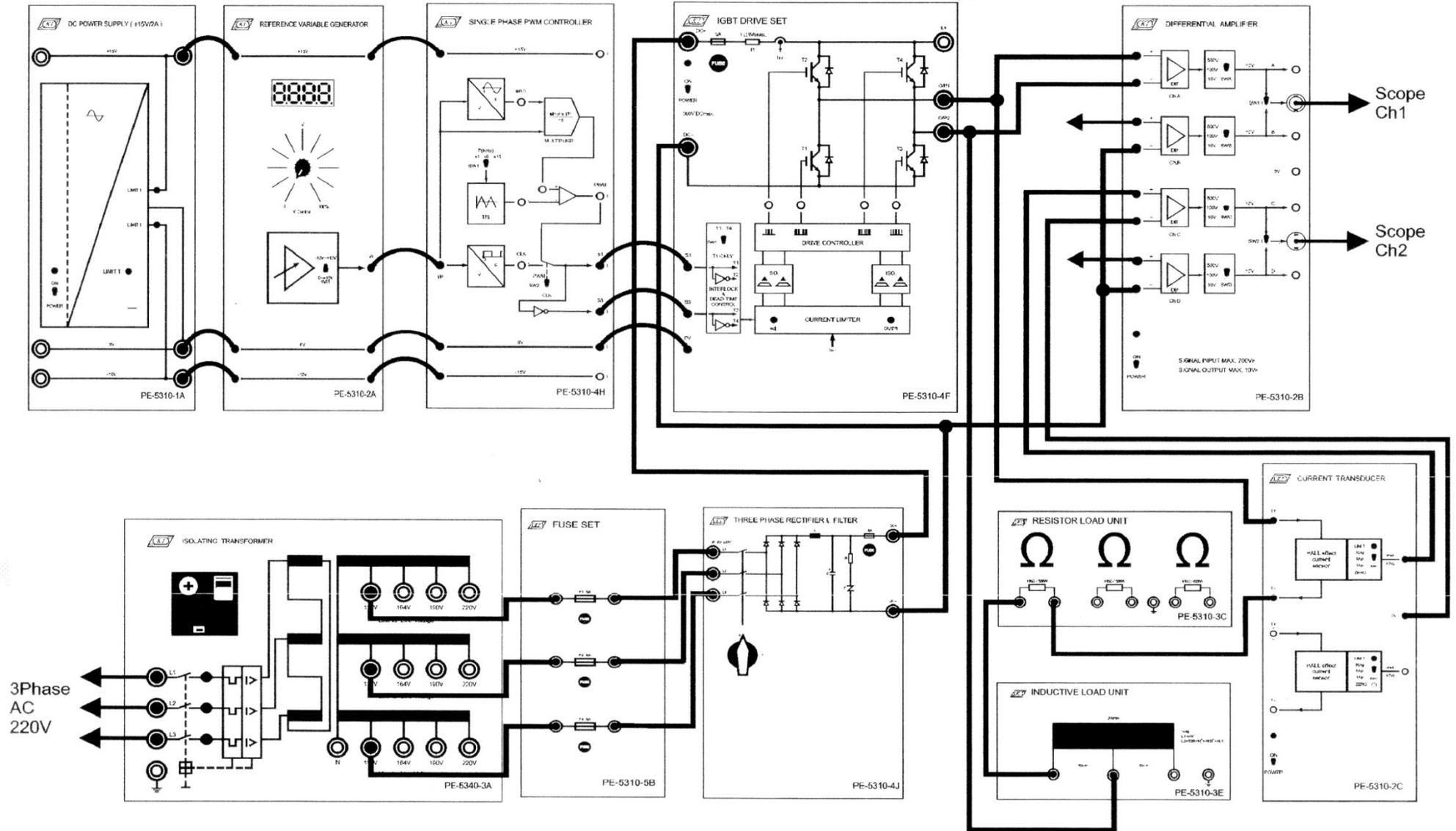
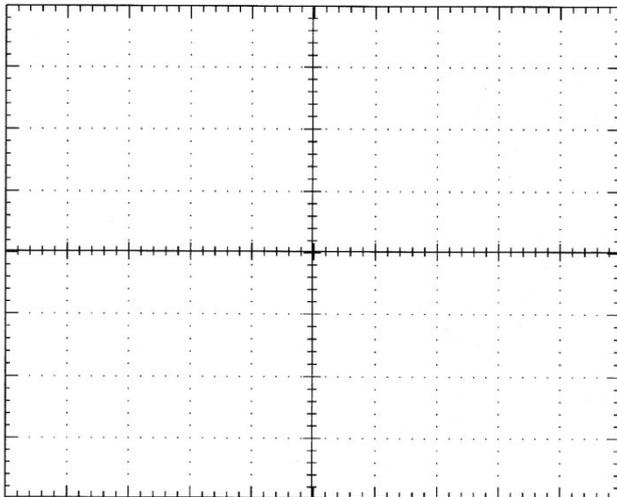
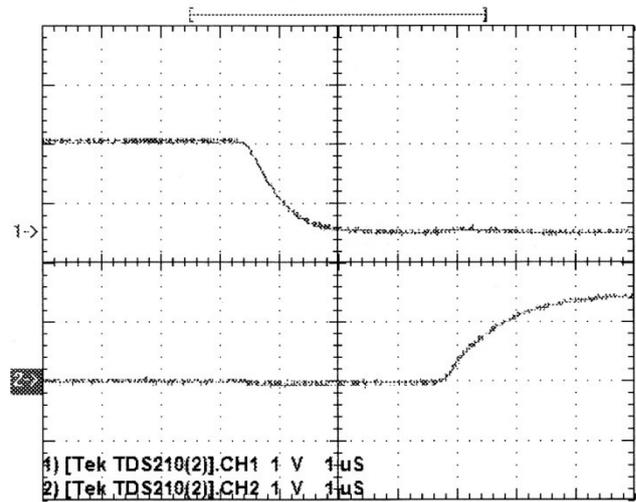


Figure 6.5:- Wiring diagram for single-phase inverter measurement

- Turn on IGBT Drive Set. Place Trigger Selector (SW1) switch in T1...T4 position. On Differential Amplifier, set V Range Selectors(SWB,SWD) of Ch.B and Ch.D to 100V and place Ch Selectors (SW1,SW2) in B and D. Connect Ch.B DIF. inputs to T1 (+ to T1, - to DC-) and connect Ch.D DIF inputs to T2 (+ to T2, - to DC-). Using oscilloscope, measure and draw the gating signals of IGBTs T1 and T2 in Fig. 6.6.

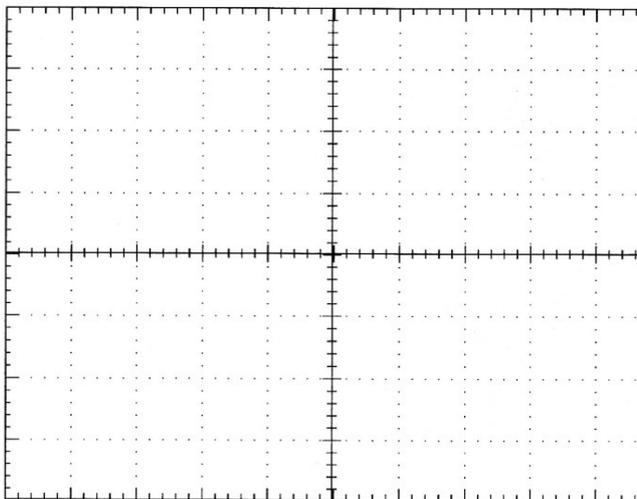


**Figure 6.6:- Measured T1 (CH1) and T2 (CH2);
Vc=5V, fc=1KHz, CLK**

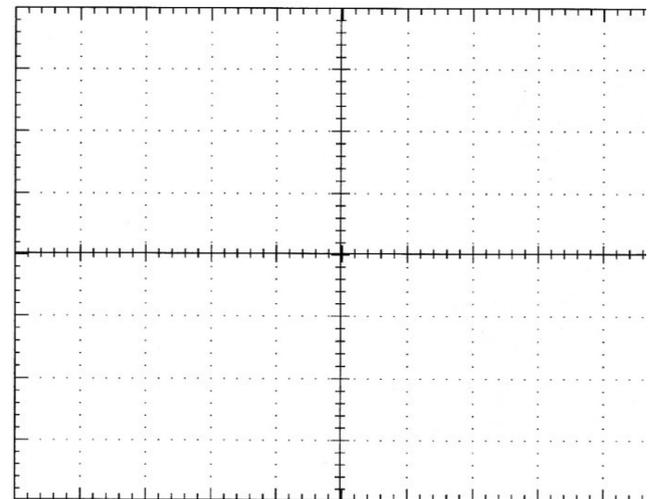


**Figure 6.7:- Measured T1 (CH1) and T2 (CH2);
Vc=5V, fc=1KHz, CLK**

- Adjust the SEC/DIV knob of DSO to view the gating signals T1 and T2 as shown in Fig 6.7. Measure and record the dead time _____ μ s.

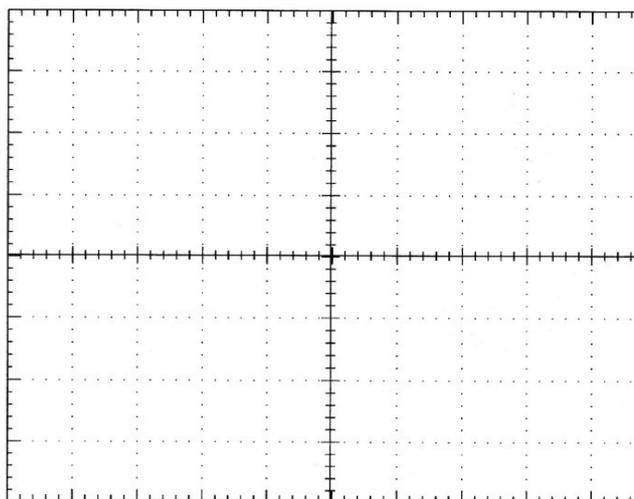


**Figure 6.8:- Measured T3 (CH1) and T4(CH2),
Vc=5V, fc=1KHz, CLK**

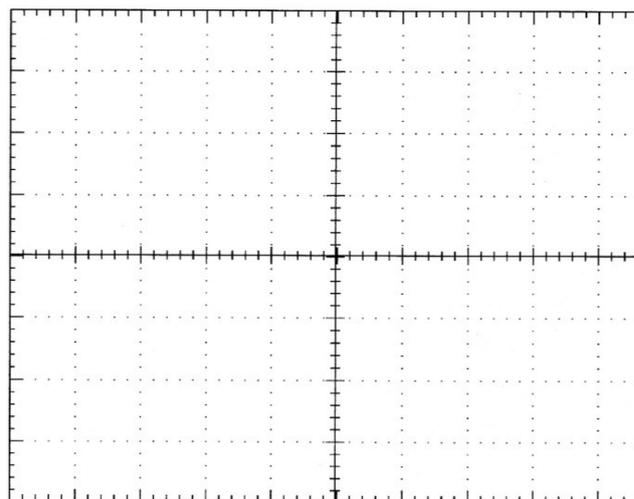


**Figure 6.9:- Measured T1 (CH1) and T4 (CH2);
Vc=5V, fc=1KHz, CLK**

- Connect Ch.B DIF inputs to T3 (+ to T3, - to DC-) and connect Ch.D DIF inputs to T4 (+ to T4, -to DC-). Using oscilloscope, measure and record the gating signals of IGBTs T3 and T4 in Fig:-6.8
- Repeat Step 6. Measure and record the dead time = _____ μ s.
- Connect Ch.B DIF inputs to T1 (+ to T1, - to DC-) and connect Ch.D DIF inputs to T4 (+ to T4, -to DC-). Using DSO, measure and record the gating signals of IGBTs T1 and T4 in fig. 6.9



**Figure 6.10:- Measured T2 (CH1) and T3 (CH2);
V_c=5V, f_c=1KHz, CLK**

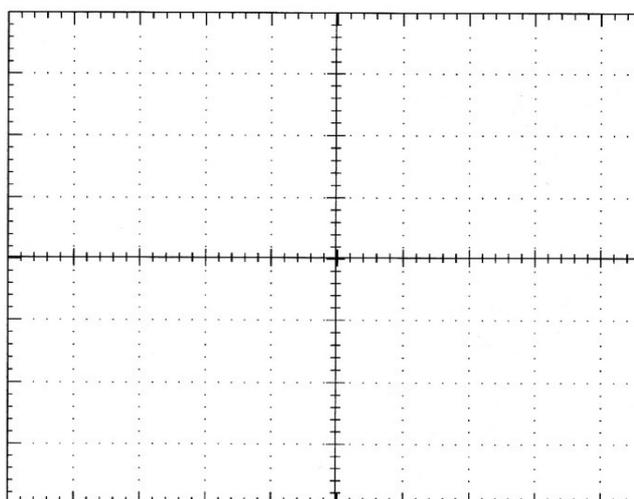


**Figure 6.11:- Measured T1 (CH1) and T2 (CH2);
V_c=10V, f_c=1KHz, PWM**

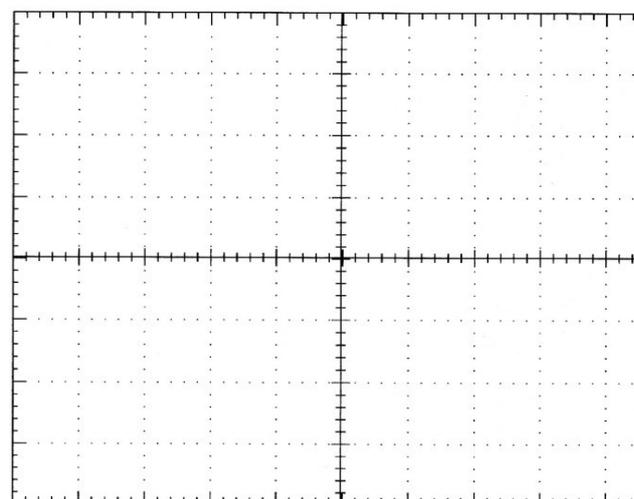
9. Connect Ch.B DIF inputs to T2 (+ to T2, - to DC-) and connect Ch.D DIF inputs to T3 (+ to T3, - to DC-). Using oscilloscope, measure and record the gating signals of IGBTs T2 and T3 in Fig 6.10

Observation of the PWM pulse

10. On Reference Variable Generator, set V_c Range Selector (SW1) switch to 0~+10V and Set V Control knob to 100% (V_c=10V approximately). On Single Phase PWM Generator, set PWM/CLK Selector (SW2) switch to PWM.
11. Connect Ch.B DIF inputs to T1 (+ to T1, - to DC-) and connect Ch.D DIF inputs to T2 (+ to T2, - to DC-). Using oscilloscope, measure and record the gating signals of IGBTs T1 and T2 in fig 6.11

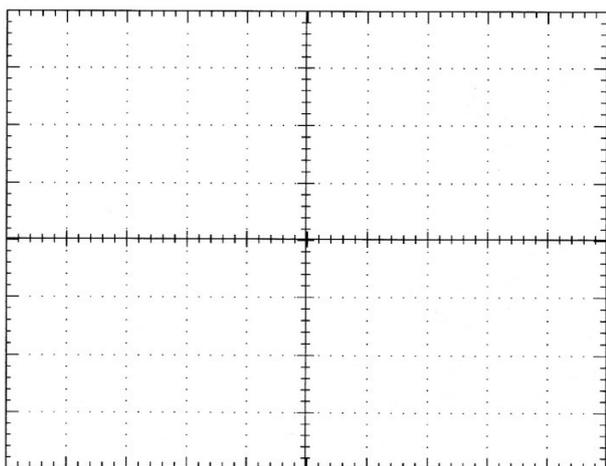


**Figure 6.12:- Measured T1 (CH1) and T4 (CH2);
V_c=10V, f_c=1KHz, PWM**

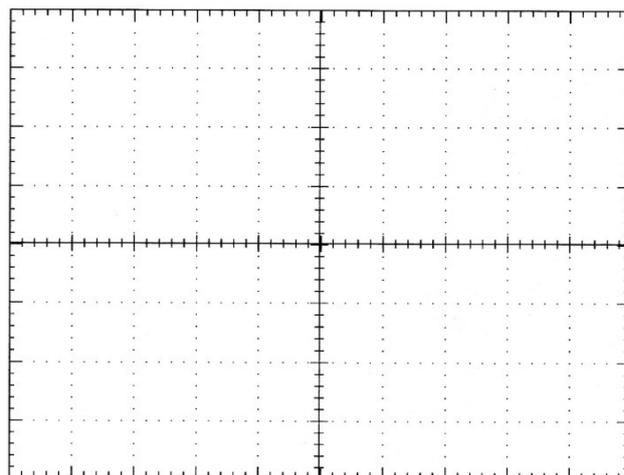


**Figure 6.13:- Measured T2 (CH1) and T3 (CH2);
V_c=10V, f_c=1KHz, PWM**

12. Connect Ch.B DIF inputs to T1 (+ to T1, - to DC-) and connect Ch.D DIF inputs to T4 (+ to T4, - to DC-). Using oscilloscope, measure record the gating signals of IGBTs T1 and T4 fig 6.12
13. Connect Ch.B DIF inputs to T2 (+to T2, - to DC-) and connect Ch.D DIF inputs to T3 (+ to T3, - to DC-). Using DSO, measure and record the gating signals of IGBTs T2 and T3 in Fig 6.13



**Figure 6.14:- Measured T3 (CH1) and T4 (CH2);
V_c=10V, f_c=1KHz, PWM**

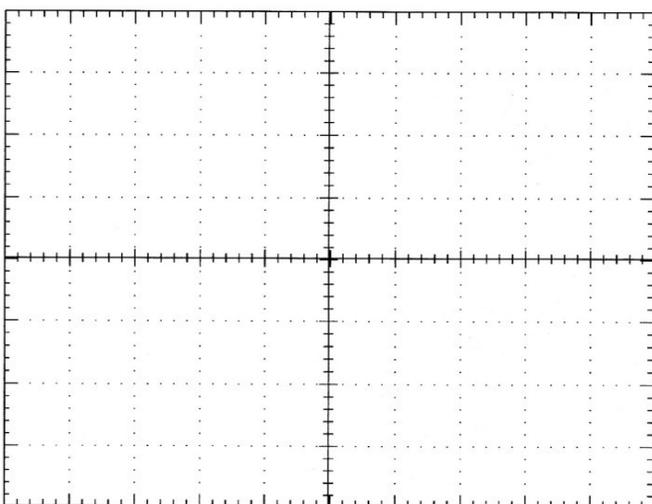


**Figure 6.15:- Measured V_L (CH1) and I_L (CH2);
V_c=5v, f_c=1 KHZ, CLK**

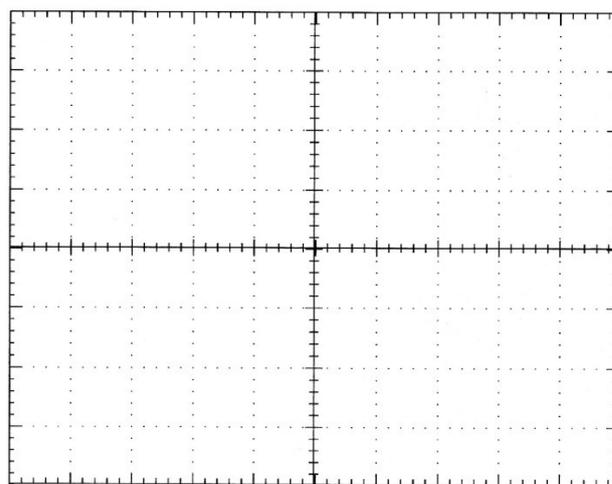
14. Connect Ch.B DIF inputs to T3 (+ to T3, - to DC-) and connect Ch.D DIF inputs to T4 (+ to T4, - to DC-). Using oscilloscope, measure and the gating signals of IGBTs T3 and T4 in fig 6.14

PWM pulse with Resistive load

15. Recover the connections of Fig. 6.5. Short out the load inductor by placing a connecting wire directly across the 50mH inductor terminals. This constructs a purely resistive load circuit (100Ω) across output terminals O/P 1 and O/P 2.
16. On Differential Amplifier, set V Range Selector (SWA) of Ch.A to 500V and set V Range Selector (SWC) of Ch.C to 100V, place Ch Selectors (SW1, SW2) in A and C. On Current Transducer module, set I range Selector to 5Ap. On Single Phase PWM Generator, set PWM/CLK Selector (SW2) switch to CLK. Turn on all power.
17. Slowly adjust the V control knob of Reference Variable Generator to set V_c=5V. Using oscilloscope, measure and record the load voltage V_L and load current I_L waveforms Fig. 6.15. Calculate and record the output frequency = _____ Hz



**Figure 6.16:- Measured V_L (CH1) and I_L (CH2);
V_c=10V, f_c=1KHz, CLK**

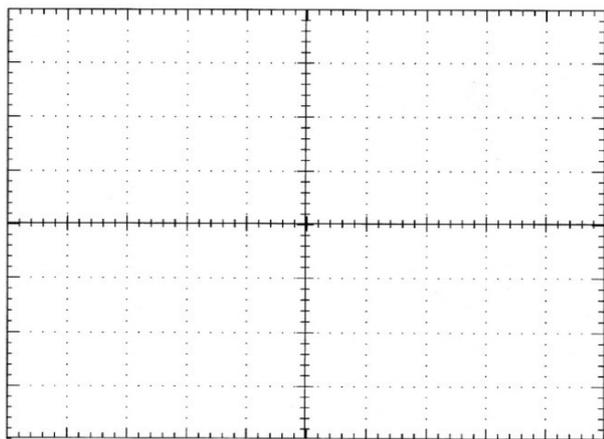


**Figure 6.17:- Measured V_L (CH1) and I_L (CH2);
V_c=10V, f_c=1KHz, CLK**

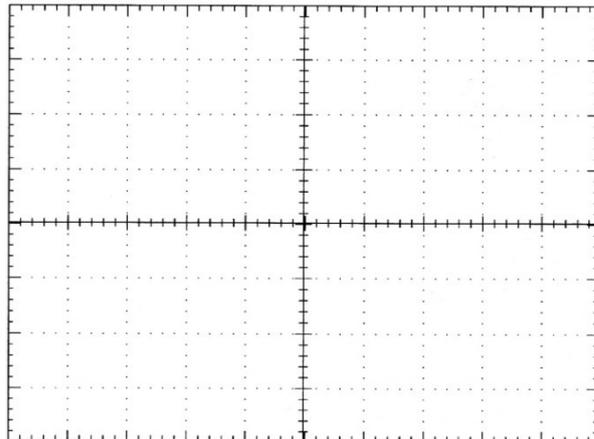
- Adjust the V control knob of Reference Variable Generator to set $V_c=10V$ approximately. Using DSO, measure and record the load voltage and load current waveforms as shown in Fig 6.16. Calculate and record the output frequency = _____ Hz.

PWM pulse with Resistive and Inductive (RL) load

- Turn power off. Recover the load inductor by removing the connecting wire from inductor terminals. This modifies the purely resistive load to an RL load (100Ω in series with 50mH). Turn power on. Slowly adjust the V control knob of Reference Variable Generator to set $V_c=10V$ approximately. Using DSO, measure and record the load voltage and load current waveforms in Fig. 17

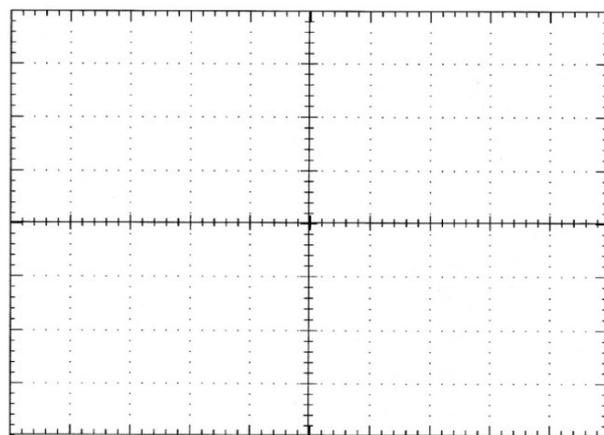


**Figure 6.18:- Measured VL (CH1) and IL (CH2);
Vc=5V, fc=1KHz, CLK**

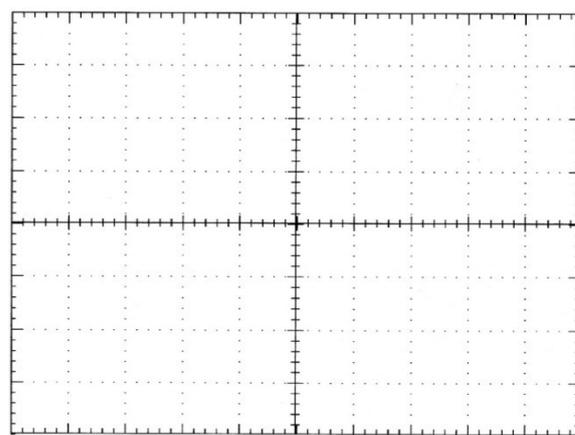


**Figure 6.19:- Measured VL (CH1) and IL (CH2);
Vc=10V, fc=1KHz, PWM**

- Slowly adjust the V control knob of Reference Variable Generator to set $V_c=5V$. Using oscilloscope, measure and record the load voltage and load current waveforms in Fig 6.18
- On Single Phase PWM Generator module, place the PWM/CLK Selector (SW2) switch in PWM position and set the F(KHz) Frequency Selector(SW1) switch of triangular wave to x1 (1 KHz). Short out the load Inductor by placing a connecting wire directly across the 50mH inductor terminals. This constructs a purely resistive load circuit (100Ω).
- Slowly turn the V control knob of Reference Variable Generator to set $V_c=10V$ approximately. Using DSO, measure and record the load voltage and load current waveforms in fig 6.19

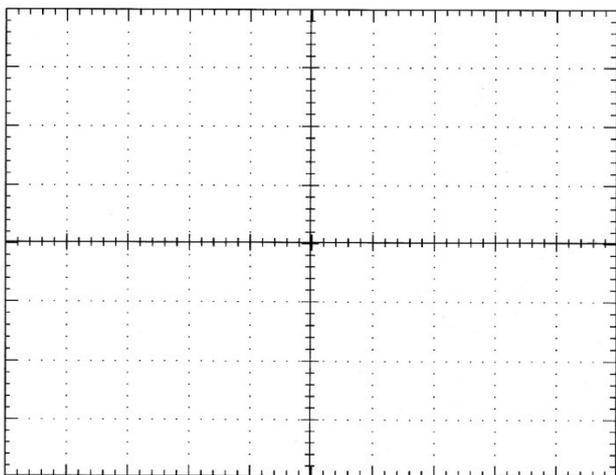


**Figure 6.20:- Measured VL (CH1) and IL (CH2);
Vc=5V, fc=1KHz**

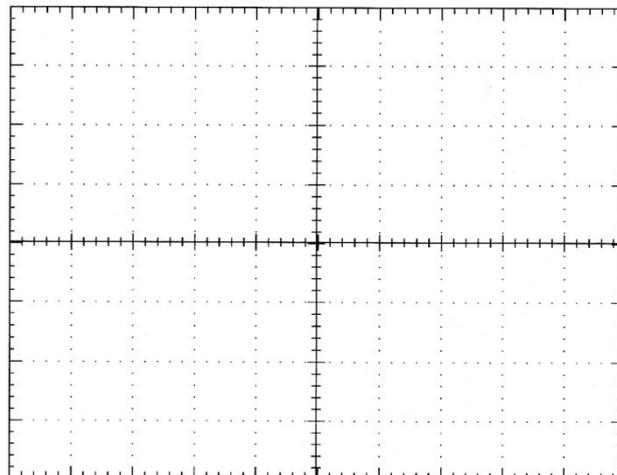


**Figure 6.21:- Measured VL (CH1) and IL (CH2);
Vc=10V, fc=1KHz, PWM**

- 23. Slowly turn the V control knob of Reference Variable Generator to set $V_c=5V$ approximately. Using oscilloscope, measure and record the load voltage and load current waveforms in Fig 6.20.
- 24. Recover the load inductor by removing the connecting wire from inductor terminals. This modifies the purely resistive load to an RL load (100Ω in series with $50mH$). Slowly adjust the V control knob of Reference Variable Generator to set $V_c=10V$ approximately. Using oscilloscope, measure and record the load voltage across 100Ω and load current waveforms in fig 6.21.

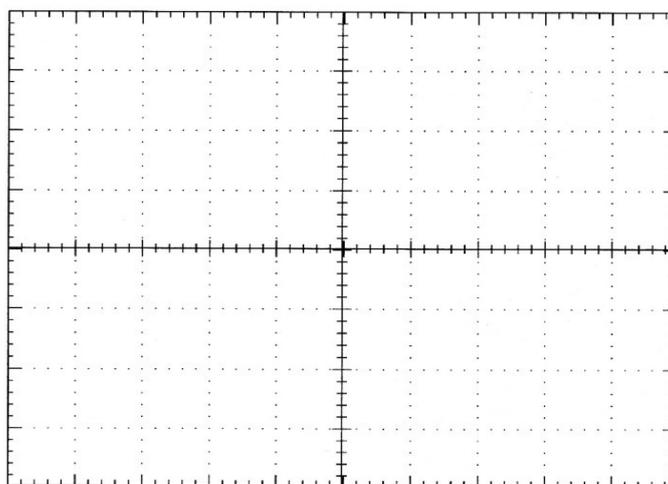


**Figure 6.22:- Measured VL (CH1) and IL (CH2);
 $V_c=5V$, $f_c=1KHz$, PWM**



**Figure 6.23:- Measured VL (CH1) and IL (CH2);
 $V_c=10V$, $f_c=5KHz$, PWM**

- 25. Slowly adjust the V control knob of Reference Variable Generator to set $V_c=5V$ approximately. Using oscilloscope, measure and record the load voltage across 100Ω) and load current waveforms in Fig 6.22.
- 26. On Single Phase PWM Controller, set F (KHz) Frequency Selector (SW1) switch of triangular wave to x5 (5 KHz). Slowly turn the V control knob of Reference Variable Generator to set $V_c=10V$ approximately. Using oscilloscope, measure and record the load voltage and load current waveforms in Fig 6.23.
- 27. On Single Phase PWM Controller, set F (KHz) Frequency Selector (SW1) switch of triangular wave to x15 (15 KHz). Using: DSO, measure and record the load voltage and load current waveforms in Fig 6.24.



**Figure 6.24:- Measured V_L (CH1) and I_L (CH2);
 $V_c=10V$, $f_c=15KHz$, PWM**

(e)Report:

1. What are the advantages of SPWM inverter over square wave inverter? Explain in term of total harmonic distortion (THD).
2. What is the effect of switching frequency on output? Is there any disadvantage of using high switching speed in the inverter?
3. What are some of the common UPS design types? With block diagram write short notes about Offline/standby, line interactive and online/Double conversion type UPS
4. Design a Square wave inverter circuit and briefly describe its operation.

Experiment No : 7
Name of the Experiment: Study of Stepper Motor drive

(a)Objective

The objective of this experiment is to observe the behavior of a stepper motor when driven by a power electronic drive system.

(b)Theory

A stepper motor is a brushless motor. It consists of a rotor (which can be Permanent magnet or Variable reluctance or Hybrid type) and a stator with multiple windings. Based on the polarity of the excitation stepper motors can be unipolar or bi-polar. Normally unipolar stepper motor consists of two winding each with a center tap. The center taps are interconnected or brought outside as two different wires, as a result they have 5 or 6 wires. Bi-polar motors have two windings, so they have 4 wires. In open loop based system stepper motors are very good choice because until the torque of the stepper motors are exceeded the speed of the motor will not change.

Unlike the induction motor or DC motor, stepper motor's rotor does not rotate continuously but in steps. Unipolar stepper motor require only positive pulse .Bipolar stepper motor require both positive and negative pulse to rotate. Compared to unipolar stepper motor bipolar motors can have more than 30% extra torque. But bipolar stepper motor requires more complex pulse generating circuit. This experiment utilized a unipolar motor and 4 bit shift register IC as the driver. There are different type of purposefully built IC made to drive unipolar/bipolar stepper motor (Ex: L297, L6291 (STM), DRV 8812, DRV 8805(TI), UCN 5804 etc.). Most of the time microcontrollers are used as a control/driver for stepper motors. Stepper motors are widely used in inkjet printer, CNC machines, robots etc.

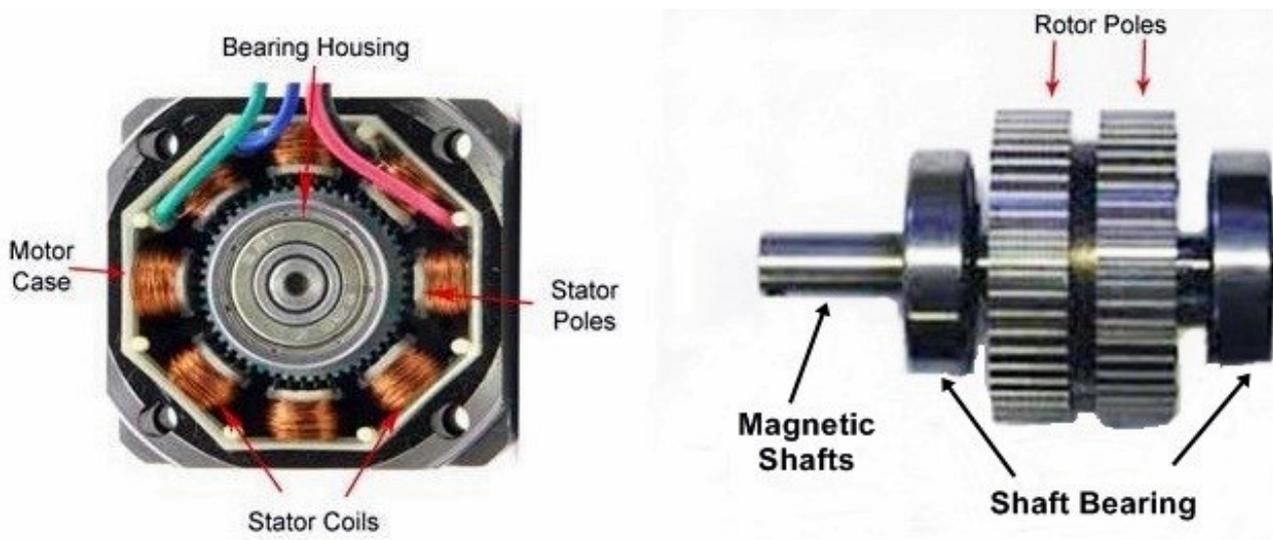


Figure 7.1:-Photograph of Hybrid (unipolar/bipolar) Stepper motor

Unipolar stepper motor rotation mechanism:

If N_A coil of the motor is energized then the rotor lines up with it so that its position is $\theta = 0^\circ$ electrical. If N_A and N_B are then both energized, the rotor moves to position $\theta = 45^\circ$ electrical. If N_A is switched off and N_B and N_C are energized, then the rotor moves to position $\theta = 135^\circ$ electrical (as shown in Fig 7.2)

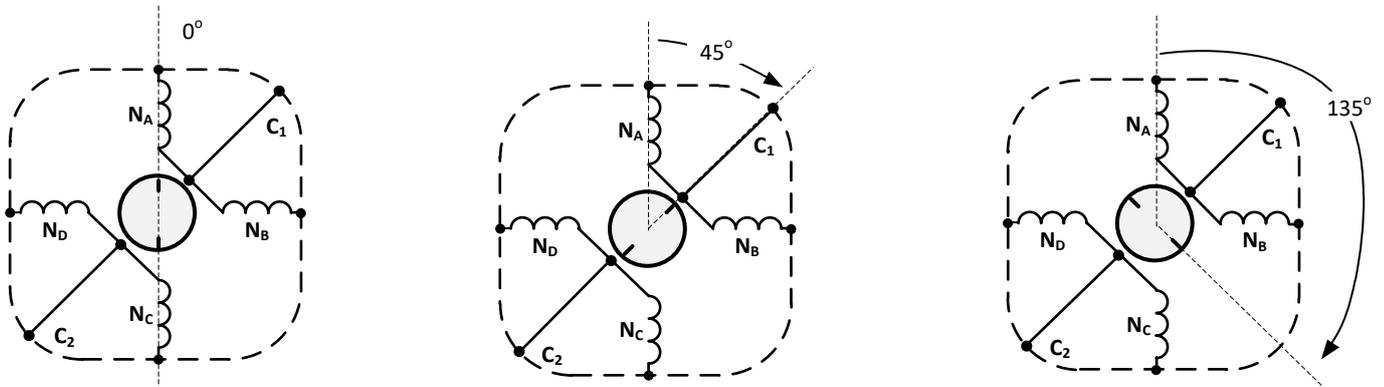


Figure 7.2:-Rotation of unipolar stepper motor

(c)Equipment Required

| | | |
|--|----------|----|
| 1. Unipolar Stepper motor | | x1 |
| 2. 4-bit PIPO bidirectional shift register | TL 74194 | x1 |
| 3. MOSFET | IRF 540 | x4 |
| 4. Signal generator | | |
| 5. Trainer board | | |

(d)Procedure

1. To energize N_A coil we have to apply +5V to C_1 and N_A terminal have to be grounded. To energize N_A and N_B coil at the same time we have to apply +5V to C_1 and both N_A and N_B need to be grounded. So the pulse required for the motor to rotate at a stepping angle of 45° will look like Fig 7.3
2. The pulse trains are generated by means of a four bit shift register 74194. The connection for the control circuit is shown in Fig.7.4
3. The output Q_0, Q_1, Q_2, Q_3 of the control circuit should be connected to the gates of four MOSFET's and to four LEDs. The MOSFETs will act as switches for the four coils of the stepper motor.
4. The pins S_0 and S_1 should be connected to logic switches. The clock input of SN 74194 should be connected to the TTL/CMOS output of the signal generator. Pin 1(Clear) should be connected to +5V or pulse switch
5. To load the register $S_1 = 1, S_0 = 1$ (Parallel load mode). Set the clock to 1 Hz and $S_1 = 0, S_0 = 1$. The stepper motor should rotate. Increase the clock speed to 10 Hz and 100 Hz to increase the speed of rotation. Set $S_1 = 1, S_0 = 0$ to rotate the motor in the opposite direction.

| CLK | Mode | | $\overline{\text{CLR}}$ | Function |
|-----|------|----|-------------------------|---------------|
| | S0 | S1 | | |
| | L | L | H | No Change |
| | L | H | H | Shift Left |
| | H | L | H | Shift Right |
| | H | H | H | Parallel Load |
| X | X | X | L | Clear |

H=Logic High (5V) L=Logic Low (0V)

Table 7.1:- 74194 modes of operation

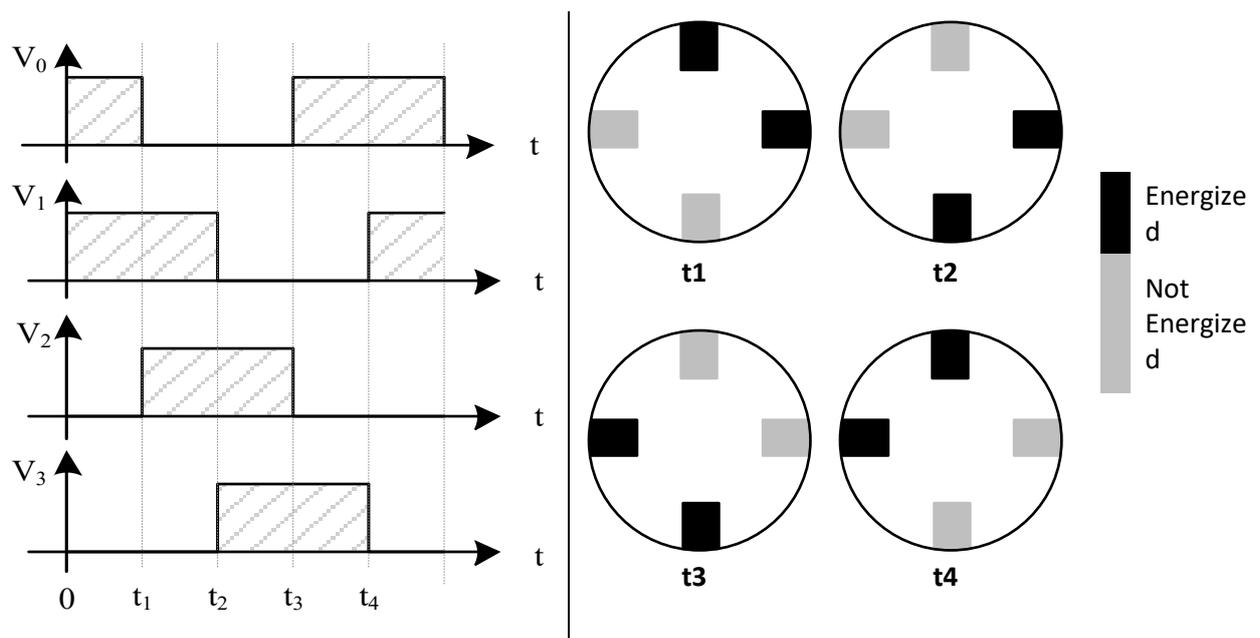


Figure 7.3:- Pulse to drive the motor at an angle of 45° and the rotor status at that time

(e)Report:

1. Draw the torque-displacement curves for the winding pattern of the stepper motor diagrammed in Fig.7.1.
2. What is Half, full and micro stepping? Which stepping technique we used in this experiment?
3. What is the purpose DSR and DSL?
4. Write down some advantage and disadvantage of using a stepper motor.
5. What is the purpose of MOSFET in the circuit? Why did we use ULN2003 instead?

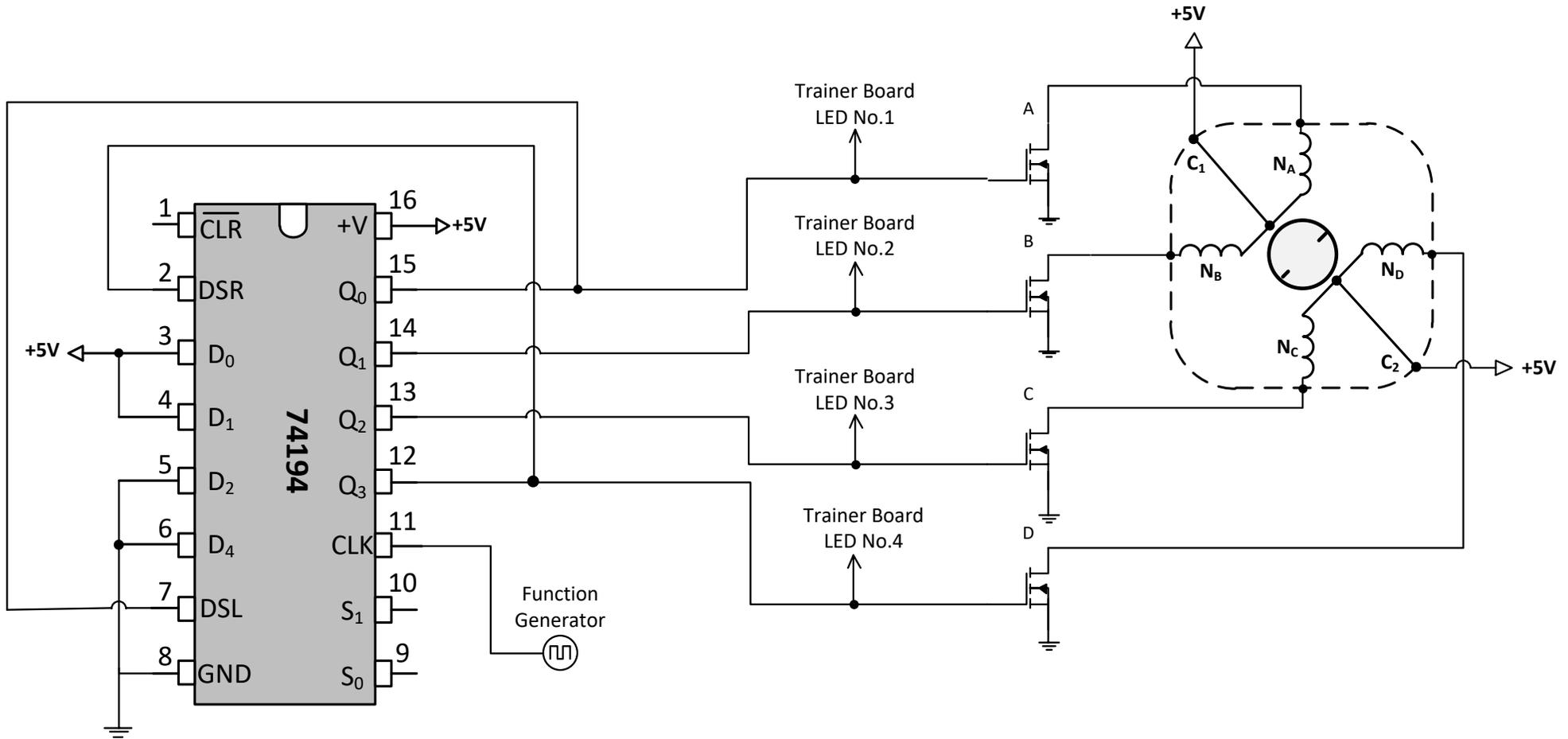


Figure 7.4:-Connection Diagram for the experiment

Experiment No : 8
Name of the Experiment: Three-Phase Full-Wave Full-Controlled Rectifier

(a)Objective

1. To understand the characteristics and operating principle of three-phase full-wave full-controlled rectifier.
2. To compare the advantages and disadvantages between three-phase full-wave semi-controlled rectifier and three-phase full-wave full-controlled rectifier.
3. To measure the voltage and current values of three-phase full-wave full-controlled rectifier with various triggering angles.
4. To verify the characteristics of three-phase full-wave full-controlled rectifier.

(b)Theory

The circuit construction of three-phase full-wave full-controlled rectifier is similar to that of three-phase full-wave diode rectifier. The only difference between the two is the six power diodes in three-phase full-wave diode rectifier are replaced by power thyristors. By varying the triggering angles of thyristors, the average output voltage of a three-phase rectifier can be varied. Compared with the single-phase full-wave controlled rectifier, three-phase full-wave full-controlled rectifier can provide smoother dc voltage and deliver higher power to the load. Compared with the three-phase full-wave semi-controlled rectifier, the three-phase full-wave full-controlled rectifier has smaller ripple component on output voltage (close to pure dc) and the polarity of output voltage is changeable; that is a two-quadrant converter

Fig. 8.1 illustrates the circuit and waveforms of three-phase full-wave full-controlled rectifier with a purely resistive load. This figure shows the three-phase source voltages in positive phase sequence; that is, V_B lags V_A by 120° , V_C leads V_A by 120° .

Similar to the three-phase full-wave semi-controlled rectifier, the triggering signal of thyristors in three-phase full-wave full-controlled rectifier must be continuous pulse.

When the triggering angle α of thyristors is equal to or less than $\pi/6$, this circuit performs the same function as the three-phase full-wave diode rectifier does; that is, the average output voltage cannot be varied. In normal operation, the triggering angle of the thyristors rectifier must be an angle between 30° and 180° . Moreover, since the three-phase full-wave full-controlled rectifier has six thyristors and two thyristors will conduct at a time, therefore the triggering signal of each thyristor must extend to $\pi/3$ (to overlay any two triggering signal by $\pi/3$); otherwise, only one thyristor can conduct at any instant so that no load current is generated.

As shown in Fig. 8.1(b), during the interval $\alpha \leq \omega t \leq \pi/3 + \alpha$, the voltage V_{AB} is maximum, thyristors Q1 and Q6 are triggered to conduct, so the rectified output voltage $V_0 = V_{AB}$. During the interval $\pi/3 + \alpha \leq \omega t \leq 2\pi/3 + \alpha$, the voltage V_{AC} is maximum, thyristors Q1 and Q2 are triggered to conduct, whereas the thyristor Q6 is reverse-biased and turned off, so the rectified output voltage $V_0 = V_{AC}$. During the $2\pi/3 + \alpha \leq \omega t \leq \pi + \alpha$ interval, the voltage V_{BC} is maximum, thyristors Q2 and Q3 are triggered to conduct, whereas the thyristor Q1 is reverse-biased and turned off, so the output voltage $V_0 = V_{BC}$ and so on. As discussion above, the conduction angle of every thyristor is 60° . From the waveform shown in Fig. 8.1 (b), we see that the ripple frequency of the three-phase full-controlled rectifier is 6 times the ac source frequency.

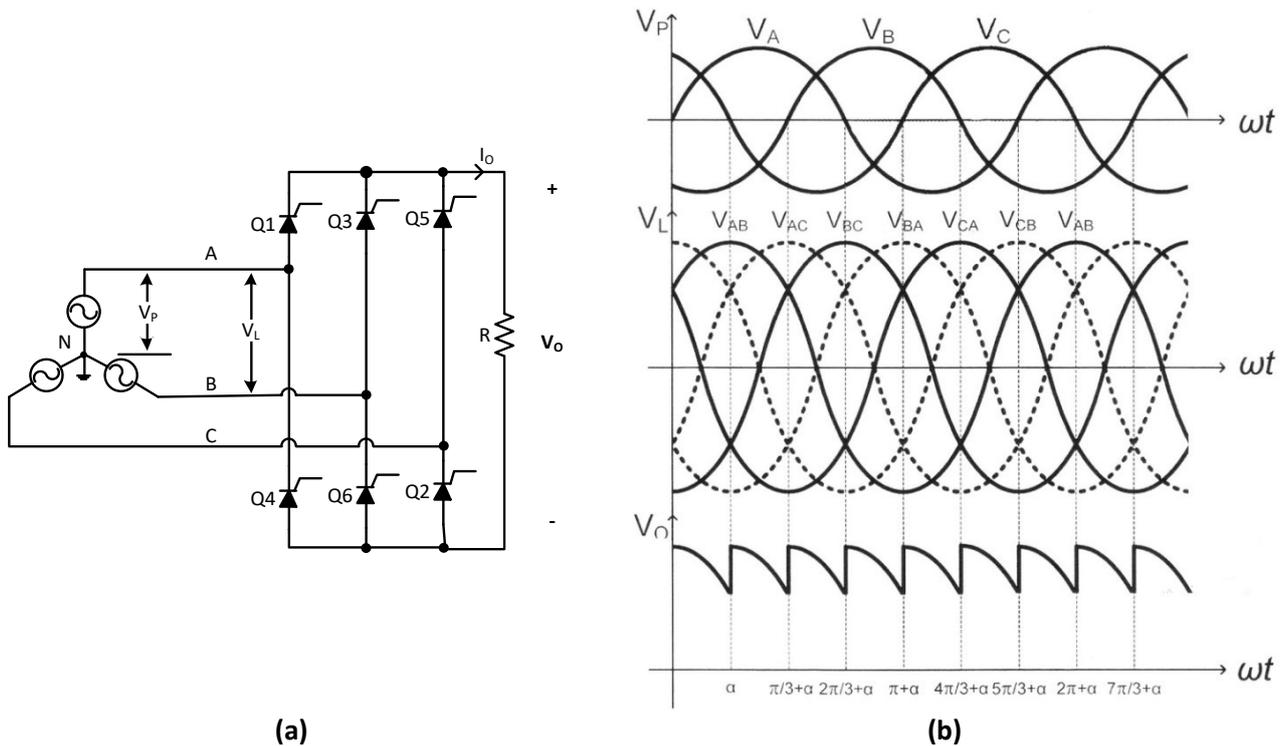


Figure 8.1: Circuit and waveforms of three-phase full-wave full-controlled rectifier with purely resistive load

By the definitions of symbols and abbreviations as previous experiments and the waveforms in Fig 8.1 (b), the average value and r.m.s. value of output voltage are expressed as:

$$V_{0(avg.)} = \frac{1}{2\pi} \int_{\alpha}^{\pi/3+\alpha} \sqrt{3}V_{P(max)} \sin\left(\omega t + \frac{\pi}{6}\right) d(\omega t) \dots\dots\dots(i)$$

$$V_{0(R.M.S.)} = \frac{1}{2\pi} \int_{\alpha}^{\pi/3+\alpha} \left[\sqrt{3}V_{P(max)} \sin\left(\omega t + \frac{\pi}{6}\right) \right]^2 d(\omega t) \dots\dots\dots(ii)$$

In Equations (i) and (ii), the integral waveform V_{AB} which leads V_A by $\pi/6$ (30°). When $\alpha=30^\circ$, $V_{0(avg.)}$ is equal to that of the three-phase full-wave diode rectifier. By varying various α values, $V_{0(avg.)}$ can be varied from $2.34V_{P(R.M.S.)}$ to $-2.34V_{P(R.M.S.)}$. That is, three-phase full-wave full-controlled rectifier is a two-quadrant converter and the polarity of average output voltage is changeable.

(c)Equipment required

- | | | |
|-----|-------------------------------------|----|
| 1. | Isolating Transformer | x1 |
| 2. | Fuse Set | x1 |
| 3. | Thyristor Set | x3 |
| 4. | Differential Amplifier | x1 |
| 5. | Resistor Load Unit | x1 |
| 6. | Inductive Load Unit | x1 |
| 7. | Current Transducer | x1 |
| 8. | DC Power Supply ($\pm 15V/2A$) | x1 |
| 9. | Reference Variable Generator | x1 |
| 10. | 3 Phase Angle Controller | x1 |
| 11. | Digital Storage Oscilloscope (DSO) | x1 |
| 12. | Connecting Wires and Bridging Plugs | |

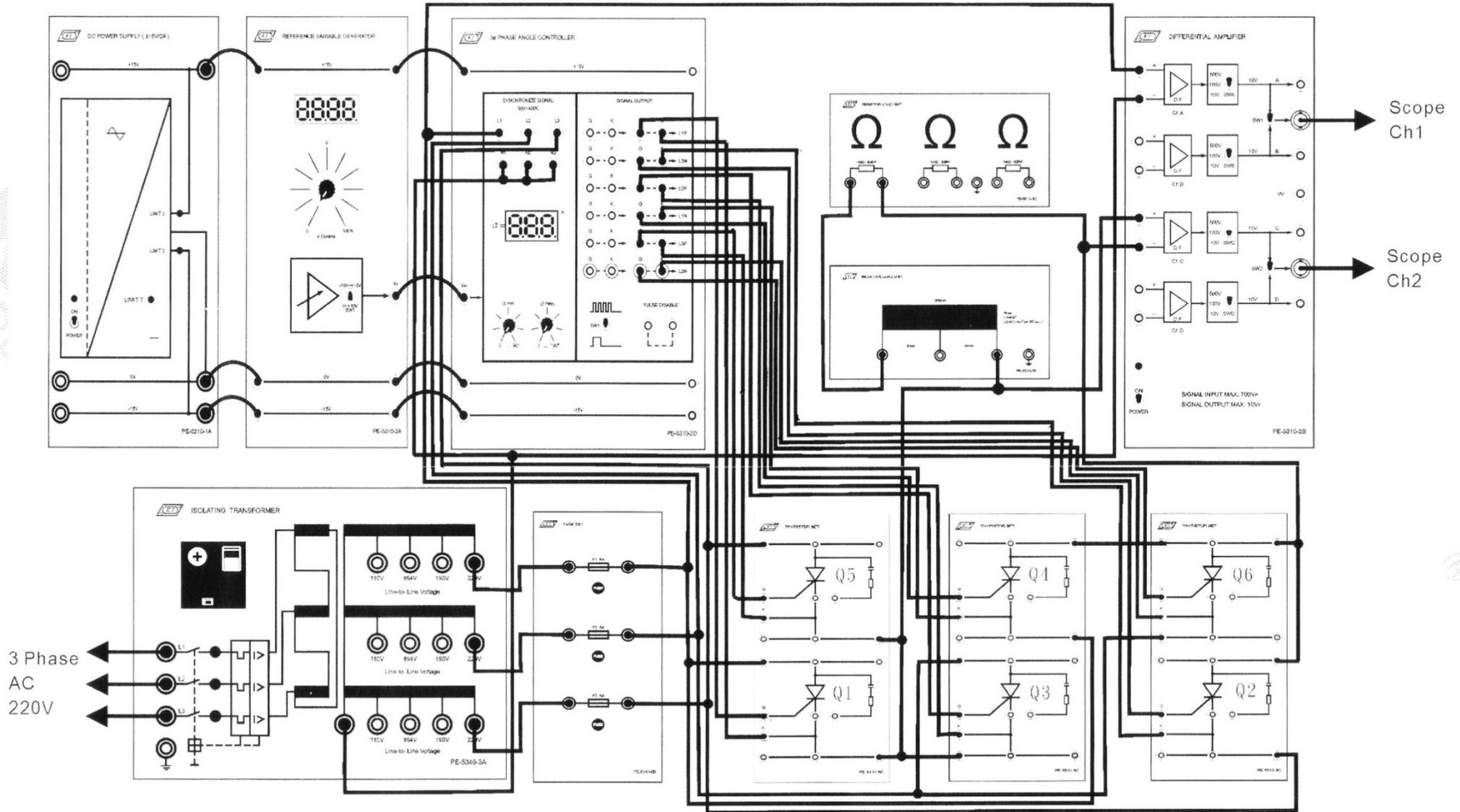


Figure 8.2: Wiring diagram for three-phase full-wave full-controlled rectifier

(d) Procedure

1. Complete the connections by referring to the wiring diagram in Fig. 8.2 using bridging plugs (curved lines) and connecting wires.
2. This rectifier operates from three-phase four-wire 220V (phase voltage = 127V) and the load circuit is a 100Ω resistor connected in series with a 200mH inductor. On Reference Variable Generator module, set the V_C Range selector switch to 0~+10V, and set the V control knob to 0%. On 3φ Phase Angle Controller module, select Pulse Train output, set $\alpha_{min}=30^\circ$ and $\alpha_{max}=180^\circ$. Therefore the triggering angle can be varied between 30° and 180° by turning the V control knob of Reference Variable Generator.
3. Short out the load inductor by placing a connecting wire directly across the inductor terminals. This forms a purely resistive load circuit. Set the V Range selector (SWA.SWC) switches of Differential Amplifiers Ch.A and Ch.C to 500V. Turn the V control knob of Reference Variable Generator to make $\alpha=60^\circ$. Using DSO, measure the phase voltage V_A (CH1) and load voltage (CH2) waveforms of the three-phase full-wave full-controlled rectifier in Fig. 8.3(a). Does the ripple frequency equal 6 times the frequency of input ac source? _____
4. Turn the V control knob of Reference Variable Generator to make $\alpha=90^\circ$. Using DSO, measure the phase voltage V_A (CH1) and the load voltage (CH2) waveforms of three-phase full-wave full-controlled rectifier in Fig. 8.3(b). Does the average output voltage decrease?

Note: With purely resistive load, the output current and output voltage are the same waveform.

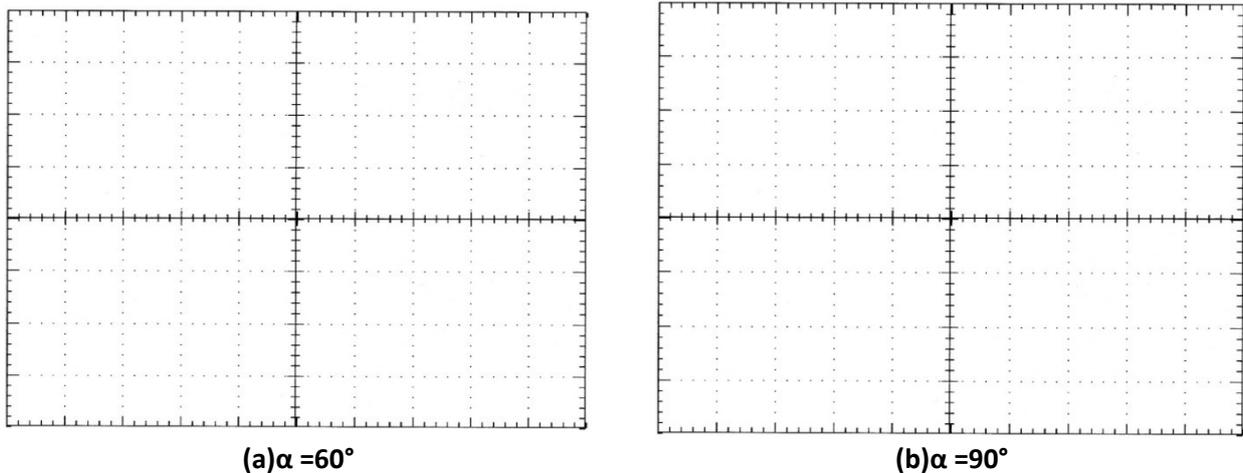


Figure 8.3: Measured phase voltage V_A (CH1) and load voltage (CH2) waveforms of three-phase full-wave full-controlled rectifier with purely resistive load

5. Recover the load inductor by removing the connecting wire from inductor terminals. This modifies the purely resistive load to an inductive load. Remain the settings of triggering angles in Step 4 unchanged. Modify the connections of Fig. 8.2 to measure the phase voltage V_A (CH1) and the load current (CH2) via Current Transducer, and record the results in Fig. 8.4. Comparing with the result of Fig. 8.3(b), does the rectifier with inductive load have more continuous load current than the rectifier with purely resistive load?

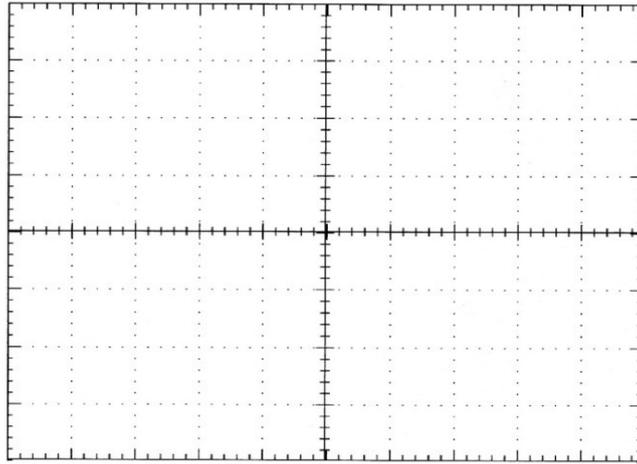


Figure 8.4: Measured phase voltage V_A (CH1) and load current (CH2) waveforms of three-phase full-wave full-controlled rectifier with inductive load ($\alpha = 90^\circ$)

(e) Report:

1. Attach all the waveform obtained during the experiment. Does the output support theory?

Simulation of three phase Full wave controlled and uncontrolled rectifier

(a)Objective:

1. Observe output wave shape of Three Phase Full wave Bridge Rectifier
2. Observe output wave shape of Three Phase Full Wave Full Converter
3. Design three phase full wave converter triggering pulse

(b)Procedure

Three Phase Full wave Bridge Rectifier:

1. Using Orcad PSPICE construct the circuit shown in Fig 1.

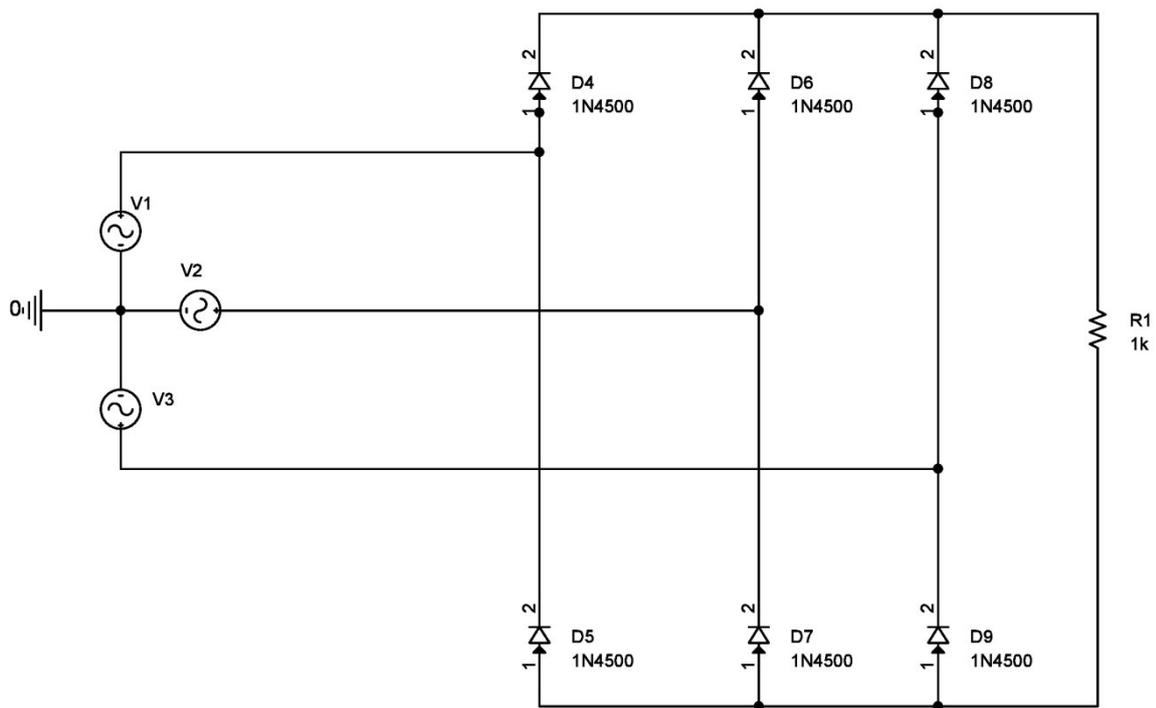


Fig 1: Three Phase Full wave Bridge Rectifier circuit

2. Use VSIN as a source with the following setting :-

| | V1 | V2 | V3 | Unit |
|------------------|----|-----|-----|-------|
| VAMPL | 12 | 12 | 12 | Volts |
| VOFF | 0 | 0 | 0 | Volts |
| PHASE | 0 | 120 | 240 | Deg |
| Frequency | 50 | 50 | 50 | Hz |

3. Use the 1N4500 diode from 'Diode' library.
4. Simulate the circuit for 20ms and observe output wave shape across the 1KΩ resistor.

Three Phase Full Wave Full Converter:

- Using Orcad PSPICE construct the circuit shown in Fig 2

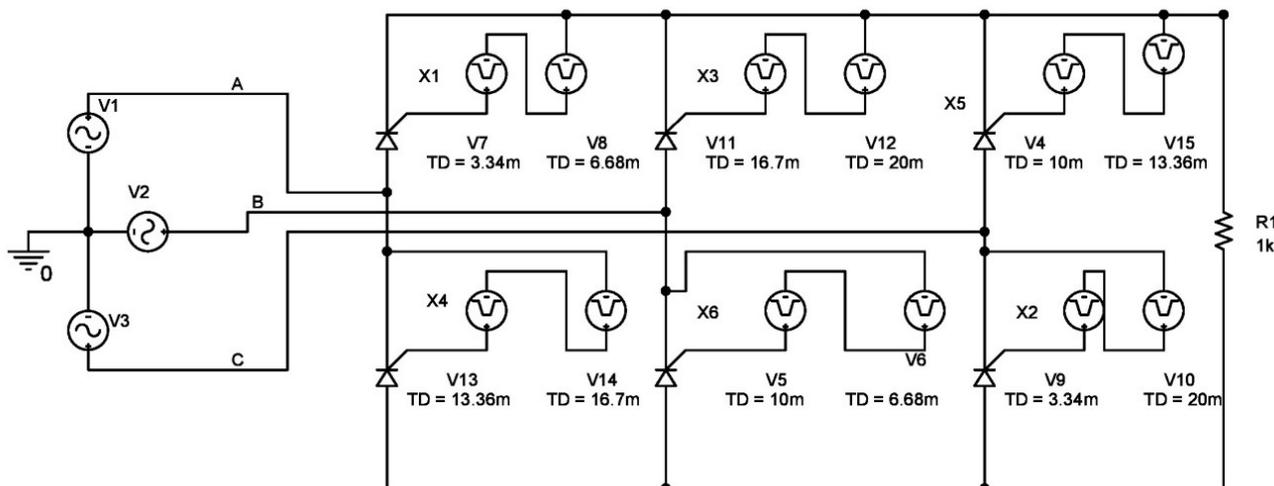


Figure 2: Three Phase Full Wave Full Converter circuit

- Use VSIN as a source with the same setting as diode rectifier circuit.
- Use the 2N1595 thyristor from 'THYRISTR' library.
- To generate the gate pulse of each thyristor use two VPULSE source in series as shown in fig-2.
- Simulate the circuit for 21ms and observe output wave shape across the 1KΩ resistor

(c)Example

- In the following example a triggering angle of 30° is used with a resistive load
- After 30 deg (1.67ms) the thyristors are triggered in 12, 16, 56, 54, 34, 32 sequence (see fig-2 and 3)
- For example the 1st two sequence (12,16) VPULSE settings for thyristor X1,X2 and X6 are as follows (for $\alpha=30^\circ$)

| | X1 | | X2 | | X6 | | Unit | Comment |
|-----|-------|-------|-------|-------|-----|-------|-------|---------------------|
| | V7 | V8 | V9 | V10 | V5 | V6 | | |
| TD | 3.34m | 6.68m | 3.34m | 3.34m | 10m | 6.68m | Sec | Time Delay |
| TF | 1u | | | | | | Sec | Fall time |
| TR | 1u | | | | | | sec | Rise time |
| V1 | 0 | | | | | | Volts | 1st level |
| V2 | 5 | | | | | | Volts | 2nd level |
| PW | 1m | | | | | | sec | Pulse width |
| PER | 20m | | | | | | sec | Period of the pulse |

(d)Report:

- Simulate the circuit of fig-1 and attach the output wave shape across the resistor
- Simulate the circuit of fig-2 for $\alpha=15^\circ$ and $\alpha=45^\circ$ and attach the output wave shape across the resistor

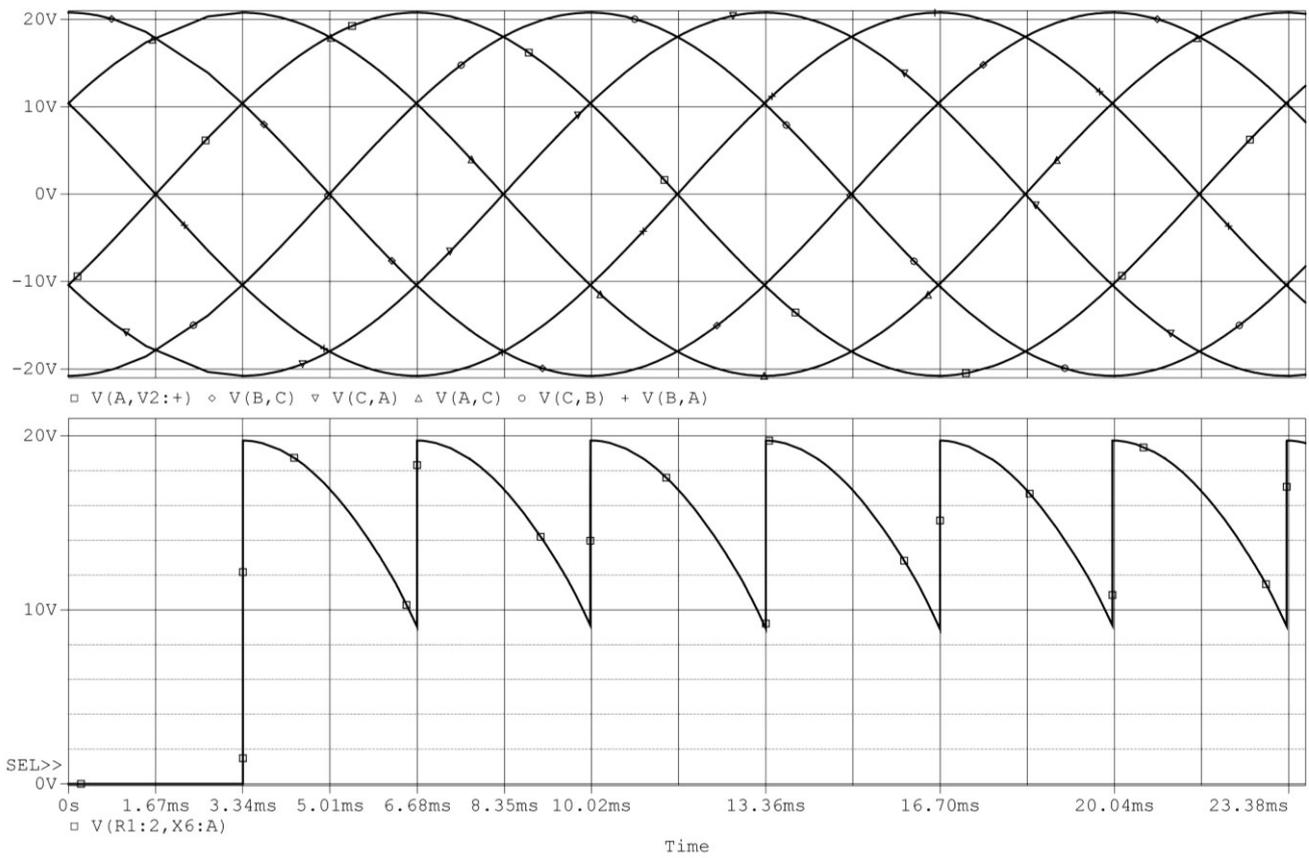


Figure 3: Input and output wave form of circuit (for $\alpha=30^\circ$)

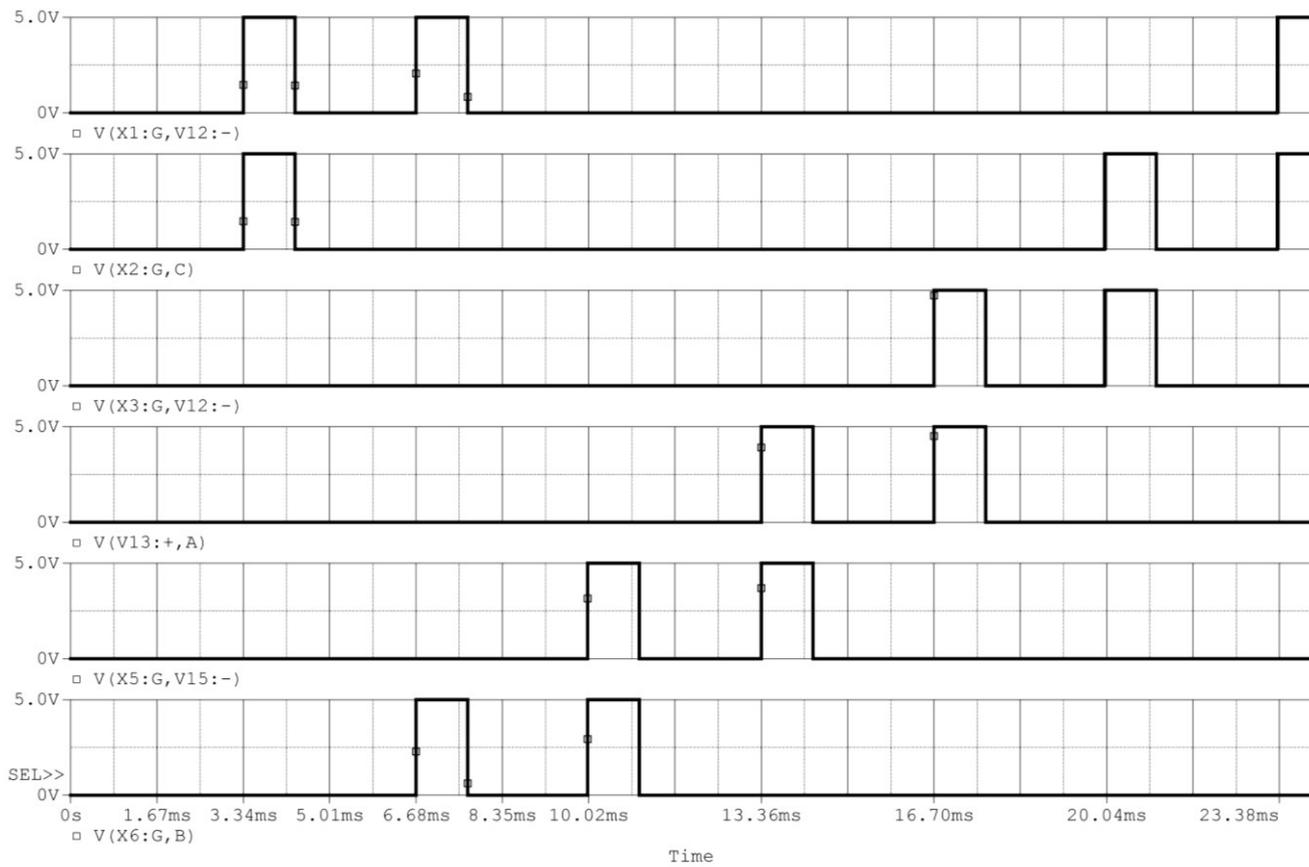


Figure 4:- Row 1-6: Triggering pulse of X1-X6 (for $\alpha=30^\circ$)

Data Sheet

TL 494 Application Information

Description

The TL494 is a fixed-frequency pulse width modulation control circuit, incorporating the primary building blocks required for the control of a switching power supply. (See Figure 1.) An internal-linear sawtooth oscillator is frequency-programmable by two external components, RT and CT. The approximate oscillator frequency is determined by:

$$f_{osc} \approx \frac{1.1}{R_T C_T}$$

For more information refer to Figure 3. Output pulse width modulation is accomplished by comparison of the positive sawtooth waveform across capacitor CT to either of two control signals. The NOR gates, which drive output transistors Q1 and Q2, are enabled only when the flip-flop clock-input line is in its low state. This happens only during that portion of time when the sawtooth voltage is greater than the control signals. Therefore, an increase in control-signal amplitude causes a corresponding linear decrease of output pulse width. (Refer to the Timing Diagram shown in Figure 2.) The control signals are external inputs that can be fed into the deadtime control, the error amplifier inputs, or the feedback input. The deadtime control comparator has an effective 120 mV input offset which limits the minimum output deadtime to approximately the first 4% of the sawtooth-cycle time. This would result in a maximum duty cycle on a given output of 96% with the output control grounded, and 48% with it connected to the reference line. Additional deadtime may be imposed on the output by setting the deadtime-control input to a fixed voltage, ranging between 0 V to 3.3 V.

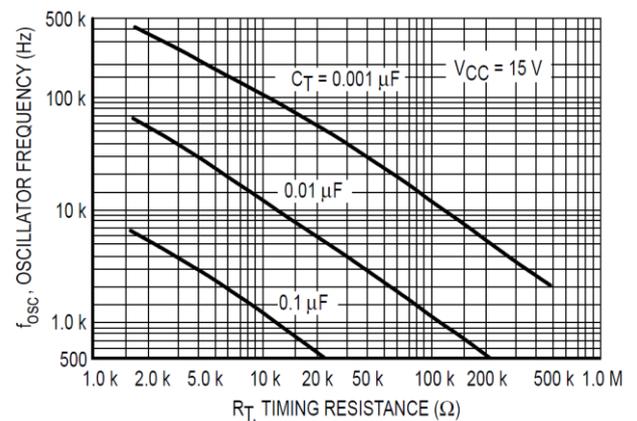
comparator. With this configuration, the amplifier that demands minimum output on time, dominates control of the loop. When capacitor CT is discharged, a positive pulse is generated on the output of the deadtime comparator, which clocks the pulse-steering flip-flop and inhibits the output transistors, Q1 and Q2. With the output-control connected to the reference line, the pulse-steering flip-flop directs the modulated pulses to each of the two output transistors alternately for push-pull operation. The output frequency is equal to half that of the oscillator. Output drive can also be taken from Q1 or Q2, when single-ended operation with a maximum on-time of less than 50% is required. This is desirable when the output transformer has a ringback winding with a catch diode used for snubbing. When higher output-drive currents are required for single-ended operation, Q1 and Q2 may be connected in parallel, and the output-mode pin must be tied to ground to disable the flip-flop. The output frequency will now be equal to that of the oscillator. The TL494 has an internal 5.0 V reference capable of sourcing up to 10 mA of load current for external bias circuits. The reference has an internal accuracy of ±5.0% with a typical thermal drift of less than 50 mV over an operating temperature range of 0° to 70°C.

Functional Table

| Input/Output | Output Function | $\frac{f_{out}}{f_{osc}} =$ |
|--------------|------------------------------|-----------------------------|
| Controls | | f_{osc} |
| Grounded | Single-ended PWM @ Q1 and Q2 | 1.0 |
| @ Vref | Push-pull Operation | 0.5 |

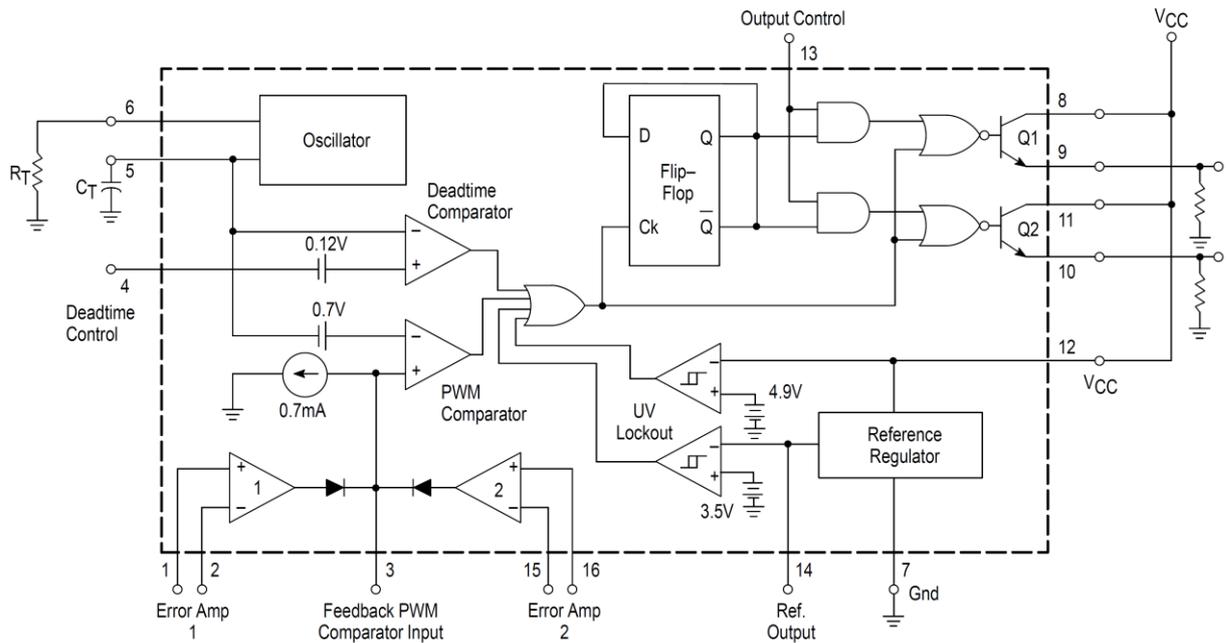
The pulse width modulator comparator provides a means for the error amplifiers to adjust the output pulse width from the maximum percent on-time, established by the deadtime control input, down to zero, as the voltage at the feedback pin varies from 0.5 V to 3.5 V. Both error amplifiers have a common mode input range from -0.3 V to (VCC - 2V), and may be used to sense power-supply output voltage and current. The error-amplifier outputs are active high and are ORed together at the noninverting input of the pulse-width modulator

Figure 3. Oscillator Frequency versus Timing Resistance



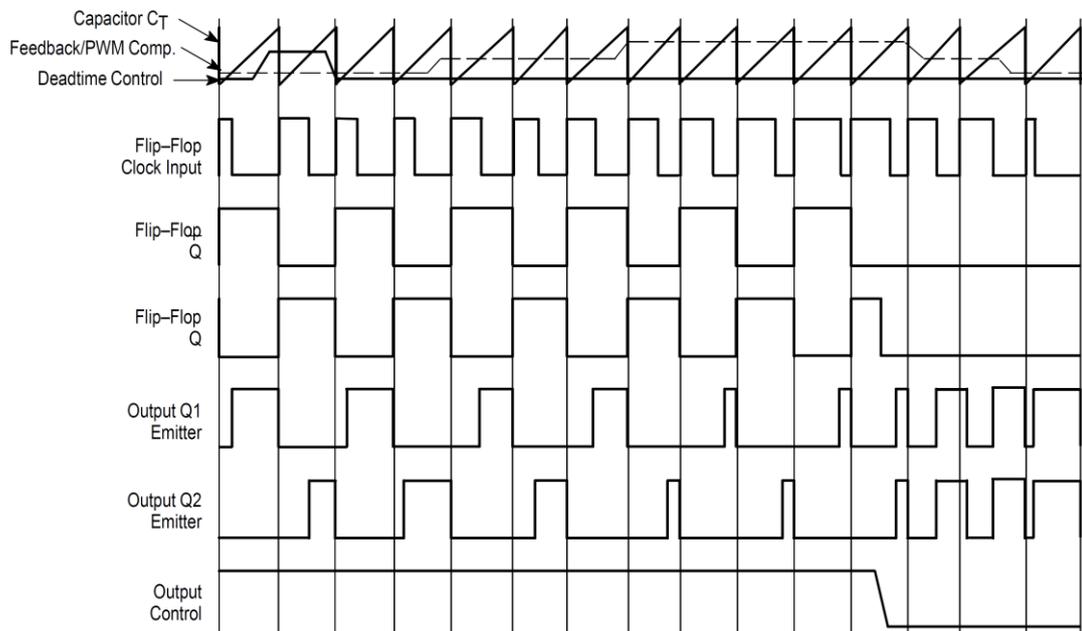
TL494

Figure 1. Representative Block Diagram



This device contains 46 active transistors.

Figure 2. Timing Diagram





ULN2003V12

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Unipolar Stepper Motor Driver

Figure 7 shows an implementation of ULN2003V12 for driving a unipolar stepper motor. The unconnected input channels can be used for other functions. When an input pin is left open the internal 300kΩ pull down resistor pulls the respective input pin to GND potential. For higher noise immunity use an external short across an unconnected input and GND pins.

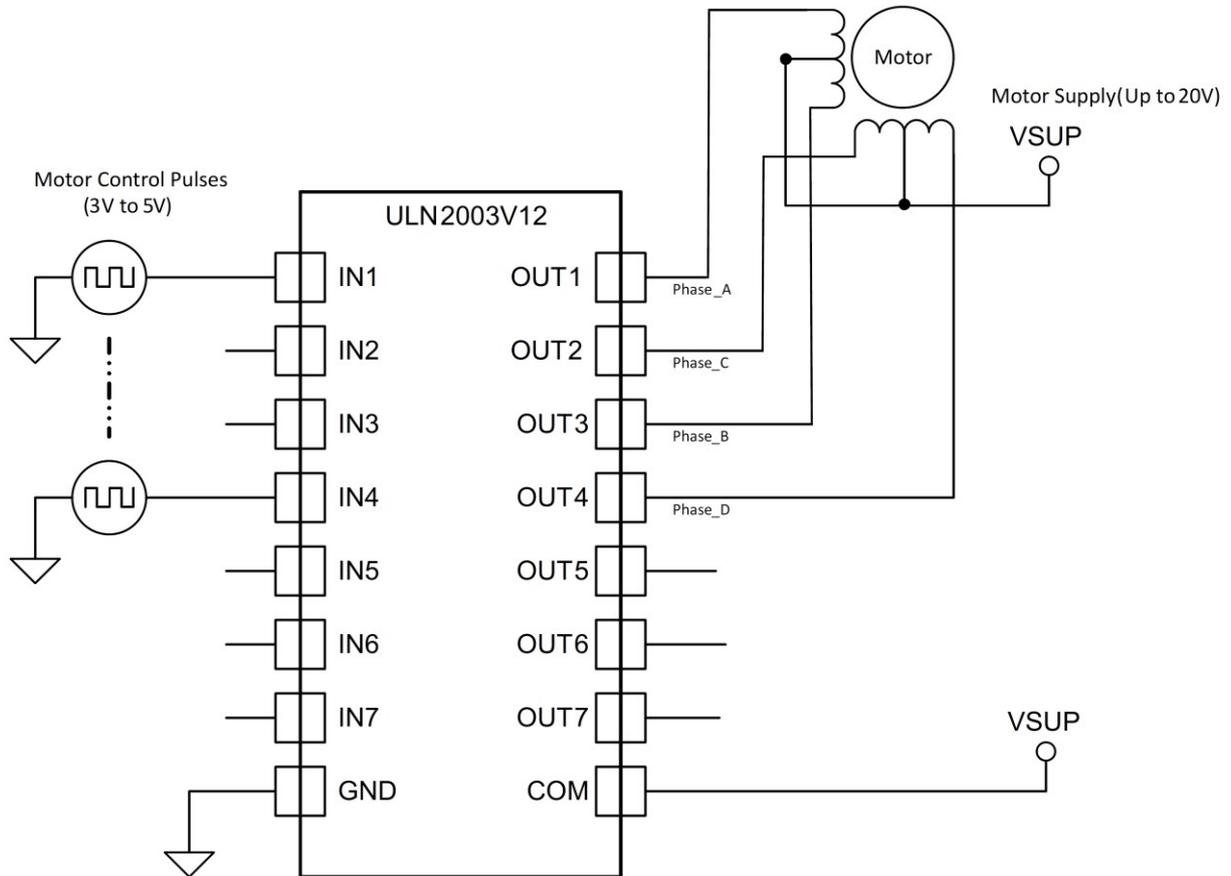


Figure 7. ULN2003V12 as a Stepper Motor Driver

Reference and Acknowledgment

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