INSTITUTE OF AERONAUTICAL ENGINEERING
(Autonomous)
Dundigal, Hyderabad - 500 043

Lab Manual:

Power Electronics Laboratory (AEEB21)

Prepared by

S. Srikanth(IARE10196)

Department Of Electrical and Electronics Engineering
Institute of Aeronautical Engineering

April 6, 2022

Contents

INTRODUCTION

Introduction

This course is intended for practical experience by conduction experiments on rectifiers, inverters, choppers, AC voltage controllers and cycloconverters. It provides hands-on experience by examining the electrical characteristics of various power converters. The power electronic converter applications have been analyzed with simulation tools.

Student Responsibilities

The student is expected to be prepared for each lab. Lab preparation includes reading the lab experiment from the lab manual. If you have questions or problems with the preparation, contact your Lab Assistant and faculty incharge but in a timely manner. Do not wait until an hour or two before the lab and then expect the Lab Assistant and faculty incharge to be immediately available.

Active participation by each student in lab activities is expected. The student is expected to ask the Lab Assistant and faculty incharge any questions they may have.

A large portion of the student's grade is determined in the comprehensive final exam, resulting in a requirement of understanding the concepts and procedure of each lab experiment for the successful completion of the lab session. The student should remain alert and use common sense while performing a lab experiment. They are also responsible for keeping a professional and accurate record of the lab experiments in the lab manual wherever tables are provided. Students should report any errors in the lab manual to the Faculty incharge or course coordinator.

Responsibilities of Faculty Teaching the Lab Course

The Lab Assistant shall be completely familiar with each lab prior to class. The Lab Assistant shall provide the students with a syllabus and safety review during the first class. The syllabus shall include the Lab Assistant office hours, telephone number, and the name of the faculty coordinator. The Lab Assistant is responsible for ensuring that all the necessary equipment and/or preparations for the lab are available and in working condition. Lab experiments should be checked in advance to make sure everything is in working order. The Lab Assistant should fully answer any questions posed by the students and supervise the students performing the lab experiments. The Lab Assistant is expected to grade the lab notebooks and reports in a fair and timely manner. The reports should be returned to the students in the next lab period following submission. The Lab Assistant should report any errors in the lab manual to the faculty coordinator.

Laboratory In-charge Responsibilities

The faculty coordinator should ensure that the laboratory is properly equipped, i.e., that the teaching assistants receive any equipment necessary to perform the experiments. The coordinator is responsible for supervising the Lab Assistant and resolving any questions or problems that are identified by the Lab Assistant or the students. The coordinator may supervise the format of the final exam for the lab. They are also responsible for making any necessary corrections to this manual and ensuring that it is continually updated and available.

Course Coordinator Responsibilities

The course coordinator is responsible fo rmaking any necessary corrections in Course Description and lab manual. He/She has to ensure that it is continually updated and available to the students in the CMS learning Portal.

Lab Policy and Grading

The student should understand the following policy:

ATTENDANCE: Attendance is mandatory as per the academic regulations.

LAB RECORD's: The student must:

1. Write the work sheets for the allotted experiment and keep them ready before the beginning of eachlab.
2. Keep all work in preparation of and obtained during lab.
3. Perform the experiment and record the observations in the worksheets.
4. Analyze the resultsand get the work sheets evaluated by the Faculty.
5. Upload the evaluated reports online from CMS LOGIN within the stipulated time.

Grading Policy:

The final grade of this course is awarded using the criterion detailed in the academic regulations. A large portion of the student's grade is determined in the comprehensive final exam of the Laboratory course (SEE PRACTICALS),resulting in a requirement of understanding the concepts and procedure of each lab experiment for successful completion of the lab course.

Pre-Requistes and Co-Requisties:

The lab course is to be taken during the same semester as AEEB21, but receives a separate grade.

Course Goals and Objectives

The Power Electronics Laboratory course is designed as a core laboratory to provide the student with the knowledge to understand the basic concepts in power electronics which have lot of applications in the field of Electrical and Electronics EngineeringEngineering.

The experiments are designed to complement the concepts introduced in AEEB20. In addition, the student should learn how to record experimental results effectively and present these results in a written report.

More explicitly, the class objectives are:

1. To gain proficiency in the use of common measuring instruments.
2. To enhance understanding of power electronics converters

- Operation of Single phase rectifier
- Operation of Three phase rectifier
- Opreration of Chppers
- Operation of inverters
- Operation of cycloconverter
- Operation of AC voltage controller

3. To develop communication skills through:
    - Verbal interchanges with the Faculty and other students.
    - Preparation of succinct but complete laboratory reports.
    - Maintenance of laboratory worksheets aspermanent, written descriptions of procedures, analysis and results.
4. To compare theoretical predictions with experimental results and to determine the source of any apparent errors.

Use of Laboratory Instruments

One of the major goals of this lab is to familiarize the student with the proper equipment andtechniques for conducting experiments. Some understanding of the lab instruments is necessaryto avoid personal or equipment damage.By understanding the device's purpose and following a fewsimple rules, costly mistakes can be avoided.

The following rules provide a guideline for instrument protection.

Instrument Protection Rules

Data Recording and Reports

The Laboratory Worksheets

The Laboratory Files/Reports

LAB-1 Orientation

1.1 Introduction

In the first lab period, the students should become familiar with the location of equipment and components in the lab, the course requirements, and the teaching instructor.

1.2 Objective

To familiarize the students with the lab facilities, equipment, standard operating procedures, lab safety, and the course requirements

1.3 Prelab Preparation:

Read the Introduction and procedure of the experiment of respective experiments which are given this manual.

1.4 Equipment needed

1. Lab manual

1.5 Procedure

1. During the first laboratory period, the instructor will provide the students with a general idea of what is expected from them in this course. Each student will receive a copy of the syllabus, stating the instructor's contact information. In addition, the instructor will review the safety concepts of the course.
2. During this period, the instructor will briefly review the equipment which will be used throughout the semester. The location of instruments, equipment, and components will be indicated. The guidelines for instrument use will be reviewed.

1.6 Probing Further Questions

Questions pertaining to this lab must be answered at the end of laboratory report.

LAB-2 SCR, MOSFET and IGBT

2.1 Introduction

The Silicon Controlled Rectifier (SCR) is the most important and mostly used member of the thyristor family. SCR can be used for different applications like rectification, regulation of power and inversion, etc. Like a diode, SCR is a unidirectional device that allows the current in one direction and opposes in another direction. MOSFET is a type of FET that is a unipolar device i.e. single charge carriers are responsible for the conduction between source and drain. Voltage applied at the gate side is used to control the current flowing through conducting channel between source and drain. An insulated-gate bipolar transistor (IGBT) is a three-terminal power semiconductor device primarily used as an electronic switch, which, as it was developed, came to combine high efficiency and fast switching. It consists of four alternating layers (P–N–P–N) that are controlled by a metal–oxide–semiconductor (MOS) gate structure. In this session, operation of SCR, MOSFET and IGBT are presented.

2.2 Objective

By the end of this lab, the student should learn the operation of SCR, MOSFET and IGBT

2.3 Prelab Preparation:

Read the material in the textbook that describes operation of SCR, MOSFET and IGBT. Prior to coming to lab class, have glance of the Procedure.

2.4 Equipment needed

1. SCR characteristics Trainer
2. MOSFET characteristics Trainer
3. IGBT characteristics Trainer
4. Patch chords
5. DC Voltmeter(0-30V)
6. DC Ammeter(0-2A)

2.5 Background

SCR is a three terminal device; anode, cathode and gate as shown in figure. SCR has built in feature to turn ON or OFF and its switching is controlled by biasing conditions and gate input terminal. MOSFET is a voltage controlled device unlike BJT which are current controlled device. Practically gate of the MOSFET draws no current. However, small amount of initial current is needed to charge the capacitance of the gate terminal. the structure of the IGBT is topologically the same as a thyristor with a "MOS" gate (MOS-gate thyristor), the thyristor action is completely suppressed, and only the transistor action is permitted in the entire device operation range. It is used in switching power supplies in high-power applications: variable-frequency drives (VFDs), electric cars, trains, variable-speed refrigerators, lamp ballasts, arc-welding machines, and air conditioners.

2.6 Procedure

i. Operation of SCR

1. Make the connections as per the circuit diagram.

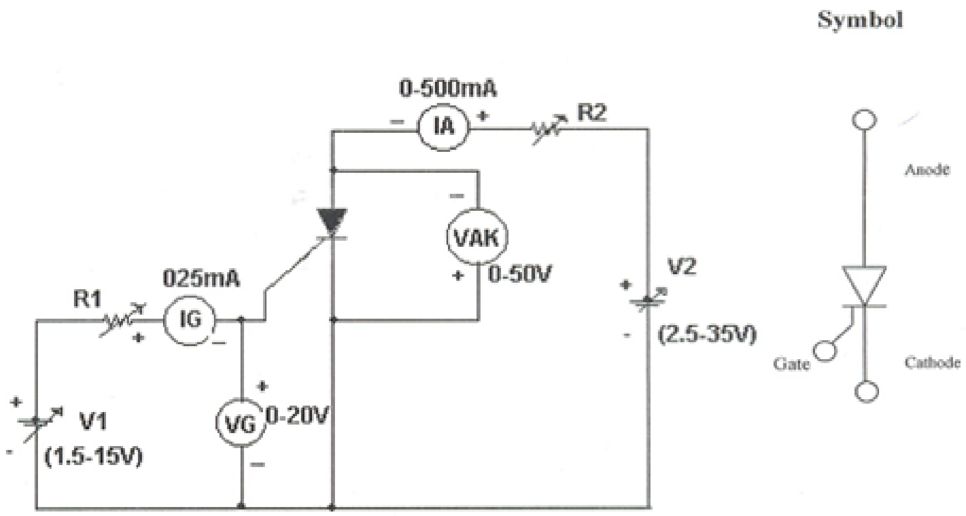

Figure 2.1 Operation of SCR

2. Initially keep V1 and V2 at minimum position and R1 and R2 maximum position.
3. Adjust Gate current Ig to some constant by varying the V1 or R1.
4. Now slowly vary V2 and observe Anode to Cathode voltage VAK and Anode current IA.
5.Tabulate the readings of Anode to Cathode voltage VAK and Anode current IA.
6.Repeat the above procedure for different Gate current Ig.

S. No	I_G= A	
	V_{AK} (Volts)	I_A (Amps)
1		
2		
3		
4		
5		

S. No	I_G= A	
	V_{AK} (Volts)	I_A (Amps)
1		
2		
3		
4		
5		

Table 2.1 SCR Operation Measured Values

GATE TRIGGRING AND FINDING VG AND IG:

1. Keep all positions at minimum.

2. Set Anode to Cathode voltage VAK to some volts say 15V.
3. Now slowly vary the V1 voltage till the SCR triggers and note down the reading of gate current(IG) and Gate Cathode voltage(VGK) and rise of anode current IA.
4. Repeat the same for different Anode to Cathode voltage and find VAK and IG values.

S. No	V_{AK} = (Volts)			S. No	V_{AK} = (Volts)	
	V_{GK} = V	I_G= A			V_{GK} = V	I_G= A
1				1		
2				2		
3				3		
4				4		
5				5		

Table 2.2 Measured Values for gate triggering

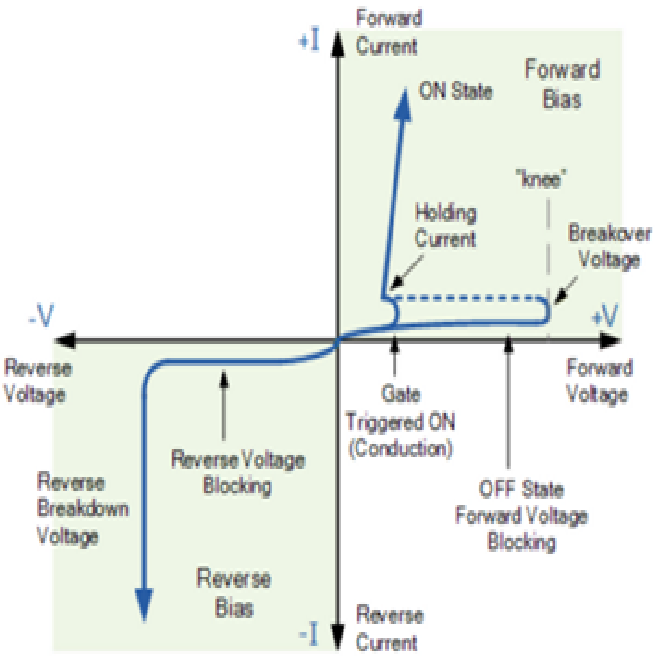

Figure 2.2 Characteristics of SCR

ii. Operation of MOSFET

TRANSFER CHARACTERISTICS:

1. Make the connections as per the circuit diagram.

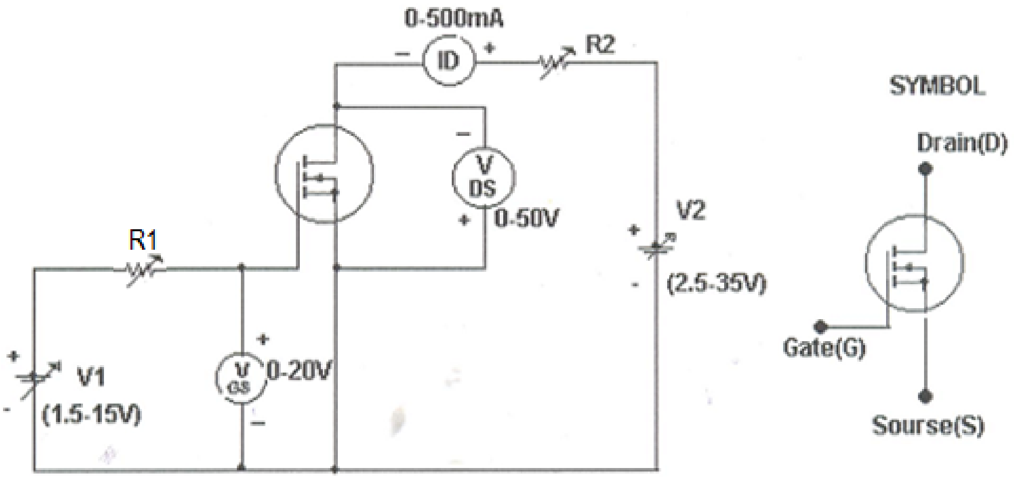

Figure 2.3 Operation of MOSFET

2. Initially keep V1 and V2 at minimum position and R1 and R2 middle position.
3. Set VDS to some say 10V.
4. Slowly vary Gate source voltage VGS by varying V1.
5. Note down ID and VGS readings for each step.
6. Repeat above procedure for 20V and 30V of VDS. Draw Graph between ID and VGS.

S. No.	V_{GS} = V	
	V_{DS} (Volts)	I_D (Amps)
1		
2		
3		
4		

S. No	V_{GS} = V	
	V_{DS} (Volts)	I_D (Amps)
1		
2		
3		
4		

Table 2.3 Measured Values for Transfer characteristics

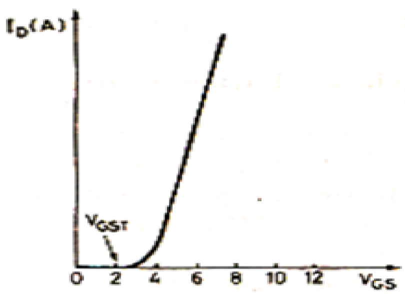

Figure 2.6 Transfer characteristics of MOSFET

OUTPUT CHARACTERISTICS:

1. Initially set VGS to some value say 3V by varying V1.
2. Slowly vary V2 and note down ID and VDS.
3. At particular value of VGS there a pinch off voltage between drain and source.

If VDS¡ VP device works in the constant resistance region and IO is directly proportional to VDS. If VDS¿VP device works in the constant current region.

4. Repeat above procedure for different values of VGS and draw graph between IDVSVDS.

S. No	V_{DS}= (Volts)	
	V_{GS} (V)	I_D(A)
1		
2		
3		
4		
5		

S. No	V_{DS} = (Volts)	
	V_{GS} (V)	I_D(A)
1		
2		
3		
4		
5		

Table 2.4 Measured Values for output characteristics

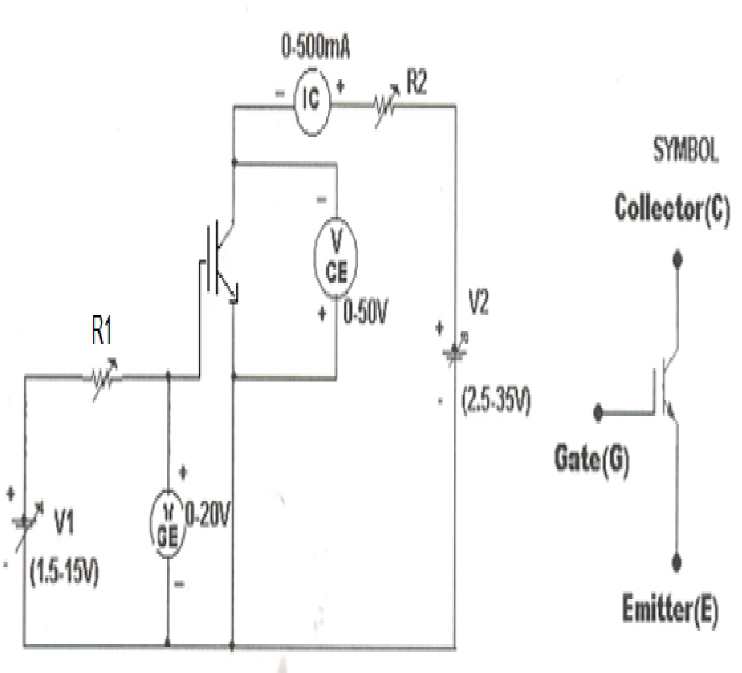

Figure 2.5 OUTPUT Characteristics of MOSFET

iii. Operation of IGBT

TRANSFER CHARACTERISTICS:

1. Make the connections as per the circuit diagram.

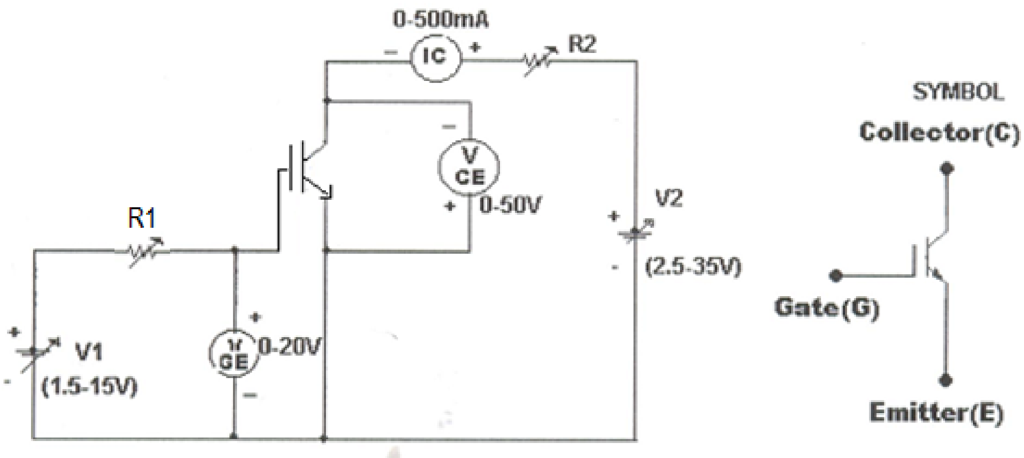

Figure 2.6 Operation of IGBT

2. Initially keep V1 and V2 at minimum position and R1 and R2 middle position.
3. Set VCE to some say 10V.
4. Slowly vary Gate Emitter voltage VGE by varying V1.
5. Note down IC and VGE readings for each step.
6. Repeat above procedure for 20V and 25V of VDS. Draw Graph between ID and VGS.

S. No	V_{CE} = V	
	V_{GE} (Volts)	I_C (Amps)
1		
2		
3		
4		
5		

S. No	V_{CE} =V	
	V_{GE} (Volts)	I_C (Amps)
1		
2		
3		
4		
5		

Table 2.5 Measured Values for Transfer characteristics

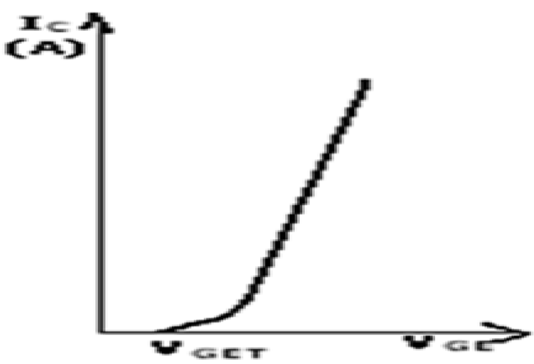

Figure 2.6 Transfer characteristics of IGBT

OUTPUT CHARACTERISTICS:

1. Initially set VGE to some value say 5V by varying V1.
2. Slowly vary V2 and note down IC and VCE readings.
3. At particular value of VGS there a pinch off voltage VP between Collector and Emitter.

If VCE¡ VP device works in the constant resistance region and IC is directly proportional to VCE. If VCE¿VP device works in the constant current region.
4. Repeat above procedure for different values of VGE and draw graph between IC VS VGE.

S. No	V_{GE}= (Volts)		S. No	V_{GE} = (Volts)	
	V_{CE} (V)	I_C(A)		V_{CE} (V)	I_C(A)
1			1		
2			2		
3			3		
4			4		
5			5		

Table 2.6 Measured Values for output characteristics

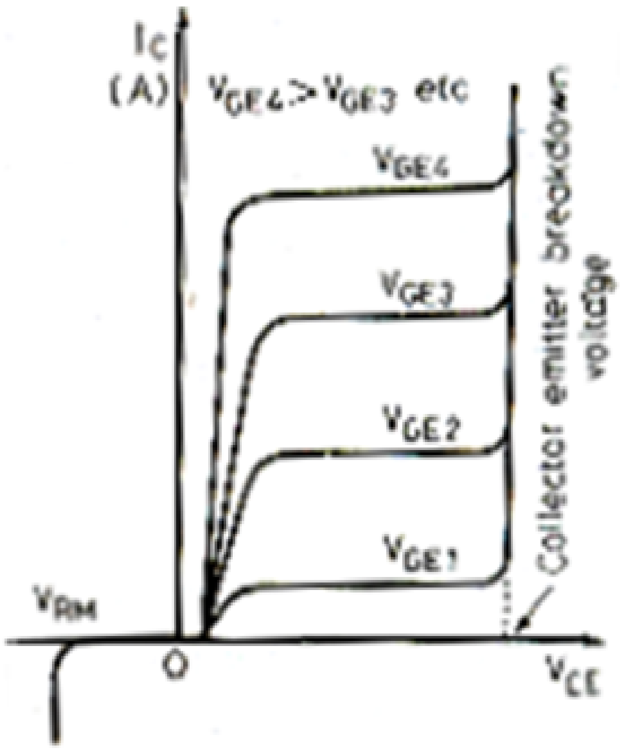

Figure 2.7 OUTPUT Characteristics of MOSFET

2.7 Probing Further Questions

Q1. Differentiate between holding and latching currents.
Q2. List the applications of SCR
Q3. Draw the structure of MOSFET
Q4. In which region does the MOSFET used as a switch
Q5. What is second breakdown phenomenon?
Q6. What is switching speed of IGBT?

LAB-3 Gate firing circuits for SCRS

3.1 Introduction

Gate triggering is the most efficient and reliable method. Most of the control applications use this type of triggering because the desired instant of SCR turning is possible with gate triggering method. In this session RC and UJT triggering methods are presented.

3.2 Objective

By the end of this lab, the student should learn the operation of RC and UJT triggering methods

3.3 Prelab Preparation:

Read the material in the textbook that describes operation of gate firing circuit for SCRs. Prior to coming to lab class, have glance of the Procedure.

3.4 Equipment needed

1. Resistance-Capacitance Firing Circuit
2. UJT Firing Circuit
3. Patch chords and Probes
4. CRO with differential module
5. R-Load

3.5 Background

Gate triggering: This form of SCR triggering is the one that is most commonly seen in the different circuits used. It is simple, reliable, efficient and also easy to implement for most applications a simple trigger signal can be applied, with suitable processing if required. This means that other electronic circuits can be used to derive a suitable trigger signal and this can then be applied to the SCR.

For gate SCR triggering to be used, the SCR must operate below its breakdown voltage, and a suitable safety margin also allowed accommodating any transients that may occur. Otherwise forward voltage or breakdown triggering may occur.

To turn-on of an SCR, a positive gate voltage between gate and cathode. This gives rise to a gate current where charges are injected into the inner p layer of the device. This effectively reduces the voltage at which forward break-over occurs. It can be gathered that the gate current determines the forward voltage at which the device switches to its conducting state. Higher the gate current, the lower the forward break-over voltage.

3.6 Procedure

i. R-C TRIGGERING

1. Make all connections as per the circuit diagram.

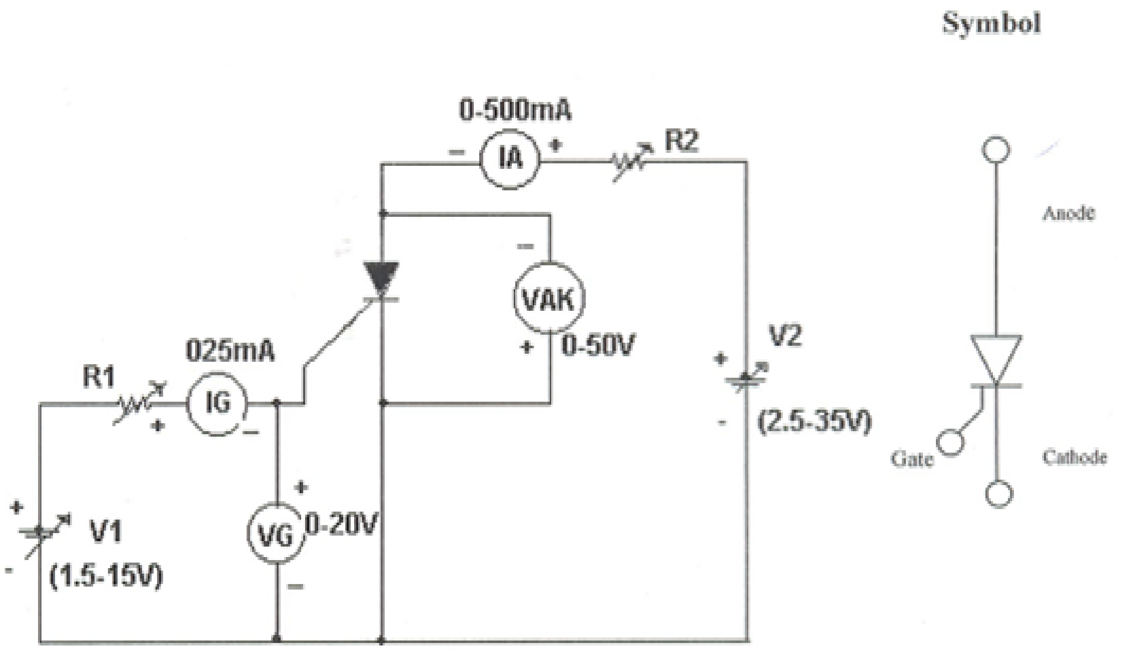

Figure 3.1 RC triggering of SCR

2. Give the AC Power supply 20V/1A from the source indicated in the front panel.
3. Connect Load i.e., Rheostat of 200Ω between two points.
4. Switch ON Power supply and observe the wave forms of input and output at a time in the CRO.
5. Slowly vary the control Resistor RC, that firing angle can vary from 0-180°.
6. Observe various voltage waveforms across load, SCR and other points, by varying the Load Resistance and Firing RC part
7. Compare practical obtained voltage waveform with theoretical waveform and observe the Firing angle in R-C Triggering

3.7 Model graphs

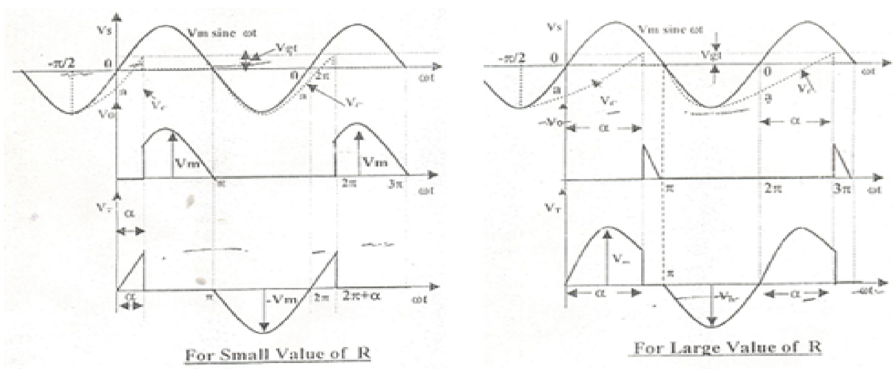

Figure 3.2 Output waveforms of RC triggering

ii. UJT TRIGGERING:
1. Make all connections as per the circuit diagram.

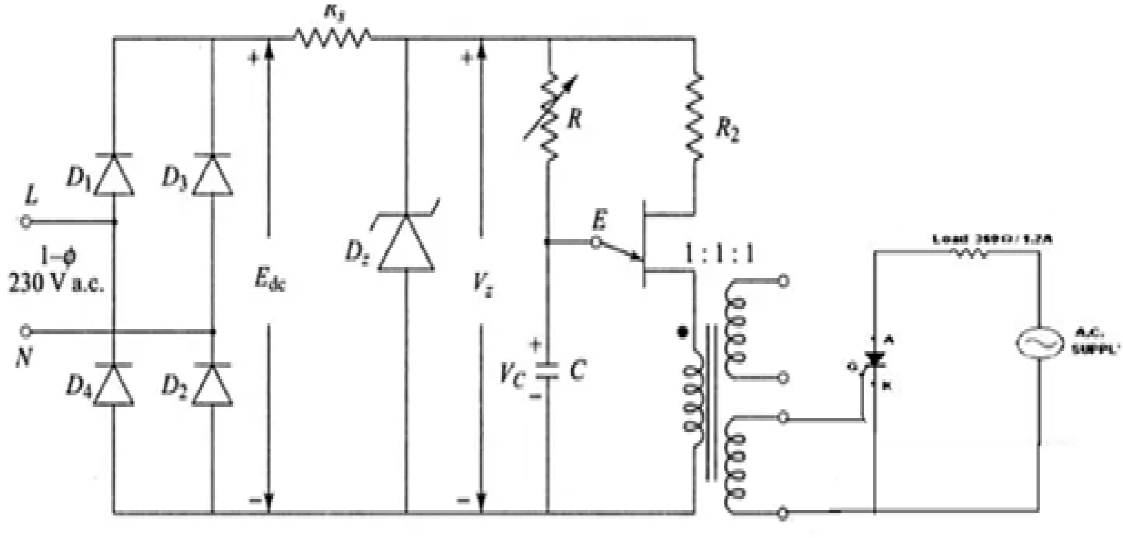

Figure 3.3 UJT triggering of SCR

2. First observe the waveforms at different points in circuit and also trigger output T1 and T2 observe the pulses are synchronized.
3. Observe the waveforms across the load and SCR and other points, by varying the variable resistor RC and resistance load, observe firing angle of SCR.
4. Use differential module for observing two waveforms (input and output) simultaneously in channel 1 and channel 2.
5. Check the waveforms for large value of RC and small value of RC and also triggering points of SCR.

3.8 Model graphs

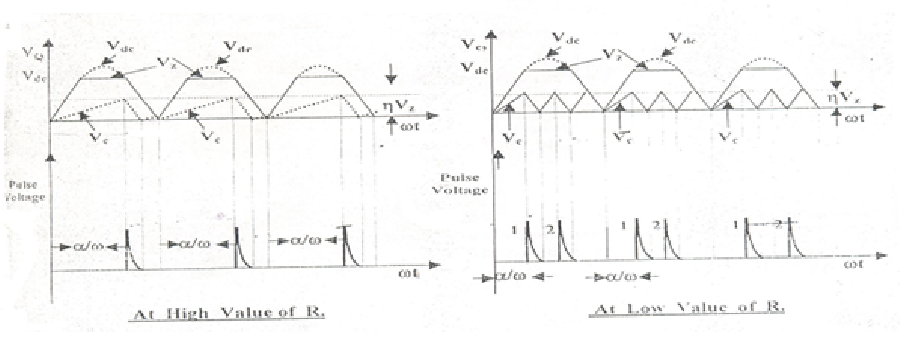

Figure 3.4 Output waveforms of UJT triggering

3.9 Probing Further Questions

Q1. What is the ratio of latching current to holding current?
Q2. What is the difference between UJT triggering and temperature triggering?
Q3. Define extinction angle.
Q4. Define firing angle.

LAB-4 Single phase half controlled bridge converter

4.1 Introduction

Half controlled convertors are single quadrant converters having one polarity of voltage and current at the DC terminals. In this session operation of single phase half controlled bridge converter with R and RL loads are presented.

4.2 Objective

By the end of this lab, the student should learn the operation of single phase half controlled bridge converter with R and RL loads.

4.3 Prelab Preparation:

Read the material in the textbook that describes operation of single phase half controlled bridge converter. Prior to coming to lab class, have glance of the Procedure.

4.4 Equipment needed

1. Single phase half controlled bridge converter power circuit and firing circuit
2. CRO with deferential module
3. Isolation Transformer
4. Variable Rheostat
5. Inductor
6. DC Voltmeter(0-30V)
7. DC Ammeter(0-2A)

4.5 Background

Single Phase Half Wave Controlled Rectifier, as the name suggests, is a rectifier circuit which converts AC input into DC output only for positive half cycle of the AC input supply. The word controlled means that, we can change the starting point of load current by controlling the firing angle of SCR. These words might seem a lot technical. But firing of SCR simply means, the SCR turn ON at certain point of time when it is forward biased.

4.6 Procedure

1. Make all connections as per the circuit diagram.

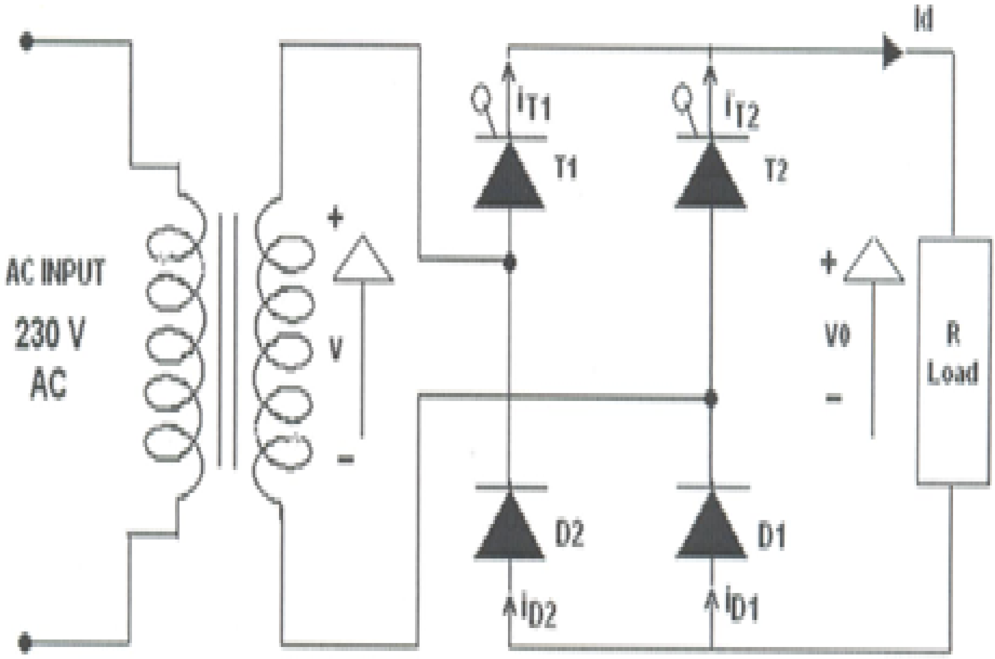

Figure 4.1 Single phase half controlled bridge converter

2. Connect first 30V AC supply from Isolation Transformer to circuit.
3. Connect firing pulses from firing circuit to Thyristors as indication in circuit.
4. Connect resistive load to load terminals and switch ON the MCB and IRS switch and trigger output ON switch.
5. Connect CRO probes and observe waveforms in CRO, Ch-1 or Ch-2, across load and device in single phase half controlled bridge converter.
6. By varying firing angle gradually up to 180 and observe related waveforms.
7. Measure output voltage and current by connecting AC voltmeter and Ammeter.
8. Tabulate all readings for various firing angles.
9. For RL Load connect a large inductance load in series with Resistance and observe all waveforms and readings as same as above.
10. Observe the various waveforms at different points in circuit by varying the Resistive Load and Inductive Load.
11. Calculate the output voltage and current by theoretically and compare with it practically obtained values.

S. No	Input Voltage (V in)	Firing angle in Degrees	Output voltage (V_0)		Output Current (I_0)	
			Theoretical	Practical	Theoretical	Practical
1						
2						
3						
4						
5						
6						

Table 4.1 Measured values for Single phase half controlled bridge converter

4.7 Calculations:

$V_0 = (\sqrt{2}V / \prod) * (1+\cos\alpha)$

$I_0 = (\sqrt{2}V / \prod R) * (1+\cos\alpha)$

α = Firing Angle

V = RMS Value across transformer output

4.8 Model graphs

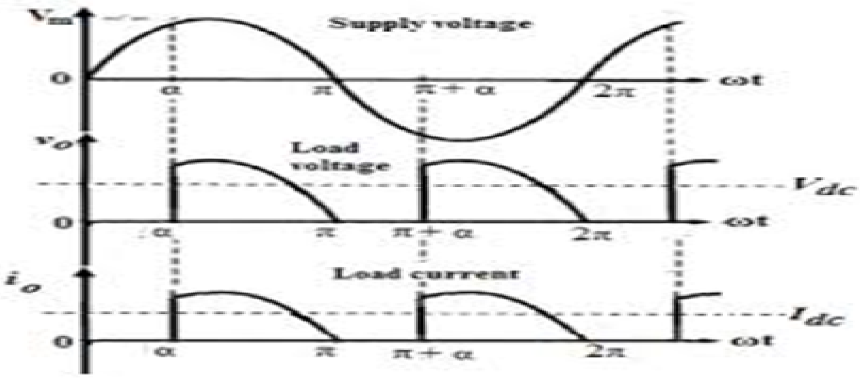

Figure 4.2 Output waveforms of Single phase half controlled bridge converter

4.9 Probing Further Questions

Q1. What is conduction angle?
Q2. What are the effects of adding freewheeling diode in this circuit?
Q3. What are the effects of removing the freewheeling diode in single phase semi converter?
Q4. Why is the power factor of semi converters better than that of full converters?

LAB-5 Forced commutation circuits

5.1 Introduction

A thyristor can be turned ON by applying a positive voltage of about a volt or a current of a few tens of milliamps at the gate-cathode terminals. It will turn-off only after the anode current is nulled either naturally or using forced commutation techniques. In this session operation of forced commutation circuits are presented.

5.2 Objective

By the end of this lab, the student should learn the operation of forced commutation circuits

5.3 Prelab Preparation:

Read the material in the textbook that describes operation of forced commutation circuits. Prior to coming to lab class, have glance of the Procedure.

5.4 Equipment needed

1. Commutation Study Unit
2. Dc power supply
3. Rheostat
4. Digital multimeter
5. CRO
6. Patch Cards

5.5 Background

In case of DC circuits, there is no natural current zero to turn OFF the SCR. In such circuits, forward current must be forced to zero with an external circuit (known as Commutating Circuit) to commutate the SCR. Hence the name, Forced Commutation. This commutating circuit consists of components like inductors and capacitors and they are called Commutating Components. These commutating components cause to apply a reverse voltage across the SCR that immediately bring the current in the SCR to zero. Depending on the process for achieving zero current in the SCR and the arrangement of the commutating components, Forced Commutation is classified into different types. They are:

- Class A – Self Commutation by Resonating the Load
- Class B – Self Commutation by Resonating the Load

• Class C – Complementary Commutation
• Class D – Auxiliary Commutation
• Class E – Pulse Commutation
such as class A, B, C, D, and E. This commutation is mainly used in chopper and inverter circuits.

5.6 Procedure

Class – A Commutation:
1. Connect the circuit as shown in the circuit.

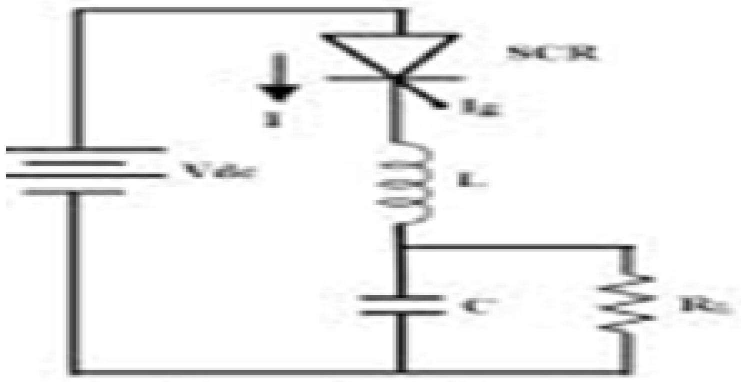

Figure 5.1 Class A commutation circuit

2. Connect trigger output T1 to gate and cathode of SCR T1.
3. Switch on the DC supply to the power circuit and observe the voltage waveform across load by varying frequency potentiometer.
4. Repeat the same for different values of L, c and R.

5.7 Model graphs

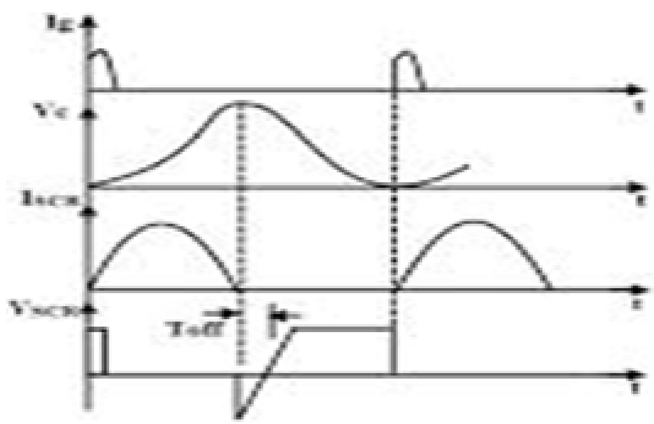

Figure 5.2 Output waveforms of Class A commutation

Class –B Commutation:
1. Connect the circuit as shown in the circuit.

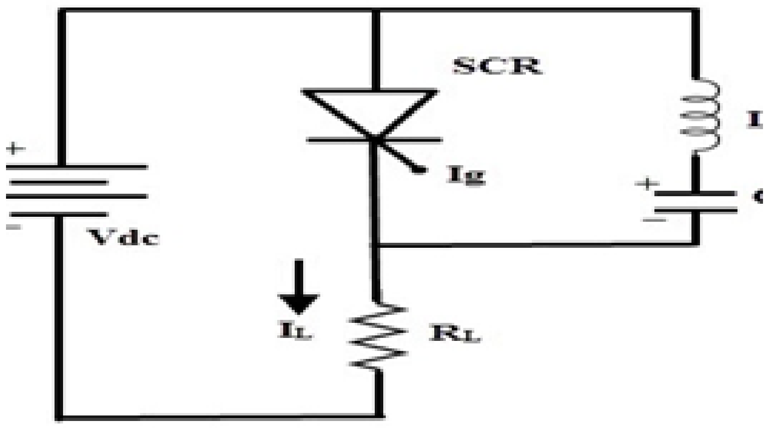

Figure 5.3 Class B commutation circuit

2. Connect trigger output T1 to gate and cathode of SCR T1.
3. Switch on the DC supply to the power circuit and observe the voltage waveform across load by varying frequency potentiometer.
4. Repeat the same for different values of L, c and R.

Model graphs

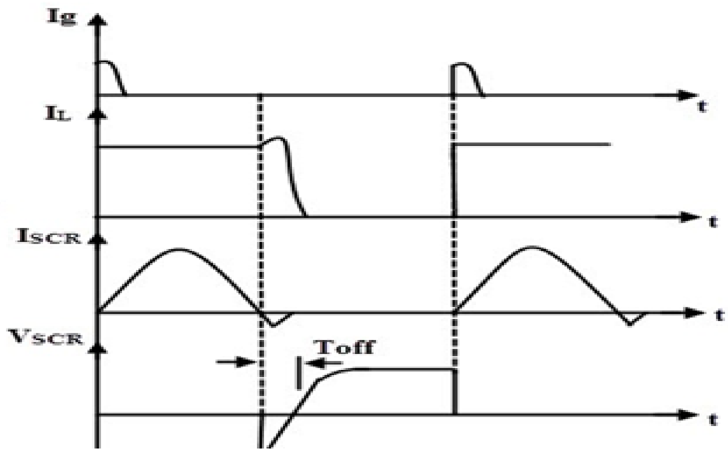

Figure 5.4 Output waveforms of Class B commutation circuit

Class –C Commutation:

1. Connect the circuit as shown in the circuit.

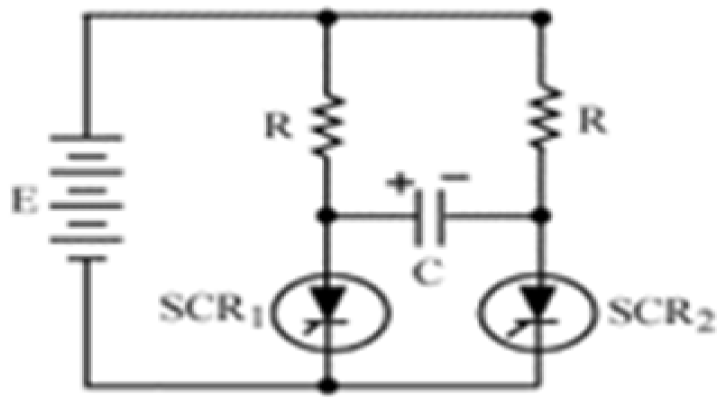

Figure 5.5 Class C commutation circuit

2. Connect T1 and T2 from firing circuit to gate and cathode of SCR T1 and T2.
3. Observe the waveforms across R1, R2 and C by varying frequency and also duty cycle potentiometer.
4. Repeat the same for different values of L, c and R.

Model graphs

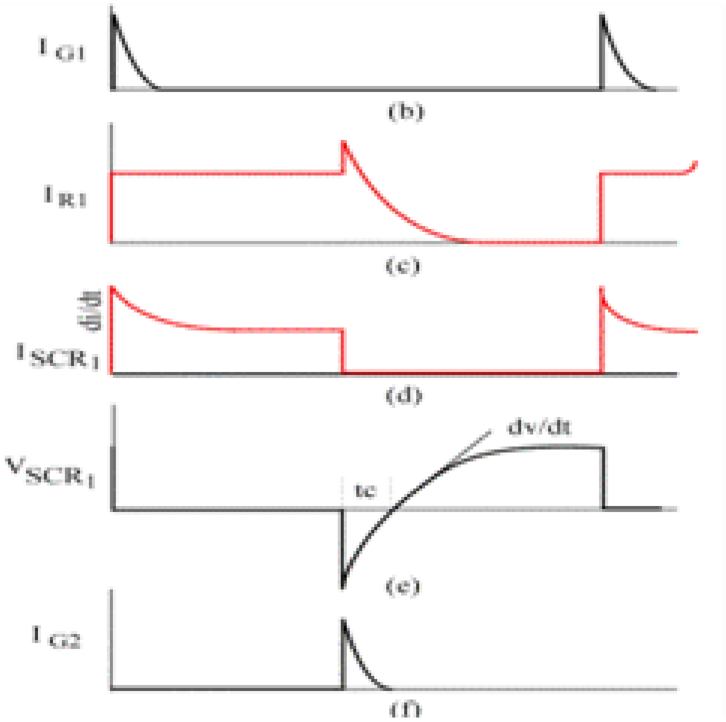

Figure 5.6 Output waveforms of Class C commutation circuit

Class –D Commutation:

1. Connect the circuit as shown in the circuit.

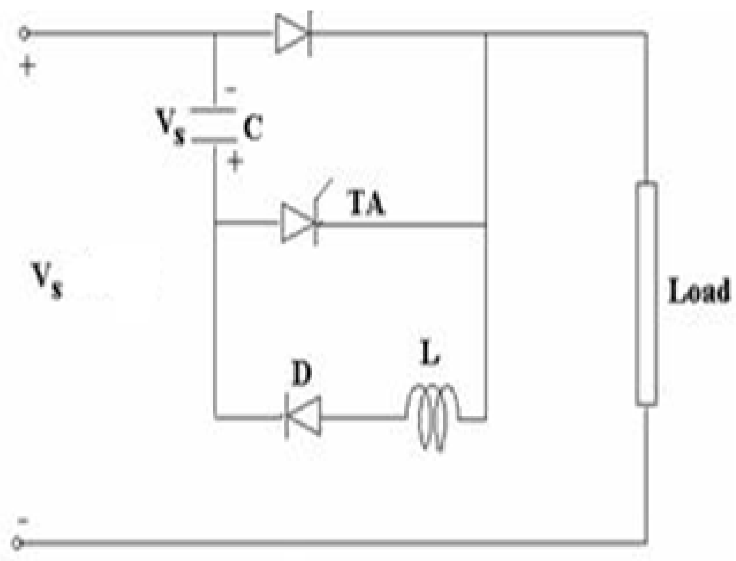

Figure 5.7 Class D commutation circuit

2. Connect T1 and T2 from firing circuit to gate and cathode of SCR T1 and T2.
3. Observe the waveforms across R1, R2 and C by varying frequency and also duty cycle potentiometer.
4. Repeat the same for different values of L, c and R.

Model graphs

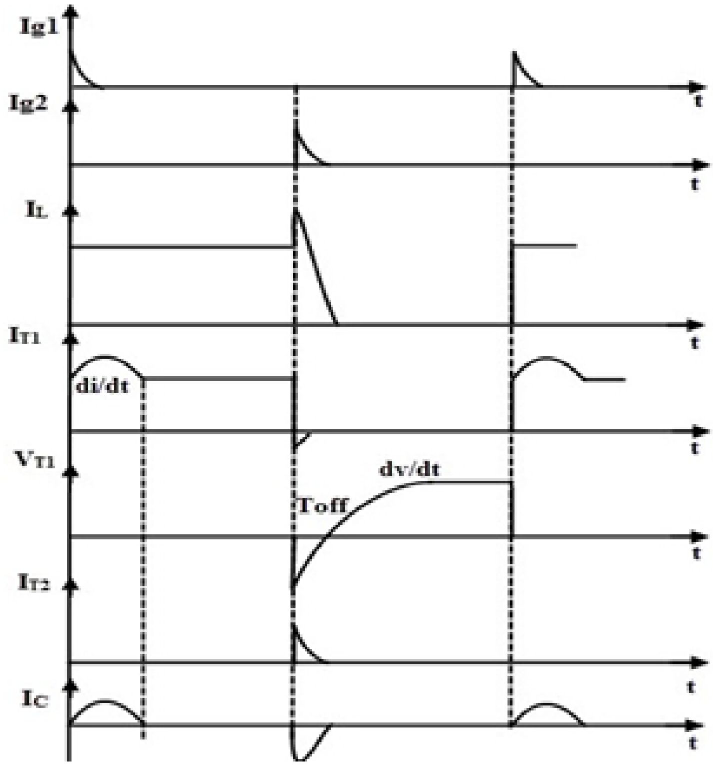

Figure 5.8 Output waveforms of Class D commutation circuit

5.8 Probing Further Questions

Q1. What is the need of commutation circuits?
Q2. What is the difference between forced commutation and natural commutation?
Q3. What is the difference between Class A and class B commutations?
Q4. Which type of commutation circuit is easy to construct?

LAB-6 Single phase full controlled bridge converter

6.1 Introduction

The single phase fully controlled converter is used to convert single phase A.C supply to D.C supply. The fully controlled converter uses four thyristors. It is a two quadrant converter was voltage polarity can reverse, but current direction cannot reverse because of unidirectional nature of thyristors. In this session operation of single phase full controlled bridge converter with R and RL loads are presented.

6.2 Objective

By the end of this lab, the student should learn the operation of single phase full controlled bridge converter with R and RL loads.

6.3 Prelab Preparation:

Read the material in the textbook that describes operation of single phase full controlled bridge converter. Prior to coming to lab class, have glance of the Procedure.

6.4 Equipment needed

1. Single phase full controlled bridge converter power circuit and firing circuit
2. CRO with deferential module
3. Isolation Transformer
4. Variable Rheostat
5. Inductor
6. DC Voltmeter(0-30V)
7. DC Ammeter(0-2A)

6.5 Background

In a fully controlled converter the output voltage can be controlled by controlling the firing delay angle of the thyristors. Thyristors T1 and T2 are fired together while T3 and T4 are fired 180° after T1 and T2. Depending on the load condition and the firing angle a fully controlled bridge converter can operate either in the continuous conduction mode or in the discontinuous conduction mode. In the continuous conduction mode, the load voltage depends only on the firing angle and not on load parameters. In the discontinuous conduction mode, the output voltage decreases with increasing load current. However, the output voltage is always greater than that in the continuous conduction mode for the same firing angle.

6.6 Procedure

1. 1. Make all connections as per the circuit diagram.

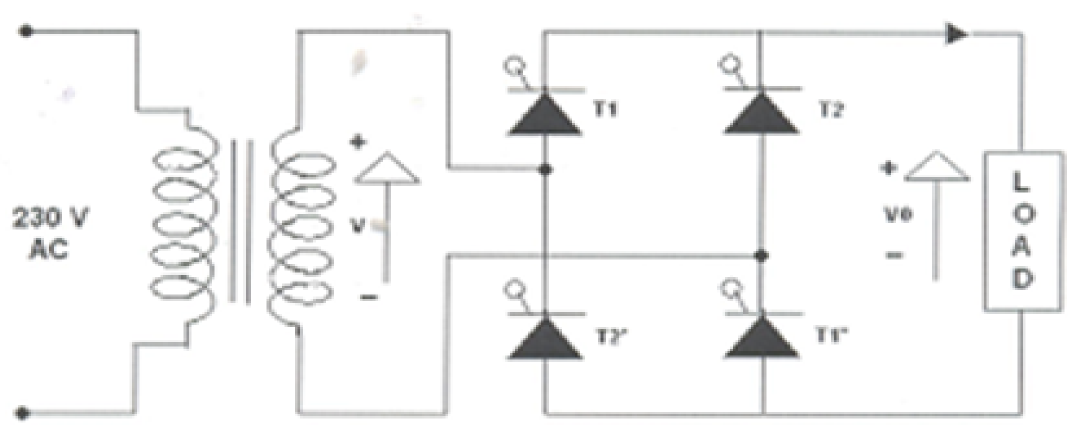

Figure 6.1 Single phase fully controlled bridge converter

2. Connect firstly 30V AC supply from Isolation Transformer to circuit.
3. Connect firing pulses from firing circuit to Thyristors as indication in circuit.
4. Connect resistive load to load terminals and switch ON the MCB and IRS switch and trigger output ON switch.
5. Connect CRO probes and observe waveforms in CRO across load and device in single phase fully controlled bridge converter.
6. By varying firing angle gradually up to 180 and observe related waveforms.
7. Measure output voltage and current by connecting AC voltmeter and Ammeter.
8. Tabulate all readings for various firing angles.
9. For RL Load connect a large inductance load in series with Resistance and observe all waveforms and readings as same as above.
10. Observe the various waveforms at different points in circuit by varying the Resistive Load and Inductive Load.
11. Calculate the output voltage and current by theoretically and compare with it practically obtained values.

S. No	Input Voltage (V_{in})	Firing angle in Degrees	Output voltage (V_0)		Output Current (I_0)	
			Theoretical	Practical	Theoretical	Practical
1						
2						
3						
4						
5						
6						

Table 6.1 Measured values for Single phase fully controlled bridge converter

6.7 Calculations:

For R-L Load:		For R Load:
V_0	$= (2\sqrt{2}V/\Pi) * \cos\alpha$	$V_0 = (\sqrt{2}V/\Pi) * (1+\cos\alpha)$
I_0	$= (2\sqrt{2}V/\Pi R) * \cos\alpha$	$I_0 = (\sqrt{2}V/\Pi R) * (1+\cos\alpha)$
α	=Firing Angle	
V	= RMS Value across transformer output	

6.8 Model graphs

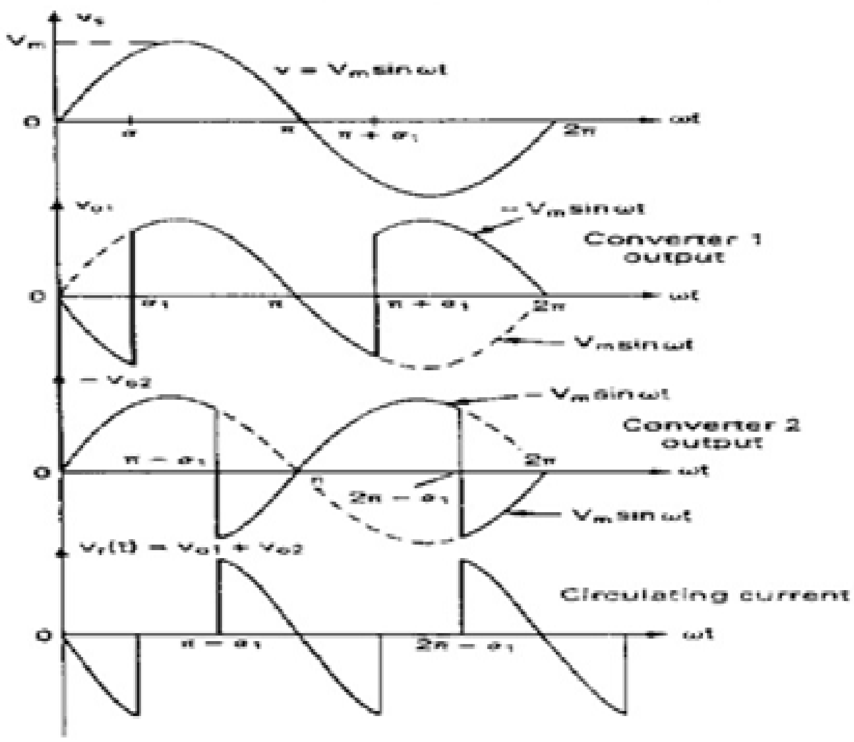

Figure 6.2 Output waveforms of Single phase full controlled bridge converter

6.9 Probing Further Questions

Q1. State the type of commutation used in this circuit.
Q2. What will happen if the firing angle is greater than 90 degrees?
Q3. What are the performance parameters of rectifier?
Q4. What is the difference between half wave and full wave rectifier?

LAB-7 Series Inverter

7.1 Introduction

Inverter is used to convert the direct current (DC) to alternating Current (AC) of required voltage. In series inverter, the commutating elements L and C are connected in series with the load. This constitutes a series RLC resonant circuit. In this session operation of series inverter with R and RL loads are presented.

7.2 Objective

By the end of this lab, the student should learn the operation of series inverter with R and RL loads.

7.3 Prelab Preparation:

Read the material in the textbook that describes operation of series inverter. Prior to coming to lab class, have glance of the Procedure.

7.4 Equipment needed

1. Series inverter power circuit and firing circuit
2. CRO with deferential module
3. Patch chords and probes
4. Regulated dc power supply
5. Variable Rheostat
6. Inductor

7.5 Background

In the first half of the output currents when SCR T1 is triggered it will allow the current to flow through L1, and load, and C2 thus charging. The capacitor C1 which is already charged at these instant discharges through SCR1, L1 and the Load. Hence 50 percent of the current is drawn from the input source and 50 percent from the capacitor. Similarly in the second half of the output current C1 will be charged and C2 will discharge through the load, L2 and SCR2, Again 50 percent of the load current is obtained from the DC input source and rest from the capacitor. The SCRs T1 and T2 are alternatively fired to get AC voltage and current.

7.6 Procedure

1. Make all connections as per the circuit diagram.

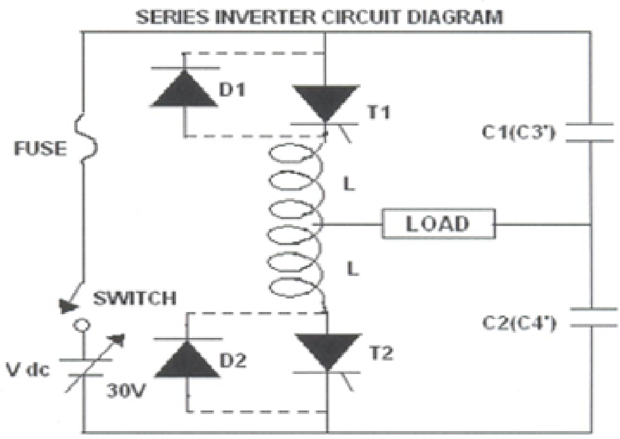

Figure 7.1 Single phaseseries inverter

2. Give the DC power supply 30V to the terminal pins located in the power circuit.
3. Connect firing pulses from firing circuit to Thyristors as indication in circuit.
4. Connect resistive load to load terminals and switch ON the MCB and IRS switch and trigger output ON switch.
5. By varying the frequency pot, observe related waveforms.
6. If the inverter frequency is increases above the resonant frequency of the power circuit commutation fails. Then switch OFF the DC supply, reduce the inverter frequency and try again.
7. Repeat the above same procedure for different value of L,C load and also above the wave forms with and without fly wheel diodes.
8. Total output wave forms entirely depends on the load, and after getting the perfect wave forms increase the input supply voltage up to 30V and follow the above procedure.
9. Switch OFF the DC supply first and then Switch OFF the inverter.(Switch OFF the trigger pulses will lead to short circuit)

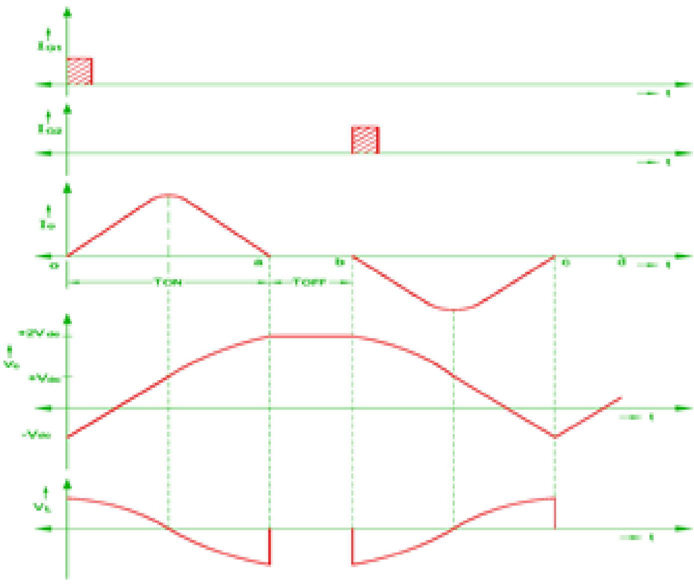

Figure 7.2 Output waveforms of series inverter

7.7 Probing Further Questions

Q1. What is the dead zone of an inverter?
Q2. Up to what maximum voltage will the capacitor charge during circuit operation?
Q3. What is the amount of power delivered by capacitor?
Q4. What is the purpose of coupled inductors in half bridge resonant inverters?

Lab 8 – Parallel Inverter

8.1 Introduction

Inverter is used to convert the direct current (DC) to alternating Current (AC) of required voltage. In series inverter, the commutating elements L and C are connected in parallel with the load. This constitutes a parallel RLC resonant circuit. In this session operation of parallel inverter with R and RL loads are presented.

8.2 Objective

By the end of this lab, the student should learn the operation of parallel inverter with R and RL loads.

8.3 Prelab Preparation:

Read the material in the textbook that describes operation of parallel inverter. Prior to coming to lab class, have glance of the Procedure.

8.4 Equipment needed

1. Parallel inverter power circuit and firing circuit
2. CRO with deferential module
3. Patch chords and probes
4. Regulated dc power supply
5. Variable Rheostat
6. Inductor

8.5 Background

The single phase parallel inverter circuit consists of two SCRs T1 and T2, an inductor L, an output transformer and a commutating capacitor C. The output voltage and current are Vo and Io respectively. The function of L is to make the source current constant. During the working of this inverter, capacitor C comes in parallel with the load via the transformer. So it is called a parallel inverter.

8.6 Procedure

1. Make all connections as per the circuit diagram.

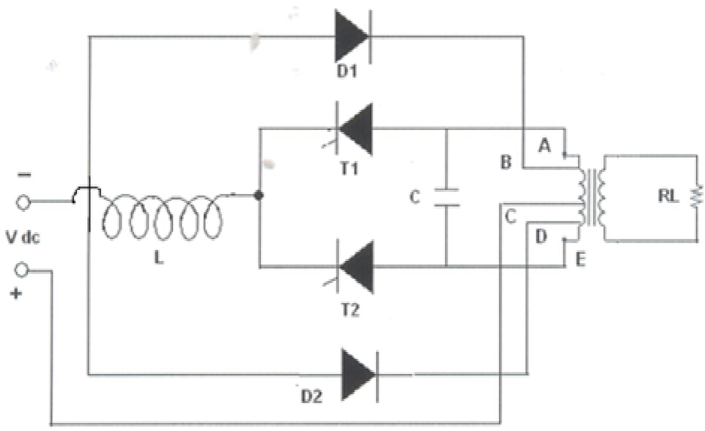

Figure 8.1 Single phase parallel inverter

2. Give trigger pulses from firing circuit to gate and cathode of SCR's T1 and T2.
3. Set input voltage 15V, connect load across load terminals.
4. Now switch ON the DC supply, switch ON the trigger output pulses.
5. Observe the output voltage waveforms across load by varying the frequency pot.
6. Repeat the above same procedure for different value of L, C load values.
7. Switch off the DC supply first and then switch off the inverter.

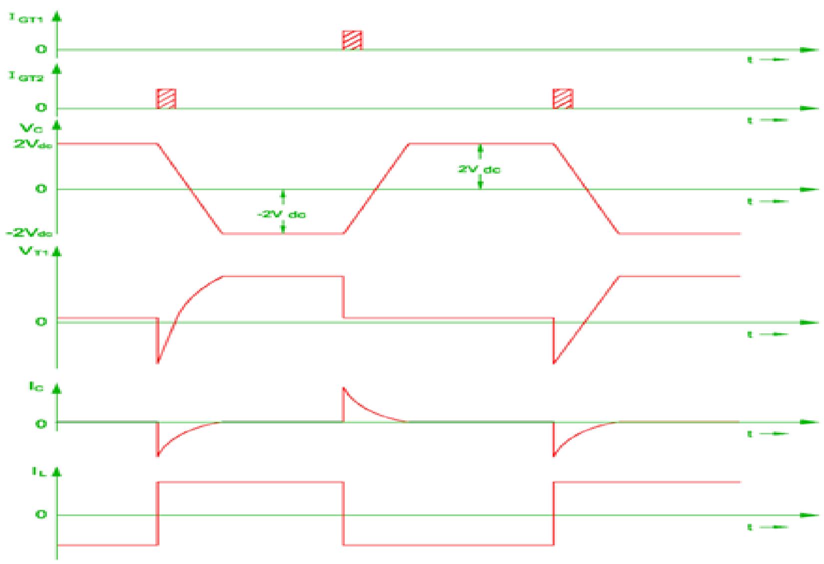

Figure 8.2 Output waveforms of parallel inverter

8.7 Probing Further Questions

Q1. Why is this circuit called as parallel inverter?
Q2. What is the type of commutation for parallel inverter?
Q3. What is the configuration of capacitor?
Q4. What is the principle of parallel inverter?

Lab 9 – Single phase A.C. voltage controller

9.1 Introduction

Single Phase AC Voltage Controller is a device which converts fixed single phase alternating voltage directly to a variable alternating voltage without a change in frequency. The input and output of the device is single phase. In this session operation of Single Phase AC Voltage Controller with R and RL loads are presented.

9.2 Objective

By the end of this lab, the student should learn the operation of Single Phase AC Voltage Controller with R and RL loads.

9.3 Prelab Preparation:

Read the material in the textbook that describes operation of Single Phase AC Voltage Controller. Prior to coming to lab class, have glance of the Procedure.

9.4 Equipment needed

1. Single phase AC voltage controller power circuit and firing circuit
2. CRO with deferential module
3. Patch chords and Probes
4. Isolation Transformer
5. Variable Rheostat
6. Inductor
7. AC Voltmeter
8. AC Ammeter

9.5 Background

A single phase full wave AC voltage controller comprises of two thyristor connected in anti-parallel. For the positive half cycle of input source, thyristor T1 is forward biased and hence it is able to conduct provided gate signal is applied. This means that T1 will remain OFF until gate signal is applied. Now suppose, at some angle called the firing angle, thyristor T1 is gated. As soon as T1 is fired / gated, it starts conducting and hence, load gets directly connected to the source.

9.6 Procedure

AC VOLTAGE CONTROLLER WITH TWO THYRISTORS:

1. Make all connections as per the circuit diagram.

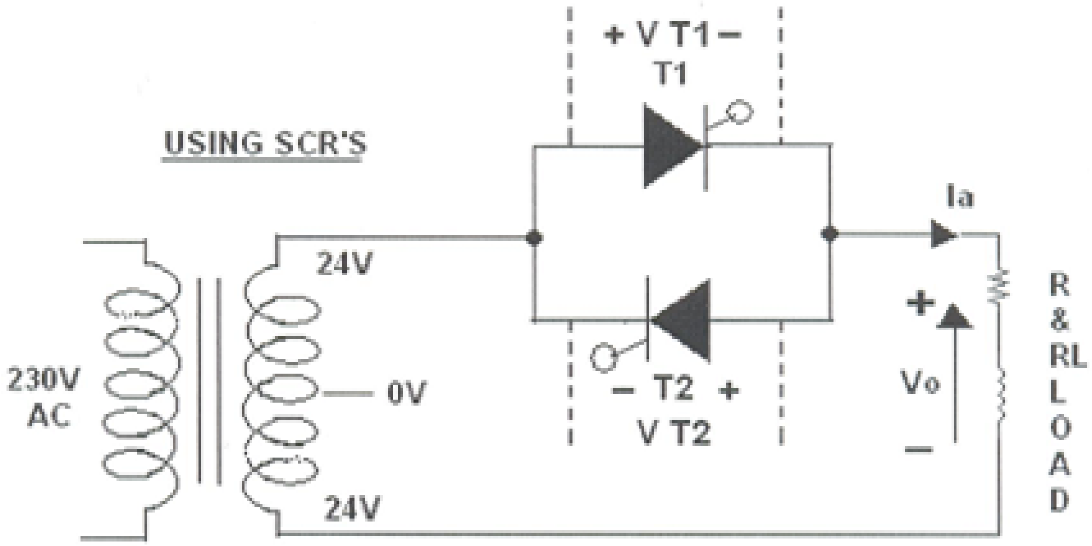

Figure 9.1 Single Phase AC Voltage Controller with Thyristors

2. Connect firstly 30V AC supply from Isolation Transformer to circuit.
3. Connect firing pulses from firing circuit to Thyristors as indication in circuit.
4. Connect resistive load to load terminals and switch ON the MCB and IRS switch and trigger output ON switch.
5. Observe waveforms in CRO, across load by varying firing angle gradually up to 180.
6. Measure output voltage and current by connecting AC voltmeter and Ammeter.
7. Tabulate all readings for various firing angles.
8. For RL Load connect a large inductance load in series with Resistance and observe all waveforms and readings as same as above.
9. Observe the various waveforms at different points in circuit by varying the Resistive Load and Inductive Load.
10. Calculate the output voltage and current by theoretically and compare with it practically obtained values.

S. No.	Input Voltage (V_{in})	Firing angle in Degrees	Output voltage (V_{0r})		Output Current (I_{0r})	
			Theoretical	Practical	Theoretical	Practical
1						
2						
3						
4						
5						
6						

Table 9.1 Measured values of Single Phase AC Voltage Controller with Thyristors

9.7 Model graphs

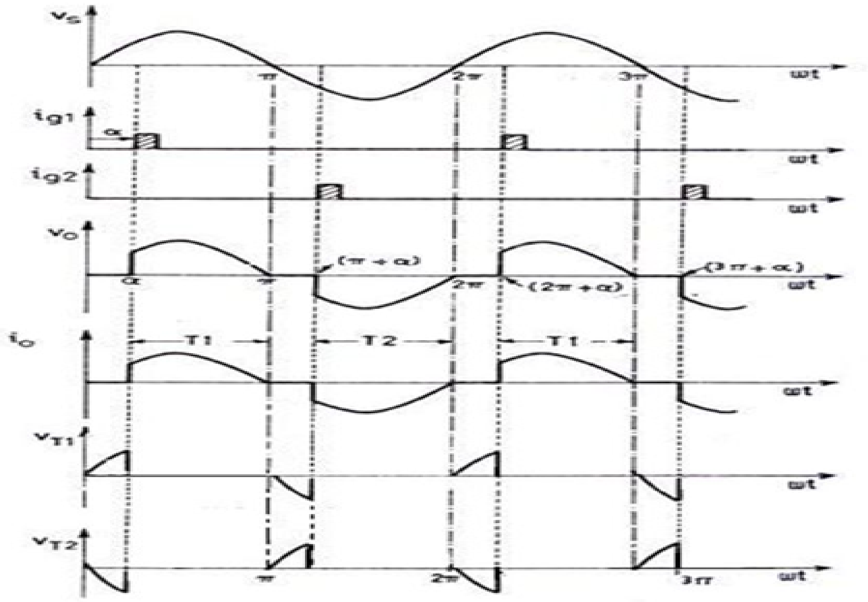

Figure 9.2 Output waveforms of AC voltage controller

ii. UJT TRIGGERING:

1. Make all connections as per the circuit diagram.

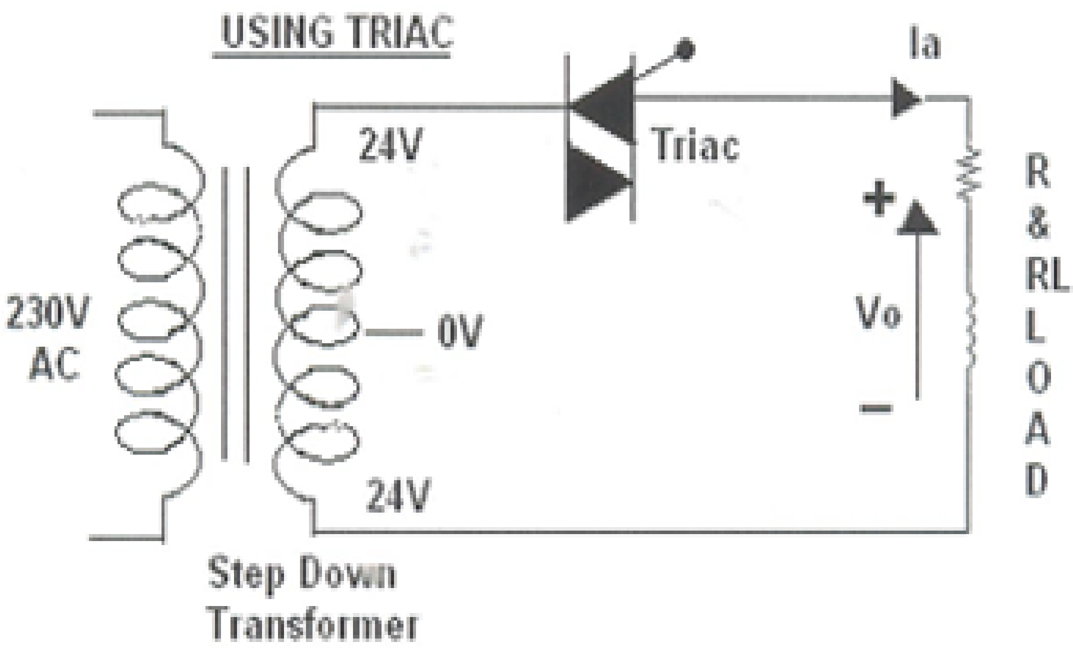

Figure 9.3 Single Phase AC Voltage Controller with TRIAC

2. Connect firstly 30V AC supply from Isolation Transformer to circuit.
3. Connect firing pulse from firing circuit to TRIAC as indication in circuit.
4. Connect resistive load to load terminals and switch ON the MCB and IRS switch and trigger output ON switch.
5. Observe waveforms in CRO, across load by varying firing angle gradually up to 180.
6. Measure output voltage and current by connecting AC voltmeter and Ammeter.
7. Tabulate all readings for various firing angles.
8. For RL Load connect a large inductance load in series with Resistance and observe all waveforms and readings as same as above.
9. Observe the various waveforms at different points in circuit by varying the Resistive Load and Inductive Load.
10. Calculate the output voltage and current by theoretically and compare with it practically obtained values.

S. No.	Input Voltage (V_{in})	Firing angle in Degrees	Output voltage (V_{0r})		Output Current (I_{0r})	
			Theoretical	Practical	Theoretical	Practical
1						
2						
3						
4						
5						
6						

Table 9.2 Measured values of Single Phase AC Voltage Controller with TRIAC

9.8 Model graphs

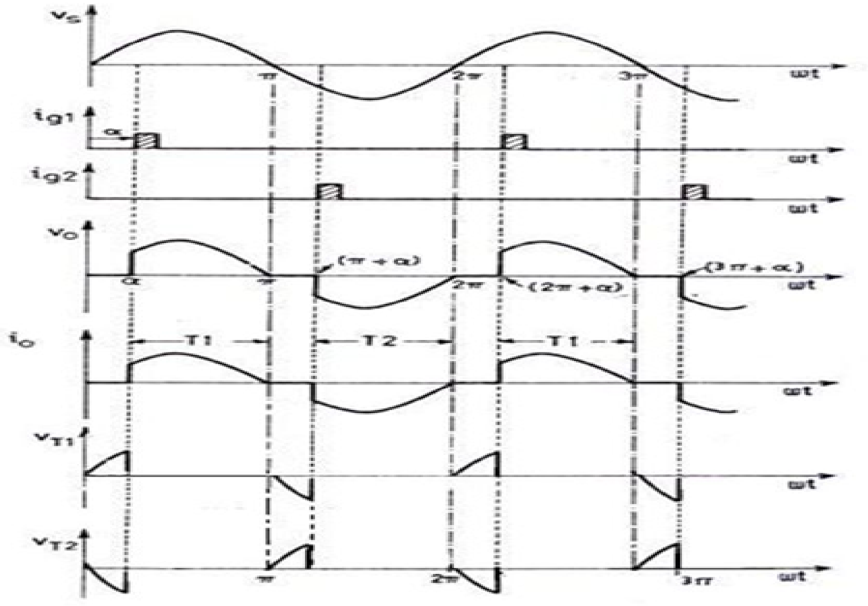

Figure 9.4 Output waveforms of AC voltage controller with TRIAC

9.9 Probing Further Questions

Q1. What are the advantages and the disadvantages of phase control?
Q2. What is phase control?
Q3. What are the advantages of bidirectional controllers?
Q4. What is meant by duty cycle in ON-OFF control method?

Lab 10 – Single phase cycloconverter

10.1 Introduction

The Cycloconverter has four thyristors divided into a positive and negative bank of two thyristors each. When positive current flows in the load, the output voltage is controlled by phase control of the two positive bank thyristors whilst the negative bank thyristors are kept off and vice versa when negative current flows in the load. In this session operation of Single Phase cycloconverter with R and RL loads are presented.

10.2 Objective

By the end of this lab, the student should learn the operation of Single Phase cycloconverter with R and RL loads.

10.3 Prelab Preparation:

Read the material in the textbook that describes operation of Single Phase cycloconverter. Prior to coming to lab class, have glance of the Procedure.

10.4 Equipment needed

1. Single phase Cycloconverter power circuit and firing circuit
2. CRO with deferential module
3. Patch chords and probes
4. Isolation Transformer(Centre-Tapped)
5. Variable Rheostat
6. Inductor
7. AC Voltmeter
8. AC Ammeter

10.5 Background

In a single phase Cycloconverter, the output frequency is less than the supply frequency. These converters require natural commutation which is provided by AC supply. During positive half cycle of supply, thyristors P1 and N2 are forward biased. First triggering pulse is applied to P1 and hence it starts conducting.

10.6 Procedure

1. Make all connections as per the circuit diagram.

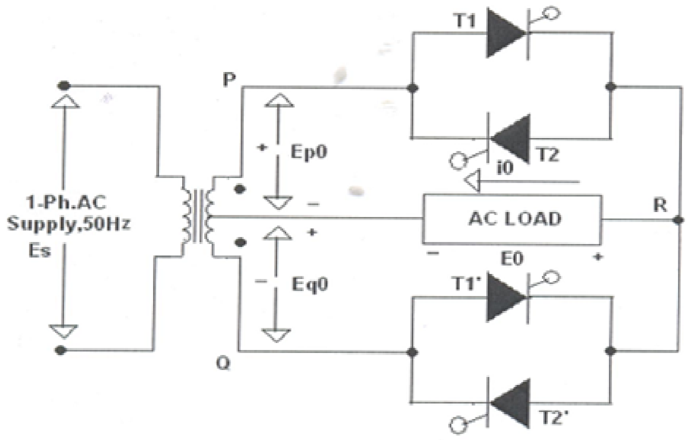

Figure 10.1 Single phasecycloconverter

2. Connect firstly (30V-0-30V) AC supply from Isolation Transformer to circuit.
3. Connect firing pulses from firing circuit to Thyristors as indication in circuit.
4. Connect resistive load to load terminals.
5. Set the frequency division switch to (2, 3, 4. . . 9) your required output frequency.
6. Switch ON the MCB and IRS switch and trigger output ON switch.
7. Observe waveforms in CRO, across load by varying firing angle gradually up to 1800 and also for various frequency divisions (2, 3, 4. . . 9).
8. Measure output voltage and current by connecting AC voltmeter and Ammeter.
9. Tabulate all readings for various firing angles.
10. For RL Load connect a large inductance load in series with Resistance and observe all waveforms and readings as same as above
. 11. Observe the various waveforms at different points in circuit by varying the Resistive Load and Inductive Load.
12. Calculate the output voltage and current by theoretically and compare with it practically obtained values.

S. No	Input Voltage (V_{in})	Firing angle in Degrees	Frequency Division	V_0 (V)	I_0 (A)	Input frequency f_s	Output frequency f_o	f_o/f_s

Table 10.1 Measured values of cycloconverter

10.7 Model Graph

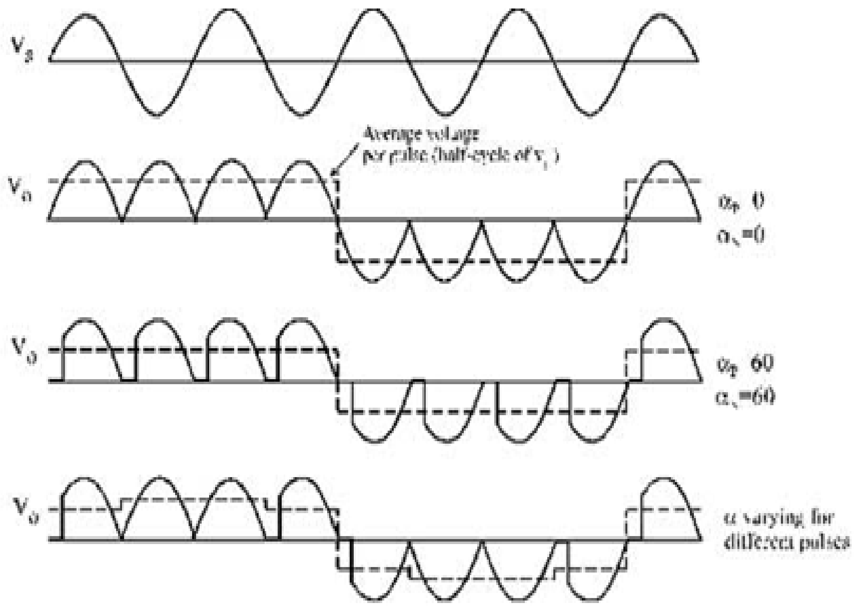

Figure 10.2 Output waveforms of Single phase cycloconverter

10.8 Probing Further Questions

Q1. What is meant by Cycloconverter? What are the types of Cycloconverters?
Q2. Classify Cycloconverters.
Q3. What is step up Cycloconverter and step down cyclo-converter?
Q4. Differentiate step-down cycloconverter and step-up cycloconverter.

Lab 11 – Operation of MOSFET based chopper

11.1 Introduction

Chopper circuits are known as DC to DC converters. Similar to the transformers of the AC circuit, choppers are used to step up and step down the DC power. They change the fixed DC power to variable DC power. Using these, DC power supplied to the devices can be adjusted to the required amount. In this session operation of MOSFET based chopper is presented.

11.2 Objective

By the end of this lab, the student should learn the operation of MOSFET based chopper.

11.3 Prelab Preparation:

Read the material in the textbook that describes operation of MOSFET based chopper. Prior to coming to lab class, have glance of the Procedure.

11.4 Equipment needed

1. MOSFET based chopper power circuit and firing circuit
2. CRO with deferential module
3. Patch chords and probes
4. Regulated dc power supply
5. Variable Rheostat
6. DC Voltmeter
7. DC Ammeter

11.5 Background

The principle of operation of chopper can be understood from the circuit diagram below. The circuit consists of a semiconductor diode, resistor, and a load. For all type of chopper circuit, the output voltage value is controlled by periodic closing and opening of the switches used in the circuit. The chopper can be viewed as an ON or OFF switch that can rapidly connect or disconnect the source to load connection. Continuous DC is given as source to the chopper as Vs and chopped DC is obtained across the load as V0.

11.6 Procedure

1. Make all connections as per the circuit diagram.

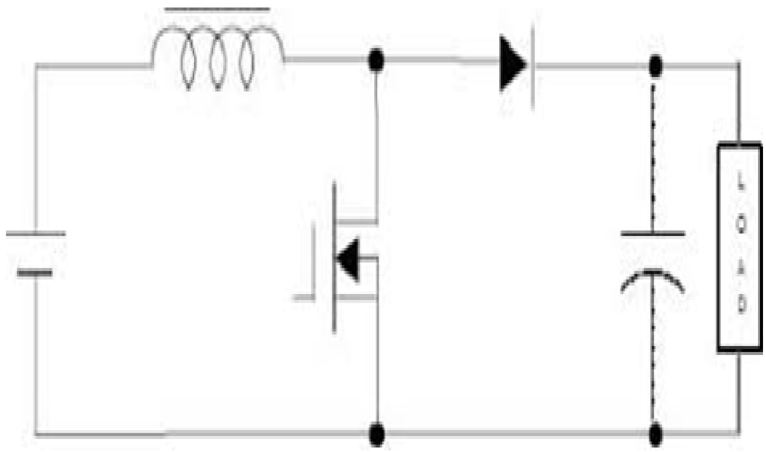

Figure 11.1 MOSFET Based Chopper

2. Adjust VRPS output to 10v and connect to DC chopper module.
3. Switch on DC toggle switch of chopper module.
4. Switch on the trigger input by pushing- in pulse switch.
5. Observe the output waveform across load on CRO.
6. Keep the duty cycle at mid position and vary the frequency from minimum to maximum and record the output voltage readings.
7. Keep the frequency at mid position, vary duty cycle from minimum to maximum and output voltage readings.
8. Note down the output wave form for mid value of frequency and duty cycle.

S. No	Frequency(Hz)	V0(Volts)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Table 11.1 Measured values for Constant pulse width and variable frequency

S. No	T_{ON}(sec)	T_{OFF}(sec)	Duty Cycle (%)	V_O(Volts)
1				
2				
3				
4				
5				
6				
7				
8				

Table 11.2 Measured values for Constant Frequency and Variable Pulse width

11.7 Model Graphs

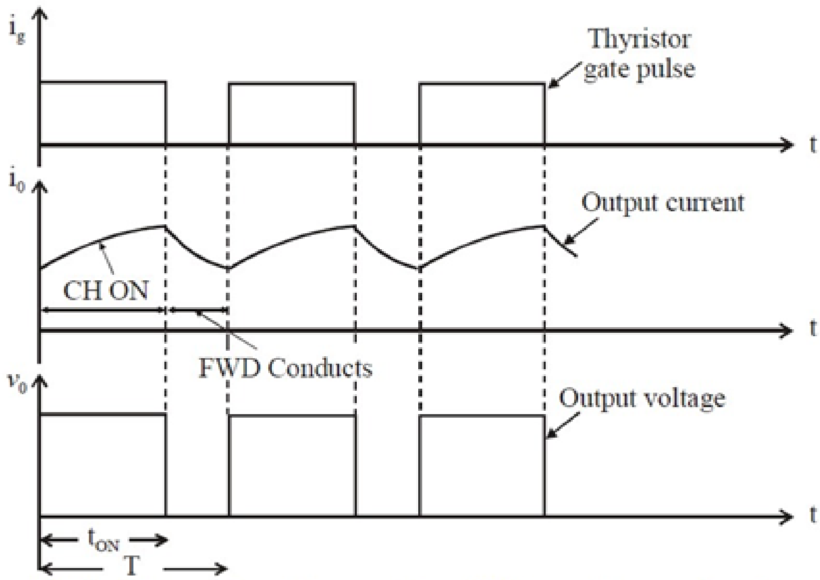

Figure 11.1 MOSFET Based Chopper Output waveforms

11.8 Probing Further Questions

Q1. What are the different control strategies found in choppers?
Q2. Explain the principle of operation of a chopper?
Q3. What is the function of chopper?
Q4. What are the advantages of DC choppers?

Lab 12 – Single phase dual converter

12.1 Introduction

Dual Converter is an Electronic Device or Circuit made by the combination of two bridges. One of them works as Rectifier (Converts A.C. to D.C.) and other bridge works as Inverter (converts D.C. into A.C.). Thus an electronic circuit or device, in which two processes take place at same time, is known as Dual Converter. In this session operation of single phase dual converter is presented..

12.2 Objective

By the end of this lab, the student should learn the operation of single phase dual converter.

12.3 Prelab Preparation:

Read the material in the textbook that describes operation of single phase dual converter. Prior to coming to lab class, have glance of the Procedure.

12.4 Equipment needed

1. Single phase dual converter power circuit and firing circuit
2. CRO with deferential module
3. Patch chords and probes
4. Isolation Transformer
5. Variable Rheostat
6. Inductor
7. DC Voltmeter(0-30V)
8. DC Ammeter(0-2A)

12.5 Background

Dual converter, the name itself says two converters. It is really an electronic converter or circuit which comprises of two converters. One will perform as a rectifier and the other will perform as an inverter. Therefore, we can say that double processes will occur at a moment. Here, two full converters are arranged in anti-parallel pattern and linked to the same dc load. These converters can provide four quadrant operations.

12.6 Procedure

1. Make all connections as per the circuit diagram.

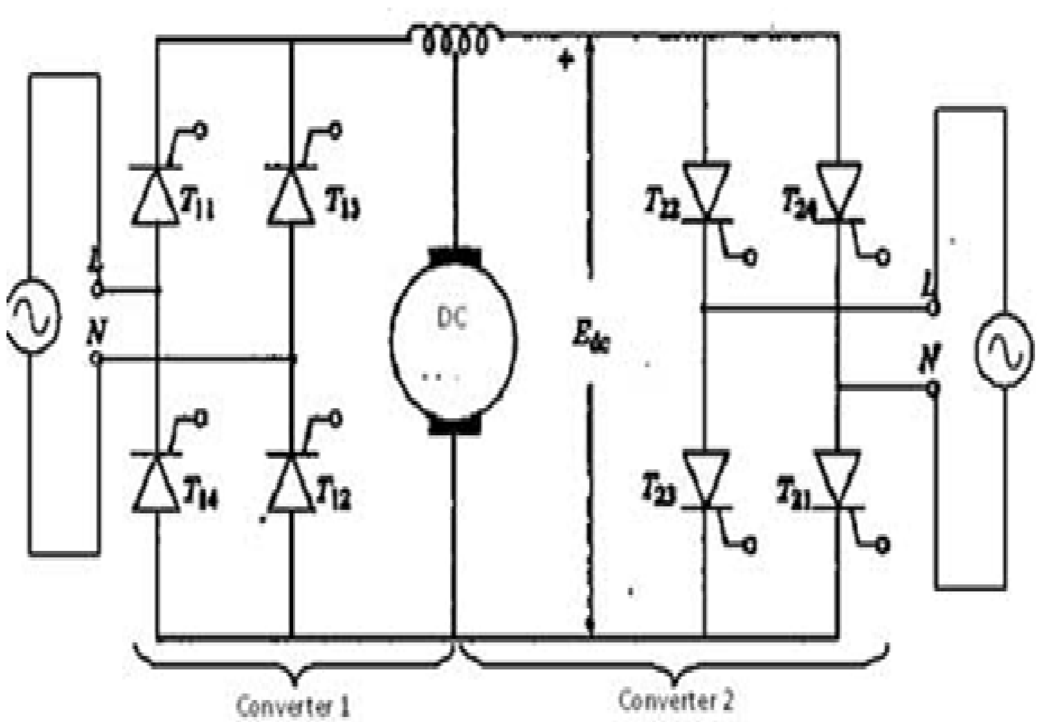

Figure 12.1 Single Phase Dual Converter

2. Connect firstly AC supply from Isolation Transformer to circuit.
3. Connect firing pulses from firing circuit to Thyristors as indication in circuit.
4. Connect resistive load to load terminals and switch ON the MCB and IRS switch and trigger output ON switch.
5. Connect CRO probes and observe waveforms in CRO across load and device in single phase dual converter.
6. By varying firing angle gradually up to 1800 and observe related waveforms.
7. Measure output voltage and current by connecting AC voltmeter and Ammeter.
8. Tabulate all readings for various firing angles.
9. For RL Load connect a large inductance load in series with Resistance and observe all waveforms and readings as same as above.
10. Observe the various waveforms at different points in circuit by varying the Resistive Load and Inductive Load.
11. Calculate the output voltage and current by theoretically and compare with it practically obtained values.

12.7 Model Graphs

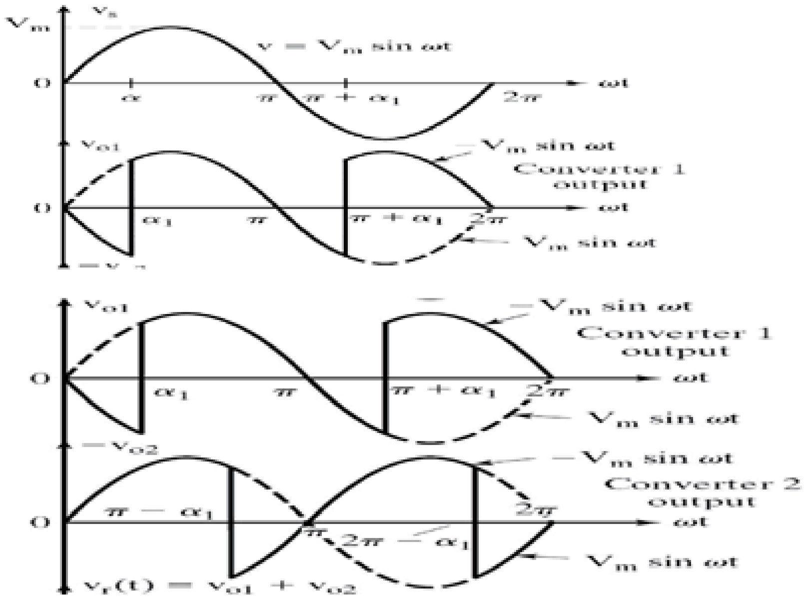

Figure 12.2 Single Phase Dual Converter output waveforms

12.8 Probing Further Questions

Q1. What is the condition for ideal dual converter operation?
Q2. What are the four quadrant operations are possible with dual converter drives?
Q3. What is the purpose of inductor in dual converters?
Q4. What are the modes of operations for a dual converter?

Lab 13 – Three phase half controlled bridge converter

13.1 Introduction

The 3-phase half wave converter combines three single phase half wave controlled rectifiers in one single circuit feeding a common load. In this session operation of three phase half controlled bridge converter is presented.

13.2 Objective

By the end of this lab, the student should learn the operation of three phase half controlled bridge converter

13.3 Prelab Preparation:

Read the material in the textbook that describes operation of three phase half controlled bridge converter. Prior to coming to lab class, have glance of the Procedure.

13.4 Equipment needed

1. Three phase half controlled bridge converter power circuit and firing circuit
2. CRO with deferential module
3. Patch chords and probes
4. Three phase transformer
5. Variable Rheostat
6. DC Voltmeter(0-60V)
7. DC Ammeter(0-5A)

13.5 Background

Three-phase controlled rectifiers have a wide range of applications, from small rectifiers to large high-voltage direct-current (HVDC) transmission systems. They are used for electrochemical processes, many kinds of motor drives, traction equipment, controlled power supplies, and many other applications

13.6 Procedure

1. Make all connections as per the circuit diagram.

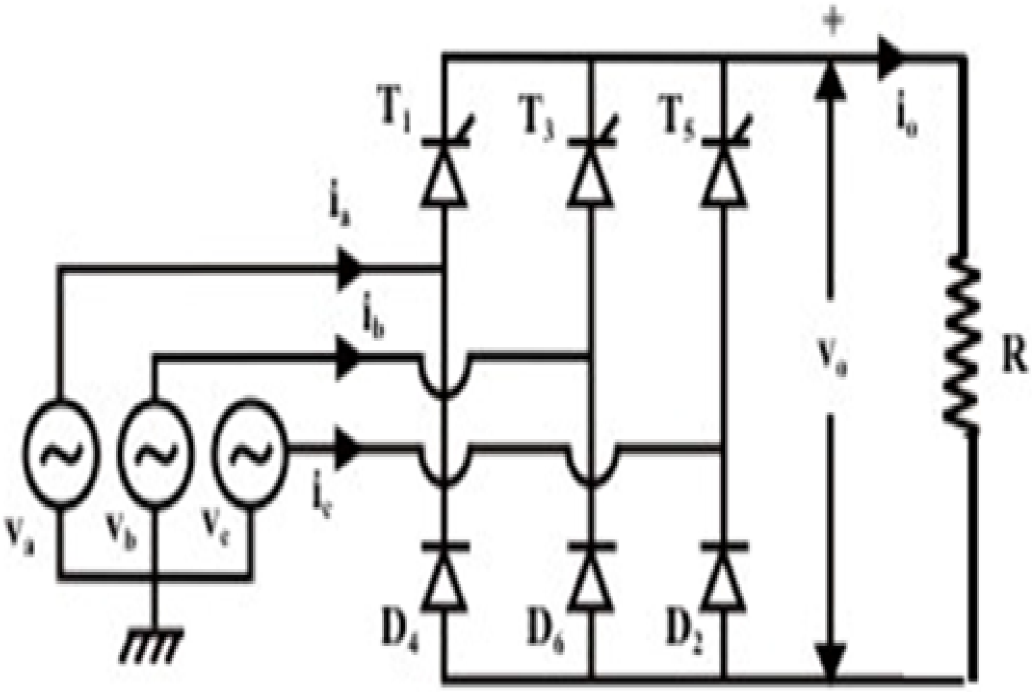

Fig – 13.1 Half Controlled bridge converter with R load

2. Connect firstly 3 phase AC supply from three phase transformer to circuit.
3. Connect firing pulses from firing circuit to Thyristors as indication in circuit.
4. Connect resistive load to load terminals and switch ON the MCB and IRS switch and trigger output ON switch.
5. Connect CRO probes and observe waveforms in CRO across load and device in three phase half controlled bridge converter.
6. By varying firing angle gradually up to 180 and observe related waveforms.
7. Measure output voltage and current by connecting DC voltmeter and Ammeter.
8. Tabulate all readings for various firing angles.
9. Calculate the output voltage and current by theoretically and compare with it practically obtained values.

13.7 Model Graphs

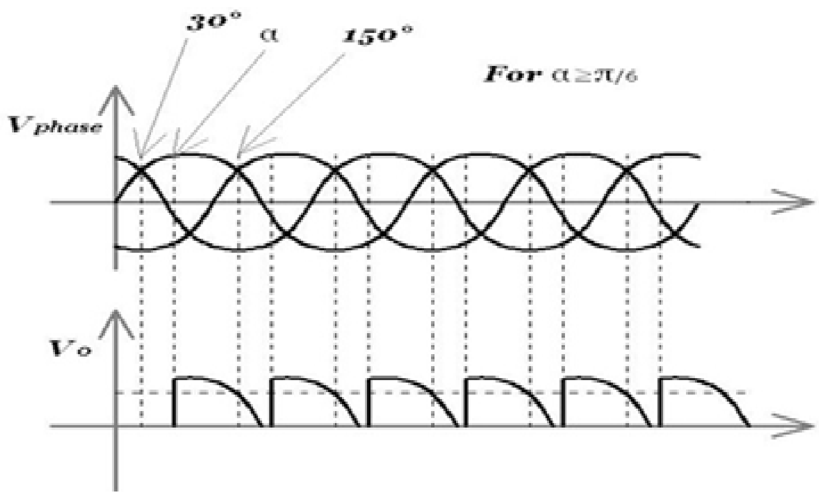

Fig – 13.2 output wave forms of a three phase half bridge converter

13.8 Probing Further Questions

Q1. A converter which can operate in both 3 pulse and six pulse modes is?
Q2. What is the interval for SCRs triggering in three phase semi converter?
Q3. What is the interval for SCRs triggering in three phase full converter?
Q4. What is the function of freewheeling diode in three phase converters?

Lab 14 – Simulation of three phase full converter and PWM inverter

14.1 Introduction

Three phase full converter is a fully controlled bridge controlled rectifier using six thyristors connected in the form of a full wave bridge configuration. All the six thyristors are controlled switches which are turned on at appropriate times by applying suitable gate trigger signals. Pulse Width Modulation or PWM technology is used in Inverters to give a steady output voltage of 230 or 110 V AC irrespective of the load. The Inverters based on the PWM technology are more superior to the conventional inverters. In this session simulation of three phase full converter and PWM inverter are presented.

14.2 Objective

By the end of this lab, the student should learn the simulation of three phase full converter and PWM inverter

14.3 Prelab Preparation:

Read the material in the textbook that describes simulation of three phase full converter and PWM inverter. Prior to coming to lab class, have glance of the Procedure.

14.4 Equipment needed

1. Desktop with MATLAB

14.5 Background

The three phase full converter is extensively used in industrial power applications upto about 120kW output power level, where two quadrant operations is required. The thyristors are triggered at an interval of at an interval of 30 degrees. The frequency of output ripple voltage is 6fs and the filtering requirement is less than that of three phase semi and half wave converters. The use of MOSFETs in the output stage and the PWM technology makes these inverters ideal for all types of loads. In addition to the pulse width modulation, the PWM Inverters have additional circuits for protection and voltage control.

14.6 Procedure

1. Make the connections as shown in the figures by using MATLAB Simulink.

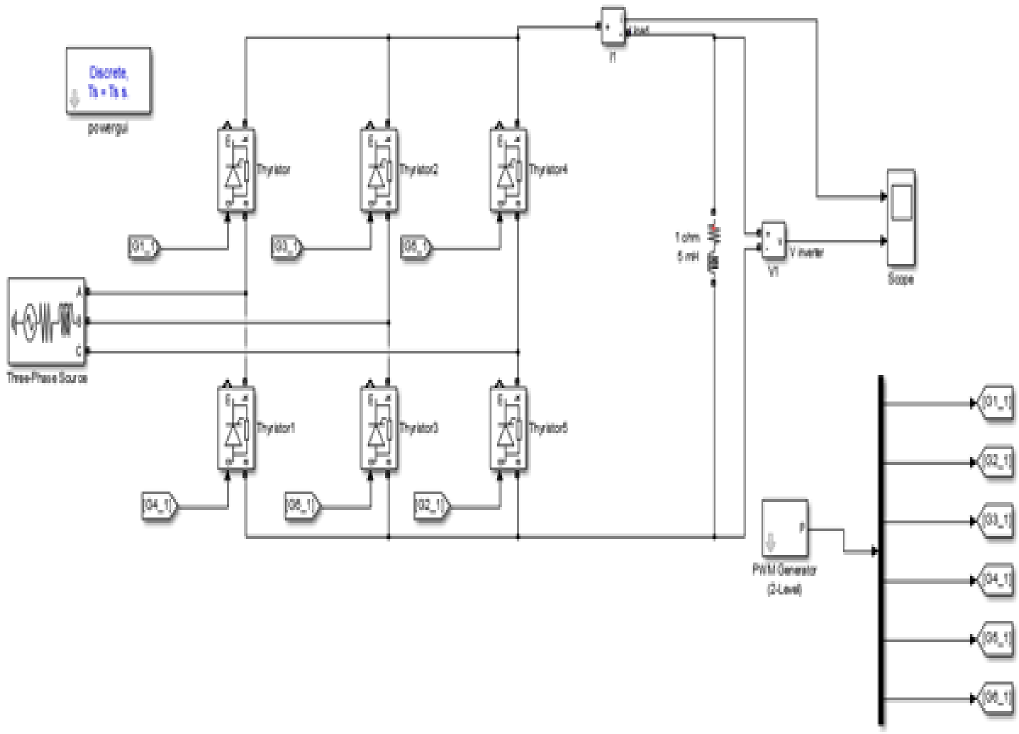

Figure14.1 Circuit diagram for three phase full converter

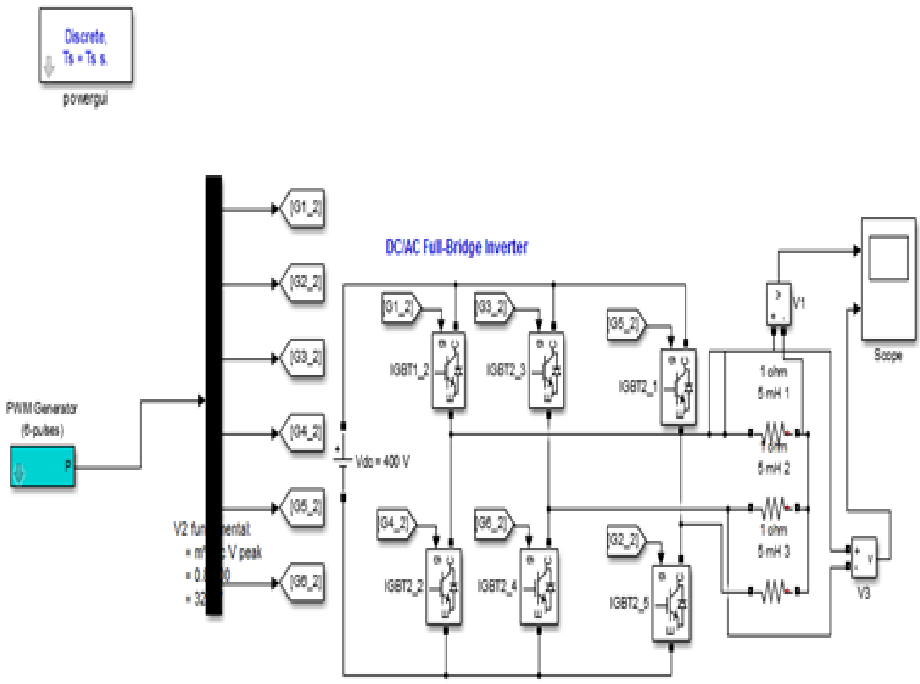

Figure14.2 Circuit diagram for PWM Inverter

2. Set the parameters in PWM generator for firing the switches, set the values for load and input voltage.
3. Check the scope wave forms in each circuit.

14.7 Model Graphs

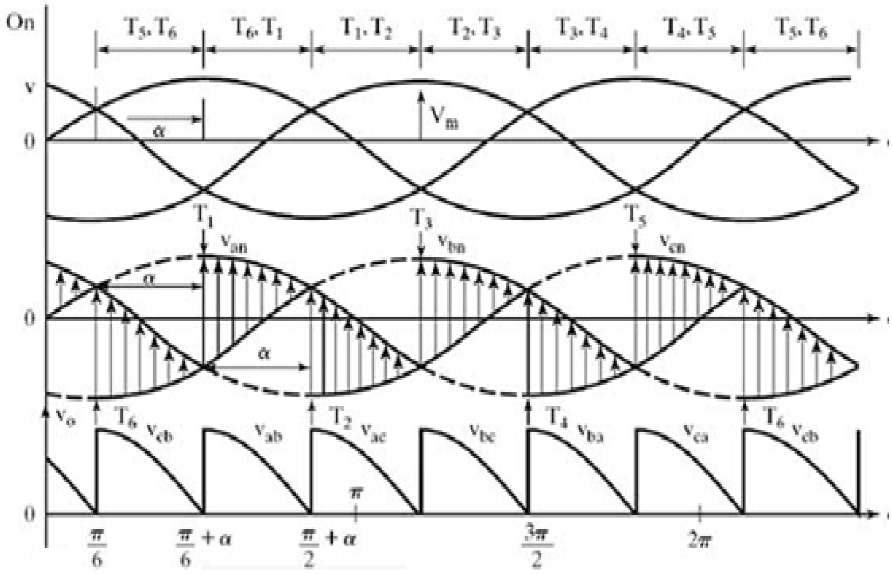

Figure 14.3 Output waveforms of three phase full converter

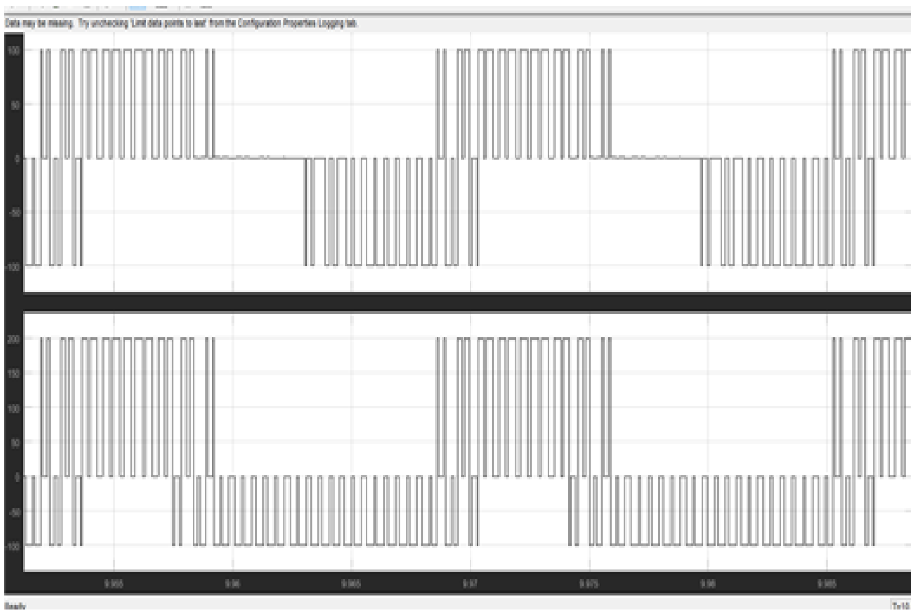

Figure 14.4 Output waveforms of PWM Inverter

14.8 Probing Further Questions

Q1. What are the advantages of PWM inverters?
Q2. What is the difference between three phase and single phase inverters?
Q3. What is the time delay for each thyristor conduction in three phase full converter?

Lab 15 – Simulation of buck – boost chopper

15.1 Introduction

DC-DC converters are also known as Choppers. Here we will have a look at 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. In this session simulation of boost, buck, buck boost converter with R and RL loads are presented.

15.2 Objective

By the end of this lab, the student should learn the simulation of boost, buck, buck boost converter with R and RL loads

15.3 Prelab Preparation:

Read the material in the textbook that describes simulation of boost, buck, buck boost converter with R and RL loads. Prior to coming to lab class, have glance of the Procedure.

15.4 Equipment needed

1. Desktop with MATLAB

15.5 Background

The input voltage source is connected to a solid state device. The second switch used is a diode. The diode is connected, in reverse to the direction of power flow from source, to a capacitor and the load and the two are connected in parallel. The controlled switch is turned on and off by using Pulse Width Modulation (PWM). PWM can be time based or frequency based. Frequency based modulation has disadvantages like a wide range of frequencies to achieve the desired control of the switch which in turn will give the desired output voltage. Time based Modulation is mostly used for DC-DC converters. It is simple to construct and use. The frequency remains constant in this type of PWM modulation. The Buck Boost converter has two modes of operation. The first mode is when the switch is on and conducting. The Switch is ON and therefore represents a short circuit ideally offering zero resistance to the flow of current so when the switch is ON all the current will flow through the switch and 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.

15.6 Procedure

1. Make all connections as per the circuit diagram.

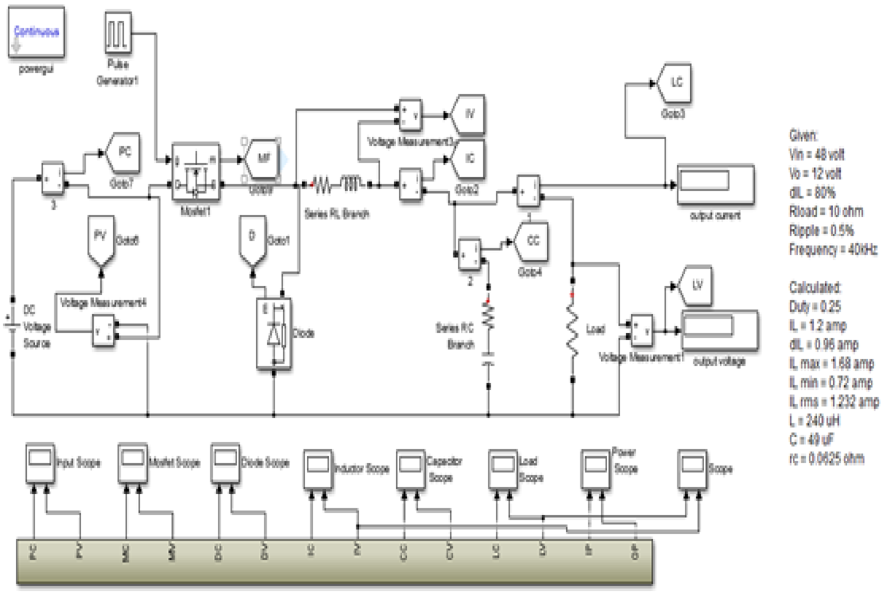

Figure15.1 circuit diagram for Buck converter

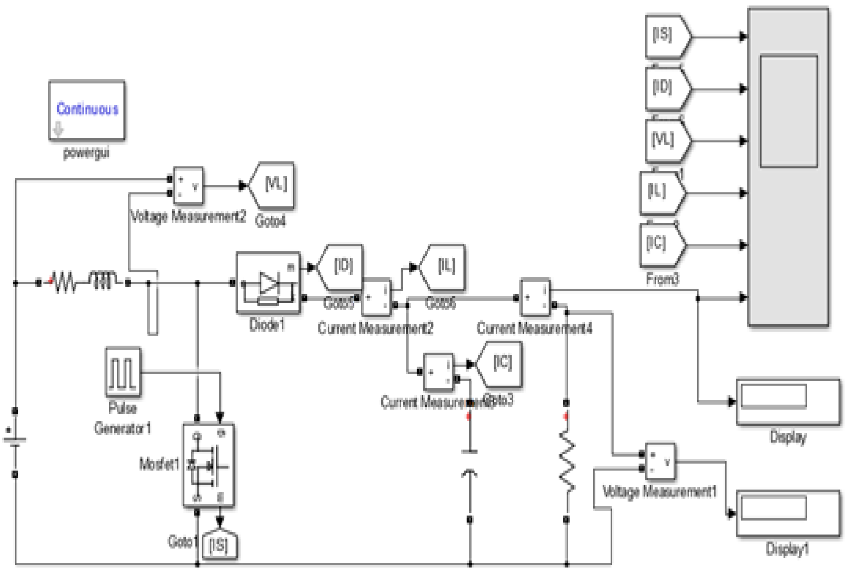

Figure15.1 circuit diagram for boost converter

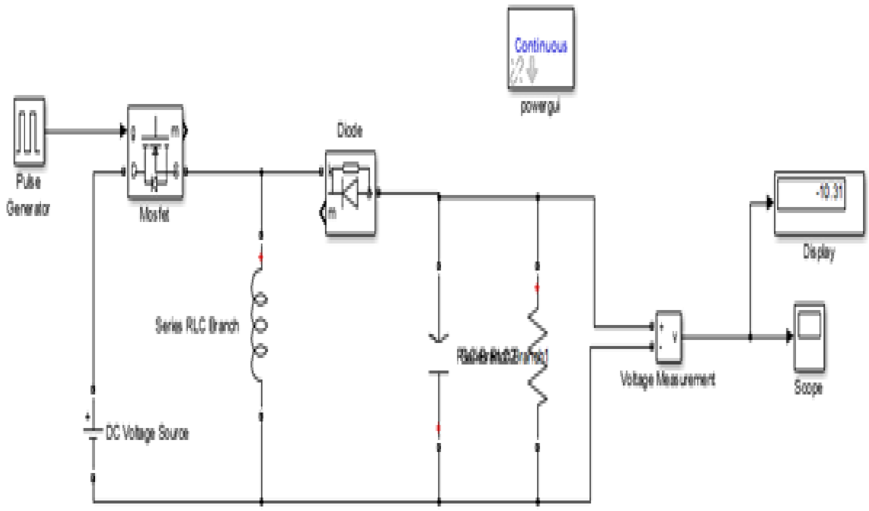

Figure15.1 circuit diagram forbuck boost converter

2. Set the parameters in PWM generator for firing the switches, set the values for load and input voltage.
3. Check the scope wave forms in each circuit.

15.7 Probing Further Questions

Q1. What is DC-DC step up converter?
Q2. What is buck converter?
Q3. What is principle of operation of buck boost converter?