Department of Electronic Engineering
NED University of Engineering & Technology

PRACTICAL WORK BOOK

For the course

POWER ELECTRONICS
(EL-344) For TE (EL)/ BS (AP)

Instructor's Name: ______________________
Student Name: ______________________
Roll No.: ______________ **Batch:** ______________
Semester : ______________ **Year:** ______________
Department: ______________________

LABORATORY WORK BOOK
FOR THE COURSE

POWER ELECTRONICS (EL-344)

Prepared By:

Ms. Hira Imtiaz (Lecturer)

Reviewed By:

Mr. Shahzad Siddiqui (Assistant Professor)

Approved By:

The Board of Studies of Department of Electronic Engineering

Power Electronic Laboratory

CONTENTS

LAB SESSION 01

Objective

To practice the 1-phase halfwave uncontrolled rectifier and 1-phase uncontrolled bridge rectifier circuit.

Components Required

- Diodes (5) –1N4001--7
- Resistor (2) –2.2k Ω / 1/4 Watt
- Transformer (1) –12-12 V/ 400mA or 600mA with power cord properly attached
- Breadboard

Introduction

Rectifier is a circuit that converts AC voltage to DC voltage (pulsating DC). There are single phase rectifiers that are used to convert single phase ac supply as well as 3 phase rectifiers for 3 phase ac supply. Each category of rectifier is further divided into uncontrolled rectifiers, controlled rectifiers and half controlled rectifiers. Diode is the main component for uncontrolled rectifiers while thyristor is used in controlled rectifiers. Half controlled rectifiers have both the thyristors and diodes.

This lab is about single phase uncontrolled rectifiers. As diode is the main component of uncontrolled rectifiers so first have a quick overview of diode. Diode is a nonlinear two terminal semiconductor device that allows current flow in one direction only. The two terminals are anode and cathode as shown in Figure 1.1. Current flows from anode to cathode whenever the potential of anode is greater than cathode potential.

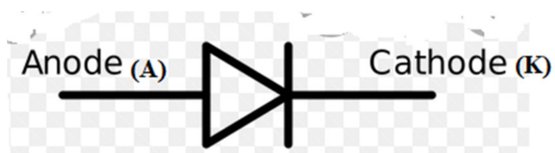

Figure 1.1: Diode symbol and its terminals

Single phase halfwave uncontrolled rectifier is shown in Figure 1.2. During positive cycle of

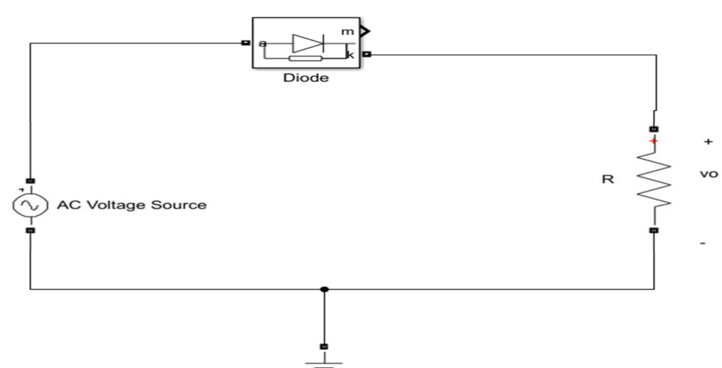

Figure 1.2: Single phase Halfwave Uncontrolled Rectifier Circuit

input the diode will be forward biased and will be replaced with short circuit so the output voltage will follow the input voltage. While during negative cycle of input the diode will be reverse biased and will behave as open circuit so the output voltage will become equal to zero as shown in Figure 1.3. Halfwave recitifier generates output for half of the input cycle while for the rest half output will be zero.

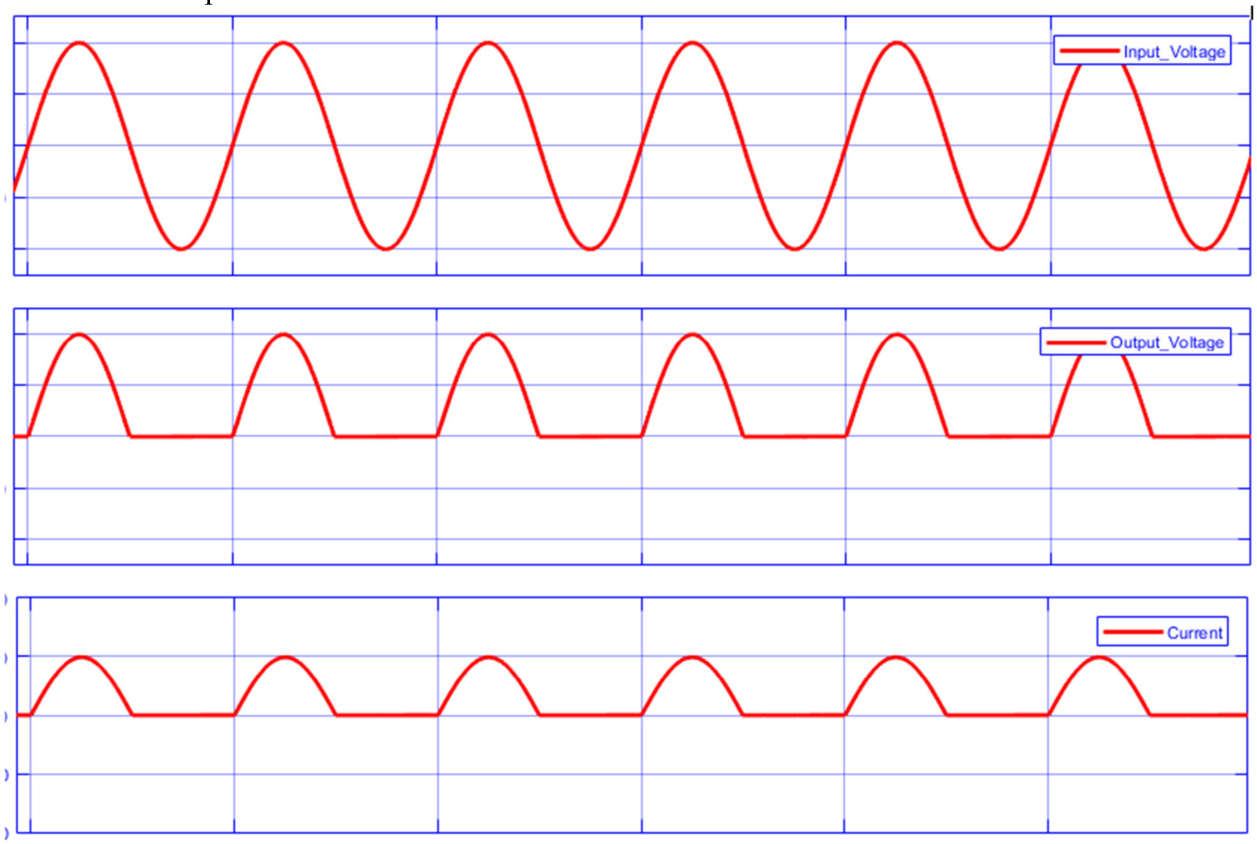

Figure 1.3: Single Phase Halfwave Uncontrolled Rectifier Input and Output Waveforms

Remember that the explanation above is for single phase halfwave rectifier with resistive load. The ON duration of diode and thus the shape of output waveform depend on the nature of load, whether the load is resistive or RL

Single phase uncontrolled bridge rectifier is shown in Figure 1.4. Diodes D1 and D3 are

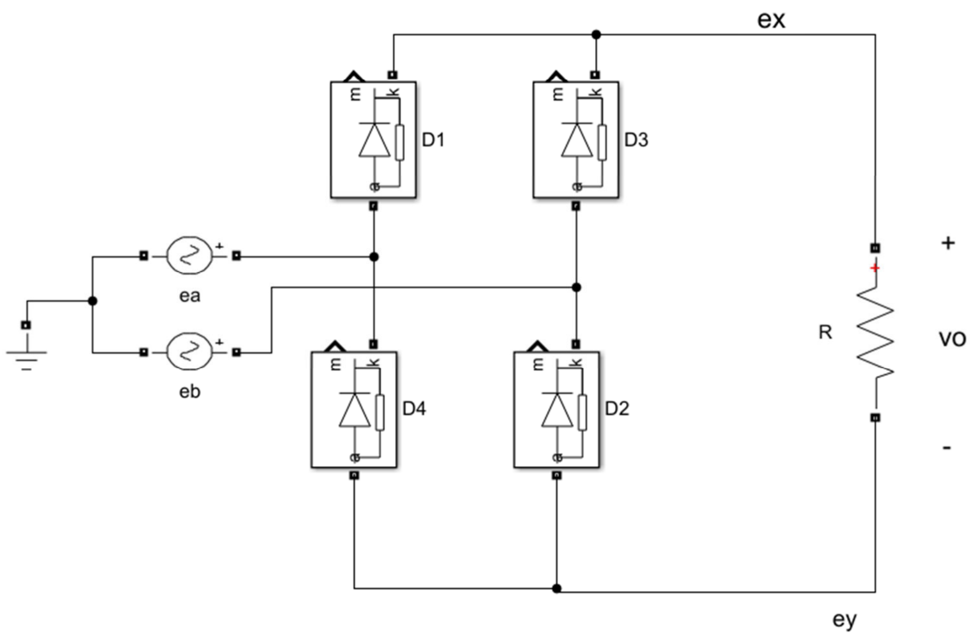

Figure 1.4: Single Phase Uncontrolled Bridge Rectifier Circuit

connected in common cathode configuration i.e. their cathodes are common while the anodes are connected with ea and eb respectively. In common cathode configuration the diode having highest potential at anode will be forward biased/ ON.

Diodes D2 and D4 are connected in common anode configuration i.e. their anodes are common while the cathodes are connected with eb and ea respectively. In common anode configuration the diode having least potential at cathode will be forward biased/ ON.

From 0 to 180^0, the potential of ea is highest so at common cathode terminal D1 will be ON and ex will follow ea (which is positive). While as eb is lowest so D2 will be ON at common anode terminal and ey will follow eb (which is negative). The output voltage is differential of ex and ey, so, it will be positive and current will flow from terminal x to y in the load. From 180^0 to 360^0, the potential of eb is highest so at common cathode terminal D3 will be ON and ex will follow eb (which is positive). While as ea is lowest so D4 will be ON at common anode terminal and ey will follow ea (which is negative). The output voltage is differential of ex and ey, so, it will be positive and current will flow from terminal x to y in the load as shown in Figure 1.5. Bridge Rectifier generates output for complete cycle of input that's why it falls in fullwave rectifiers' category.

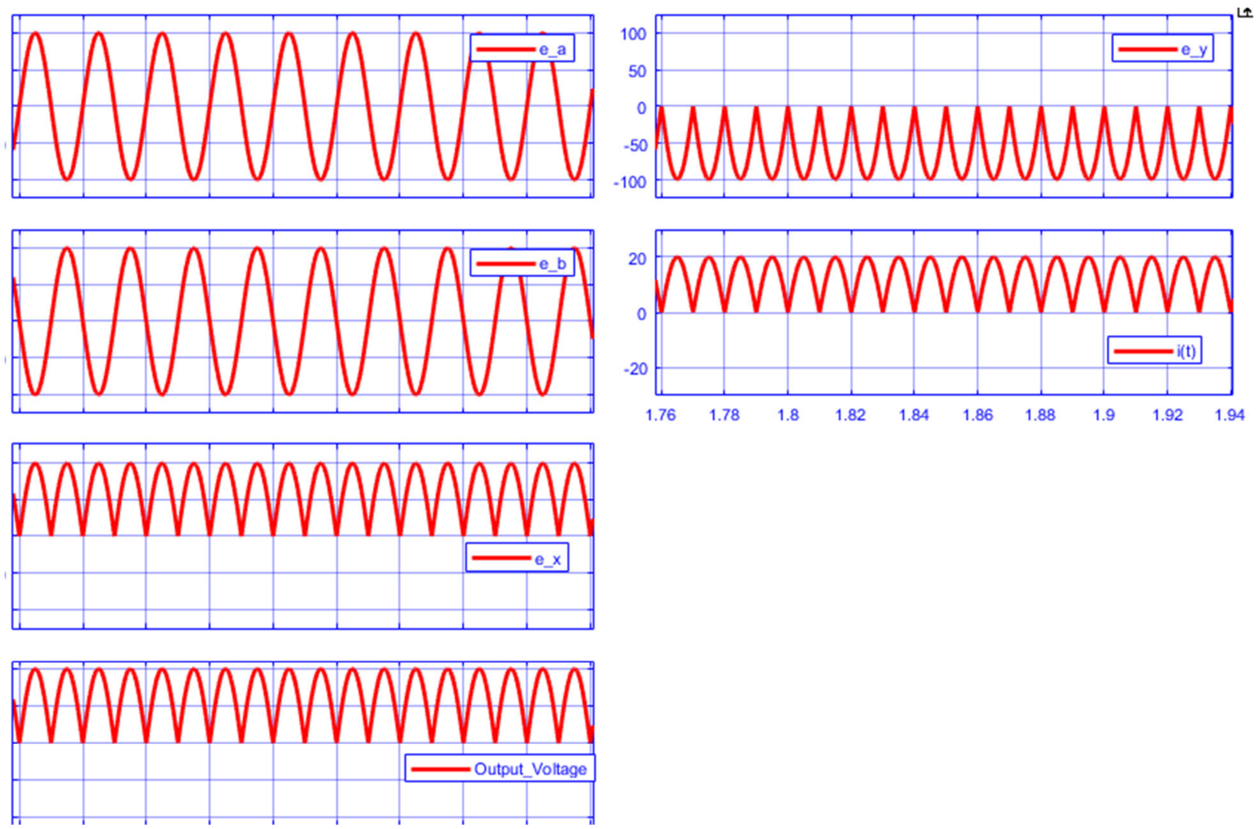

Figure 1.5: Single Phase Uncontrolled Bridge Rectifier Circuit Input and Output Waveforms

Procedure

- Implement the **single phase halfwave uncontrolled rectifier** circuit on breadboard as shown in the Figure 1.6.

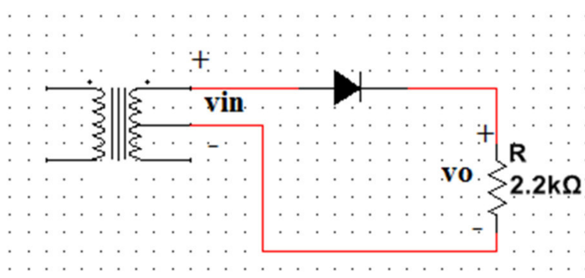

Figure 1.6: Single Phase Halfwave Uncontrolled Rectifier Circuit

- Insert plug of transformer in the socket and turn the supply ON.
- Observe the input voltage waveform (between the transformer terminals that are attached with the circuit) on oscilloscope. Measure its peak to peak, peak, frequency, mean and RMS voltage.

- Observe the output voltage waveform (across the load) on oscilloscope. Measure its peak to peak, peak, frequency, mean and RMS voltage.
- Verify the results via calculations.

- Now implement the **single phase uncontrolled bridge rectifier** circuit on breadboard as shown in the Figure 1.7. Remember that center terminal of the transformer is not attached to any of the circuit nodes.

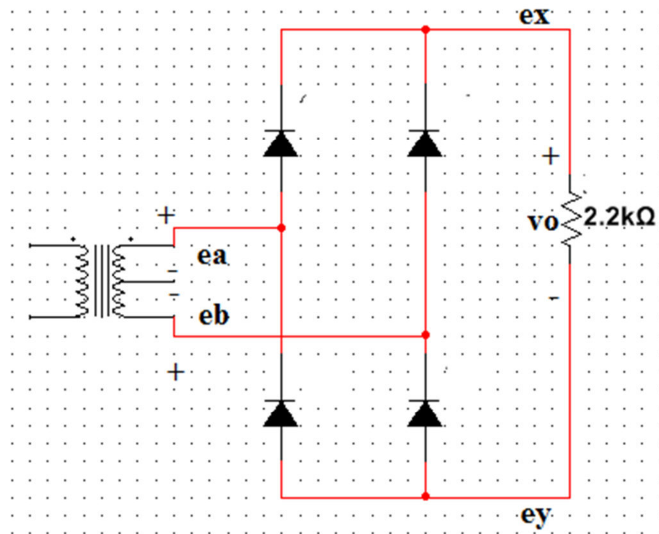

Figure 1.7: Single Phase Uncontrolled Bridge Rectifier Circuit

- Insert plug of transformer in the socket and turn the supply ON.
- Observe the waveform of input voltage ea (between one corner and center terminal of transformer). Measure its peak to peak, peak, frequency, mean and RMS voltage.

- Now observe the waveform of input voltage eb (between the other corner terminal and center terminal of the transformer. Measure its peak to peak, peak, frequency, mean and RMS voltage.

- Now observe both the waveforms ea and eb simultaneously and check the phase difference between the two waveforms.

- Now observe the waveform at terminal x (between common cathode terminal and center terminal of the transformer) on oscilloscope. Measure its peak to peak, peak, frequency and mean voltage.
- Verify the results via calculation.

- Now observe the waveform at terminal y (between common anode terminal and center terminal of the transformer) on oscilloscope. Measure its peak to peak, peak, frequency and mean voltage.
- Verify the results via calculation.

- Now observe the output waveform across the load on oscilloscope (between x terminal (common cathode) and y terminal (common anode)). Measure its peak to peak, peak, and mean voltage.
- Verify the results via calculations.

Observation and Calculation Chart:

1-phase Halfwave Uncontrolled Rectifier	
Input Voltage (obs.)	v_{in} • $V_{pk\text{-}pk}$= • V_{pk}= • Freq= • Mean= • RMS= • Waveform (Attach the waveform)
Output Voltage (obs.)	v_o • $V_{pk\text{-}pk}$= • V_{pk}= • Freq= • Mean= • RMS= • Waveform (Attach the waveform)
Output Voltage (cal.)	V_o • $V_{pk\text{-}pk}$= • Freq= • Mean= $\frac{Vpk}{\pi}$ // where Vpk is Vpk of v_{in}
1-phase Uncontrolled Bridge Rectifier	
Input Voltage (obs.)	e_a • $V_{pk\text{-}pk}$= • V_{pk}= • Freq=

	• Mean= • RMS= • Waveform (Attach the waveform)
Input Voltage (obs.)	e_b • V_{pk-pk}= • V_{pk}= • Freq= • Mean= • RMS= • Waveform (Attach the waveform)
Input Voltage (obs.)	Phase difference between e_a and e_b=
Voltage at Common Cathode terminal (x terminal) (obs.)	e_x • V_{pk-pk}= • V_{pk}= • Freq= • Mean= • Waveform (Attach the waveform)
Voltage at Common Cathode terminal (x terminal) (cal.)	e_x • Mean= $\frac{2Vpk}{\pi}$ // where Vpk is Vpk of e_a • Freq= 2* Freq of e_a
Voltage at Common Anode terminal (y terminal) (obs.)	e_y • V_{pk-pk}= • V_{pk}= • Freq=

	• Mean= • Waveform (Attach the waveform)
Voltage at Common Anode terminal (y terminal) (cal.)	e_x • Mean= $-\frac{2Vpk}{\pi}$ // where Vpk is Vpk of e_a • Freq= 2* Freq of e_a
Voltage at Common Cathode terminal (x terminal) and Voltage at Common Anode terminal (y terminal) (obs.)	e_x and e_y simultaneously • Waveform (Attach the waveform)
Output Voltage (obs.)	V_o • V_{pk-pk}= • V_{pk}= • Freq= • Mean= • Waveform (Attach the waveform)
Output Voltage (cal.)	V_o • Mean= $\frac{4Vpk}{\pi}$ // where Vpk is Vpk of e_a

	• Freq= 2* Freq of e_a

Post Lab:

Simulate the 1-phase half wave uncontrolled rectifier circuit with

a) Resistive Load
b) RL Load

Also simulate 1-phase uncontrolled bridge rectifier circuit on any circuit simulation software (Preferably Simulink) and observe all the input and output parameters.

F/OBEM 01/05/00

NED University of Engineering & Technology
Department of ____**ELECTRONIC**__ Engineering
Course Code and Title: ____**EL-344 POWER ELECTRONICS**______

Psychomotor Domain Assessment Rubric-Level P3					
Skill Sets	Extent of Achievement				
	0	1	2	3	4
Equipment Identification Sensory skill to ***identify*** equipment and/or its component for a lab work.	Not able to identify the equipment.	--	--	--	Able to identify equipment as well as its components.
Equipment Use Sensory skills to ***demonstrate*** the use of the equipment for the lab work.	Doesn't demonstrate the use of equipment.	Slightly demonstrates the use of equipment.	Somewhat demonstrates the use of equipment.	Moderately demon strates the use of equipment.	Fully demonstrates the use of equipment.
Procedural Skills ***Displays*** skills to act upon sequence of steps in lab work.	Not able to either learn or perform lab work procedure.	Able to slightly understand lab work procedure and perform lab work.	Able to somewhat understand lab work procedure and perform lab work.	Able to moderately understand lab work procedure and perform lab work.	Able to fully understand lab work procedure and perform lab work.
Response Ability to ***imitate*** the lab work on his/her own.	Not able to imitate the lab work.	Able to slightly imitate the lab work.	Able to somewhat imitate the lab work.	Able to moderately imitate the lab work.	Able to fully imitate the lab work.
Observation's Use ***Displays*** skills to use the observations from lab work for experimental verifications and illustrations.	Not able to use the observations from lab work for experimental verifications and illustrations.	Slightly able to use the observations from lab work for experimental verifications and illustrations.	Somewhat able to use the observations from lab work for experimental verifications and illustrations.	Moderately able to use the observations from lab work for experimental verifications and illustrations.	Fully able to use the observations from lab work for experimental verifications and illustrations.
Safety Adherence Adherence to ***safety*** procedures.	Doesn't adhere to safety procedures.	Slightly adheres to safety procedures.	Somewhat adheres to safety procedures.	Moderately adheres to safety procedures.	Fully adheres to safety procedures.
Equipment Handling ***Equipment care*** during the use.	Doesn't handle equipment with required care.	Rarely handles equipment with required care.	Occasionally handles equipment with required care.	Often handles equipment with required care.	Handles equipment with required care.
Group Work ***Contributes*** in a group based lab work.	Doesn't participate and contribute.	Slightly participates and contributes.	Somewhat participates and contributes.	Moderately participates and contributes.	Fully participates and contributes.

Laboratory Session No. ____01_______ Date: ______________________

Weighted CLO (Psychomotor Score)	
Remarks	
Instructor's Signature with Date:	

LAB SESSION 02

Objective

To operate under supervision the 1-phase halfwave controlled rectifier circuit (Resistive Control Method- α can vary between 0^0 and 90^0).

Components Required

- Diode (1) –1N4001--7
- Resistor (1) –2.2 k Ω / 1/4 Watt
- Resistor (1) – 68 k Ω
- Potentiometer (1) – 500 k Ω
- SCR(1) – C106
- Transformer (1) –12-12 V/ 400mA or 600mA with power cord properly attached
- Breadboard

Introduction

This lab is about single phase halfwave controlled rectifier. As SCR is the main component of controlled rectifiers so first have a quick overview of SCR. SCR is a three terminal (namely anode, cathode and gate) semiconductor device that allows current flow in one direction only i.e. from anode to cathode. SCR turns ON/ fire whenever the potential of anode is greater than cathode potential (i.e. SCR is forward biased) and a triggering signal/ pulse of appropriate amplitude is applied at the gate terminal. Once the thyristor get fired current flows from anode terminal to cathode terminal. Angle measured from the instant SCR gets forward biased to the instant it is triggered is known as **firing angle** and represented by **α**. The symbol and characteristic curve of SCR are shown in Figure 2.1.

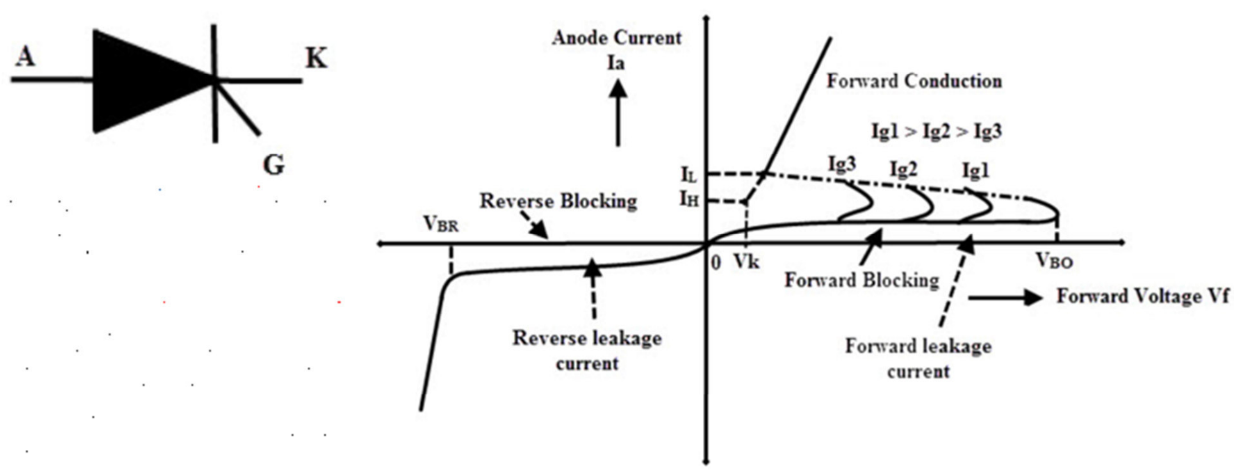

Figure 2.1: SCR Symbol and its Characteristic Curve

Three commonly used methods for generating gate pulse to fire/ON the SCR are:

- Resistive control method
- RC control method
- UJT firing method

In this lab the focus will be resistive control method. Single phase halfwave controlled rectifier is shown in the Figure 2.2.

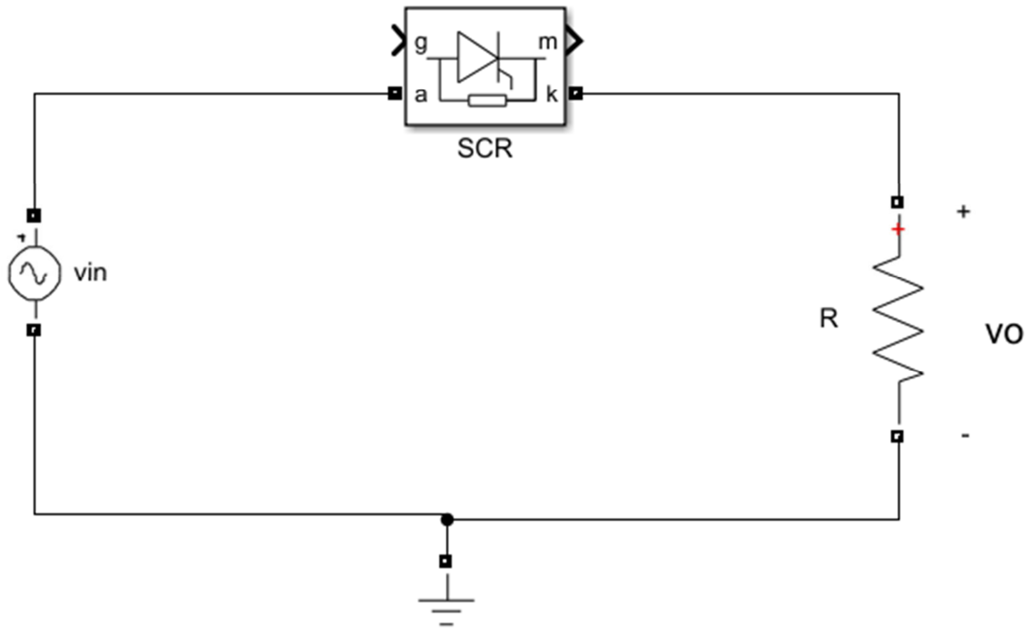

Figure 2.2: Single Phase Halfwave Controlled Rectifier

While the rectifier alongwith the controlling circuitry (resistive control method) is shown in Figure 2.3.

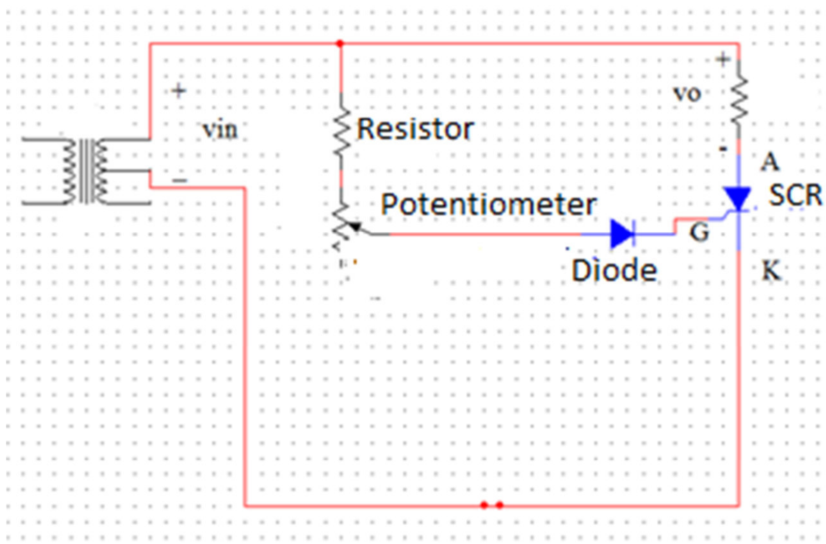

Figure 2.3: Single Phase Halfwave Controlled Rectifier and its Controlling Circuit

During positive cycle of input SCR will be forward biased but will turn ON when gate pulse will be applied. When the wiper of potentiometer is set at low value, there will be low voltage drop across the resistor and potentiometer combination. As a result of this, large gate current flows (desired current) even at low input voltage and SCR turns ON at low input/ anode voltage, equivalently at low firing angle. When the wiper of potentiometer is set at high value, there will be high voltage drop across the resistor and potentiometer combination. As a result of this the desired gate current (to fire the thyristor) will be available at high input/ anode voltage (near the peak of input). So firing angle will be near to 90^0. If the appropriate gate current doesn't generate till the positive peak of input, SCR will never get fired because after 90^0 same voltages appear that have appeared once before the 90^0. So for this method the firing angle varies in between 0 and 90^0. Once the SCR get fired, it will behave like short circuit and the output voltage will follow the input. During negative cycle of input SCR will be reverse biased, it will behave like open circuit and output voltage will be zero as shown in Figure 2.4.

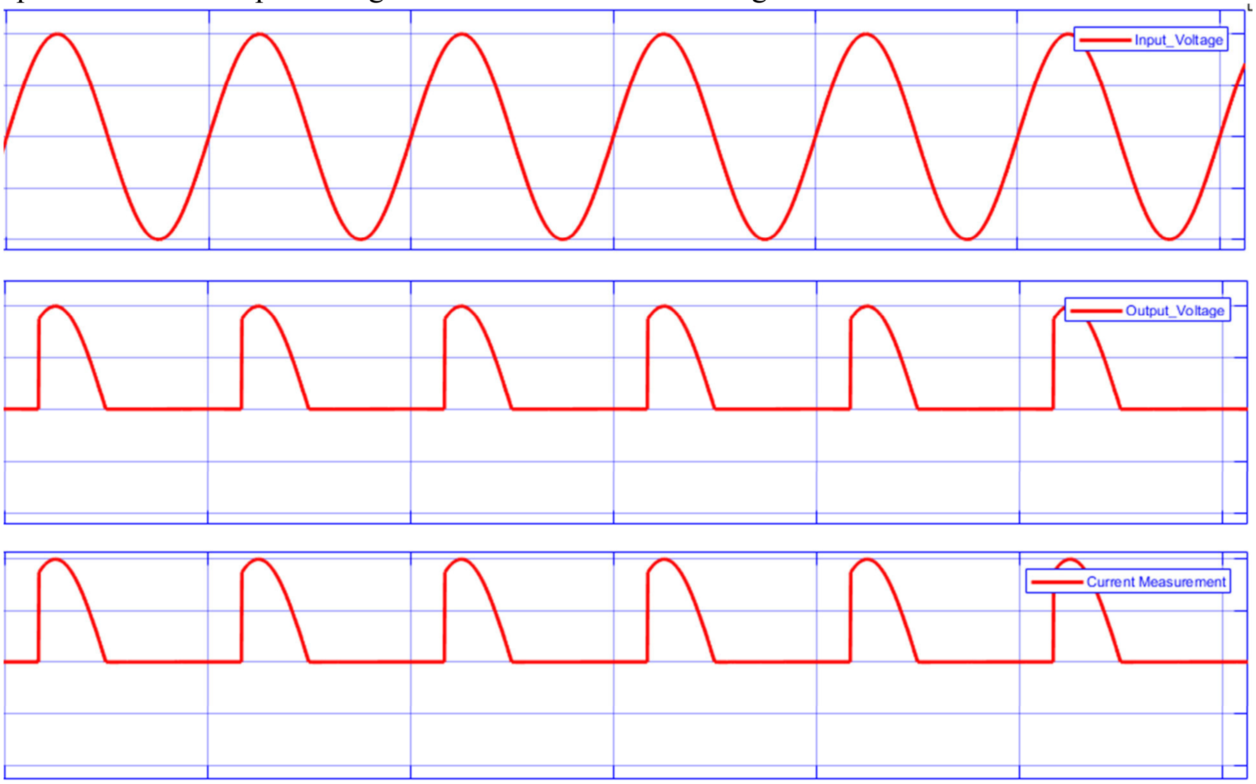

Figure 2.4: Single Phase Halfwave Controlled Rectifier Input and Output Waveforms

Remember that the explanation above is for single phase halfwave controlled rectifier with resistive load. The ON duration of SCR and thus the output waveform depends on the nature of load, whether the load is resistive or RL.

Procedure

- Implement the single phase halfwave controlled rectifier circuit on breadboard as shown in the Figure 2.5.

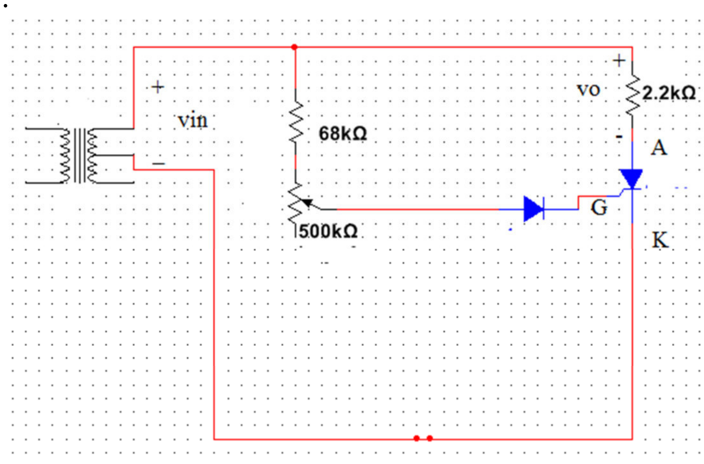

Figure 2.5: Single Phase Halfwave Controlled Rectifier

- Insert plug of transformer in the socket and turn the supply ON.
- Observe the input voltage waveform (between the transformer terminals that are attached with the circuit) on oscilloscope. Measure its peak to peak, peak, frequency, mean and

RMS voltage.

- Now adjust the potentiometer by observing the output waveform, there should be a waveform at the output (not a straight line) as shown in the Figure 2.6.

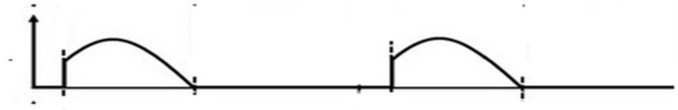

Figure 2.6: Output Waveform of Single Phase Halfwave Controlled Rectifier

- Observe the output voltage waveform (across the load) on oscilloscope. Measure its peak to peak, peak, frequency, mean and RMS voltage.
- Measure the value of tx using cursor option in the oscilloscope as shown in the Figure 2.7

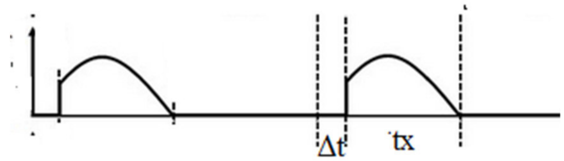

Figure 2.7: Measuring tx and Δt for Single Phase Halfwave Controlled Rectifier

- By using the value of tx determine Δt and calculate the value of α.
- Verify the output mean voltage and frequency via calculations.

Observation and Calculation Chart:

Input Voltage (obs.)	v_{in} • $V_{pk\text{-}pk}$= • V_{pk}= • Freq= • Mean= • RMS= • Waveform (Attach the waveform)
Output Voltage (obs.)	v_o • $V_{pk\text{-}pk}$= • V_{pk}= • Freq= • Mean= • RMS= • Waveform (Attach the waveform)

Output Voltage (obs.)	v_o • $tx =$
Output Voltage (cal.)	v_o • $\Delta t = 10m - tx$ • $\alpha = \frac{180}{10m} * \Delta t$
Output Voltage (cal.)	V_o • $V_{\mathbf{pk\text{-}pk}}=$ • Freq= • Mean= $\frac{Vpk}{\pi}(1 - sin^2 \frac{\alpha}{2})$ // where Vpk is Vpk of v_{in}

Post Lab:

Simulate the 1-phase halfwave controlled rectifier circuit with

a) Resistive load
b) RL load

and observe all the input and output parameters by keeping $\alpha = 60^0$

F/OBEM 01/05/00

NED University of Engineering & Technology
Department of ____**ELECTRONIC**__ Engineering
Course Code and Title: ____**EL-344 POWER ELECTRONICS**______

Psychomotor Domain Assessment Rubric-Level P3					
Skill Sets	Extent of Achievement				
	0	1	2	3	4
Equipment Identification Sensory skill to ***identify*** equipment and/or its component for a lab work.	Not able to identify the equipment.	--	--	--	Able to identify equipment as well as its components.
Equipment Use Sensory skills to ***demonstrate*** the use of the equipment for the lab work.	Doesn't demonstrate the use of equipment.	Slightly demonstrates the use of equipment.	Somewhat demonstrates the use of equipment.	Moderately demon strates the use of equipment.	Fully demonstrates the use of equipment.
Procedural Skills ***Displays*** skills to act upon sequence of steps in lab work.	Not able to either learn or perform lab work procedure.	Able to slightly understand lab work procedure and perform lab work.	Able to somewhat understand lab work procedure and perform lab work.	Able to moderately understand lab work procedure and perform lab work.	Able to fully understand lab work procedure and perform lab work.
Response Ability to ***imitate*** the lab work on his/her own.	Not able to imitate the lab work.	Able to slightly imitate the lab work.	Able to somewhat imitate the lab work.	Able to moderately imitate the lab work.	Able to fully imitate the lab work.
Observation's Use ***Displays*** skills to use the observations from lab work for experimental verifications and illustrations.	Not able to use the observations from lab work for experimental verifications and illustrations.	Slightly able to use the observations from lab work for experimental verifications and illustrations.	Somewhat able to use the observations from lab work for experimental verifications and illustrations.	Moderately able to use the observations from lab work for experimental verifications and illustrations.	Fully able to use the observations from lab work for experimental verifications and illustrations.
Safety Adherence Adherence to ***safety*** procedures.	Doesn't adhere to safety procedures.	Slightly adheres to safety procedures.	Somewhat adheres to safety procedures.	Moderately adheres to safety procedures.	Fully adheres to safety procedures.
Equipment Handling ***Equipment care*** during the use.	Doesn't handle equipment with required care.	Rarely handles equipment with required care.	Occasionally handles equipment with required care.	Often handles equipment with required care.	Handles equipment with required care.
Group Work ***Contributes*** in a group based lab work.	Doesn't participate and contribute.	Slightly participates and contributes.	Somewhat participates and contributes.	Moderately participates and contributes.	Fully participates and contributes.

Laboratory Session No. ____02_______ Date: ______________________

Weighted CLO (Psychomotor Score)	
Remarks	
Instructor's Signature with Date:	

LAB SESSION 03

Objective

To manipulate with guidance the 1-phase halfwave controlled rectifier circuit (RC Control Method- α can vary between 0^0 and 180^0).

Components Required

- Diodes (2) –1N4001--7
- Resistor (1) –2.2 k Ω / 1/4 Watt
- Resistor (1) – 4.7 k Ω / 1/4 Watt
- Potentiometer (1) – 50 k Ω
- SCR(1) – C106
- Capacitor (1) – 1µF/50V
- Transformer (1) –12-12 V/ 400mA or 600mA with power cord properly attached
- Breadboard

Introduction

This lab is about single phase halfwave controlled rectifier while RC controlling method will be used to trigger/ fire the SCR. The circuit diagram of single phase halfwave controlled rectifier is shown in Figure 3.1.

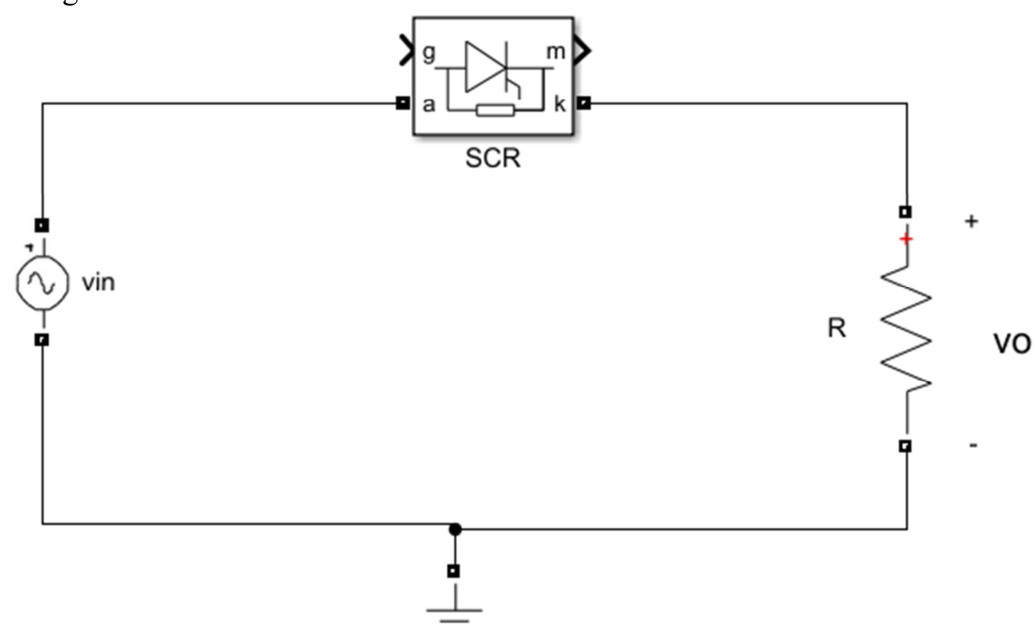

Figure 3.1: Single Phase Halfwave Controlled Rectifier

Rectifier alongwith the controlled circuitry is shown in the Figure 3.2.

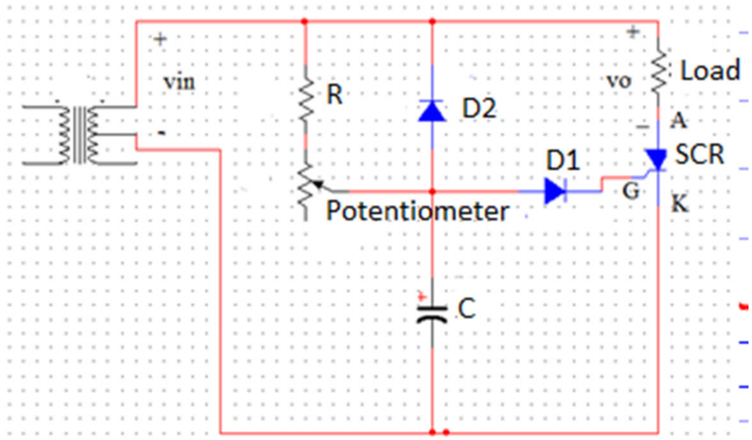

Figure 3.2: Single Phase Halfwave Controlled Rectifier and its Controlling Circuit

During negative cycle of input the capacitor will charge through diode D2. It will charge till the peak value. Top plate of the capacitor will be negatively charged while the bottom plate will be positive. Just after the negative peak of input the diode D2 will get reverse biased. Now capacitor will start to discharge through potentiometer and resistor. Depending on the position of potentiometer's wiper capacitor will discharge fast or slowly (τ = (Rpot+R)*C). Thus positive cycle will appear at input but capacitor is still discharging. When capacitor discharges completely, it will charge through the potentiometer with top plate being positively charged and then the desired gate current flows, D1 will turn ON and SCR get fired. Depending on the position of potentiometer's wiper, discharging of capacitor can be varied and thus SCR can be fired at any instant in the positive cycle of input. So for this method, firing angle can be varied anywhere in between 0 and 180^0. Remember that SCR will be reverse biased during the negative cycle of input thus it will behave like open circuit and output voltage will be zero as shown in Figure 3.3.

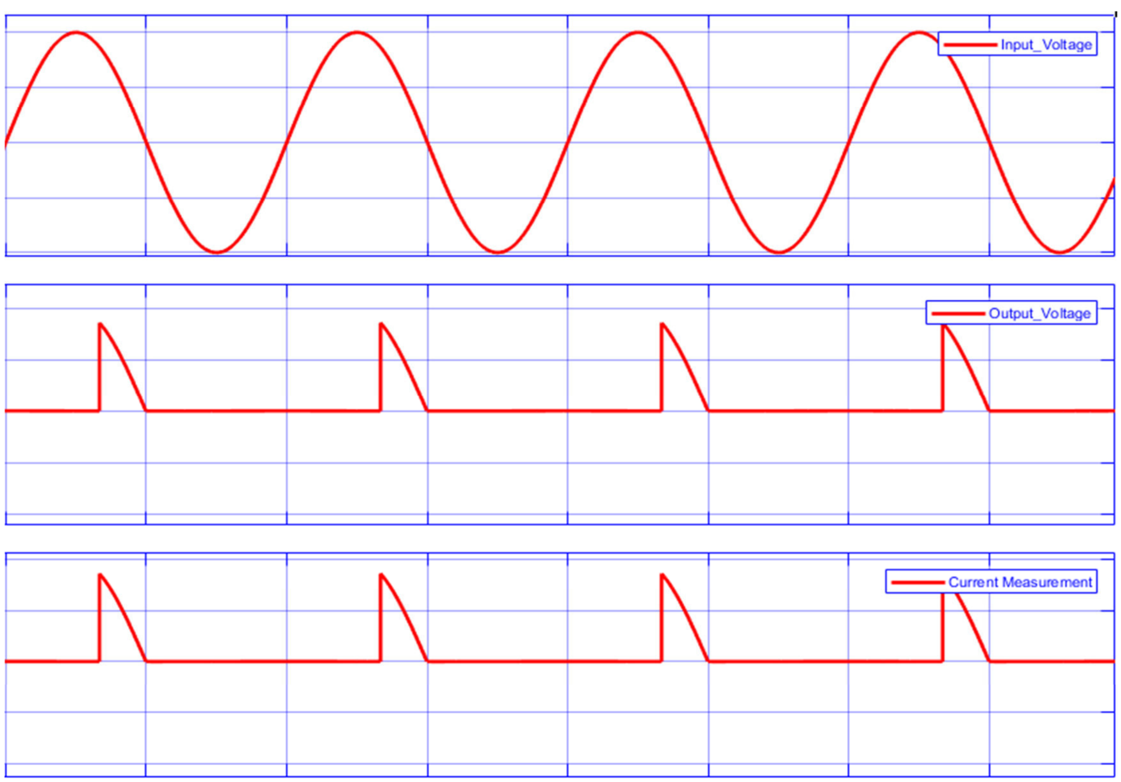

Figure 3.3: Single Phase Halfwave Controlled Rectifier Input and Output Waveforms

Remember that the explanation above is for single phase halfwave controlled rectifier with resistive load. The ON duration of SCR and thus the output waveform depends on the nature of load, whether the load is resistive or RL.

Procedure

- Implement the single phase halfwave controlled rectifier circuit on breadboard as shown in the Figure 3.4.

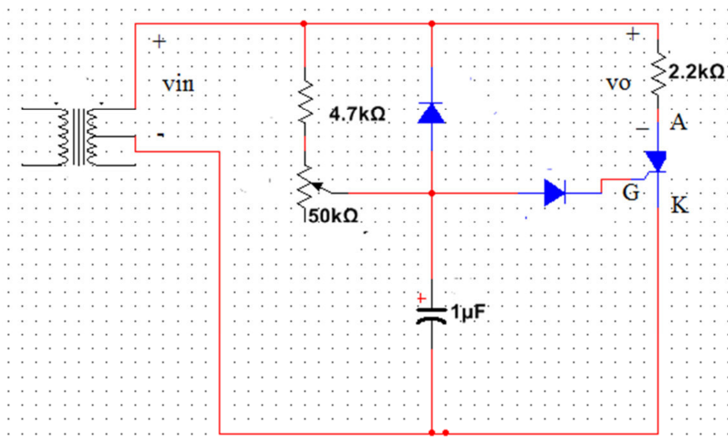

Figure 3.4: Single Phase Halfwave Controlled Rectifier

- Insert plug of transformer in the socket and turn the supply ON.
- Observe the input voltage waveform (between the transformer terminals that are attached with the circuit) on oscilloscope. Measure its peak to peak, peak, frequency, mean and RMS voltage.

- Now adjust the potentiometer by observing the output waveform, there should be a waveform at the output (not a straight line), and set **α** $<90^0$ as shown in the Figure 3.5.

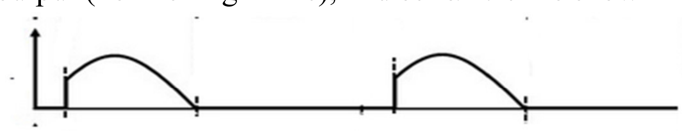

Figure 3.5: Output waveform for α < 90^0

- Observe the output voltage waveform (across the load) on oscilloscope. Measure its peak to peak, peak, frequency, mean and RMS voltage.
- Measure the value of tx using cursor option in the oscilloscope as shown in the Figure 3.6

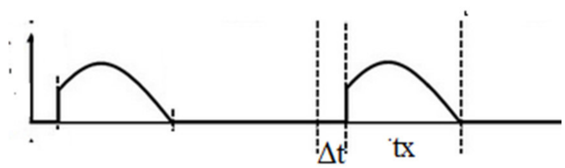

Figure 3.6: Measuring tx and Δt for Single Phase Halfwave Controlled Rectifier

- By using the value of tx determine Δt and calculate the value of α.
- Verify the output mean voltage and frequency via calculations.

- Now adjust the potentiometer by observing the output waveform, there should be a waveform at the output (not a straight line), and set $\boldsymbol{\alpha > 90^0}$.
- Observe the output voltage waveform (across the load) on oscilloscope. Measure its peak to peak, peak, frequency, mean and RMS voltage.
- Measure the value of tx using cursor option in the oscilloscope.
- By using the value of tx determine Δt and calculate the value of α.
- Verify the output mean voltage and frequency via calculations.

Observation and Calculation Chart:

Input Voltage (obs.)	v_{in} • $V_{\mathbf{pk\text{-}pk}}$= • $V_{\mathbf{pk}}$= • Freq= • Mean= • RMS= • Waveform (Attach the waveform)
Output Voltage (obs.) (α <90^0)	v_o • $V_{\mathbf{pk\text{-}pk}}$= • $V_{\mathbf{pk}}$= • Freq= • Mean= • RMS= • Waveform (Attach the waveform)
Output Voltage (obs.) (α <90^0)	v_o • $tx =$
Output Voltage (cal.) (α <90^0)	v_o • $\Delta t = 10m - tx$ • $\alpha = \frac{180}{10m} * \Delta t$
Output Voltage (cal.) (α <90^0)	V_o • $V_{\mathbf{pk\text{-}pk}}$=

	• Freq= • Mean= $\frac{Vpk}{\pi}(1 - sin^2\frac{\alpha}{2})$ // where Vpk is Vpk of v_{in}
Output Voltage (obs.) (α >90^0)	v_o • $V_{pk\text{-}pk}$= • V_{pk}= • Freq= • Mean= • RMS= • Waveform (Attach the waveform)
Output Voltage (obs.) (α >90^0)	v_o • $tx =$
Output Voltage (cal.) (α >90^0)	v_o • Δt =$10m - tx$ • α= $\frac{180}{10m} * \Delta t$
Output Voltage (cal.) (α >90^0)	V_o • Freq=

	• Mean= $\frac{Vpk}{\pi}(1 - sin^2\frac{\alpha}{2})$ // where Vpk is Vpk of v_{in}

Post Lab:

Simulate the 1-phase halfwave controlled rectifier circuit with

a) Resistive load
b) RL load

and observe all the input and output parameters by keeping α= 120^0

F/OBEM 01/05/00

NED University of Engineering & Technology
Department of ____**ELECTRONIC**__ Engineering
Course Code and Title: ____**EL-344 POWER ELECTRONICS**______

Psychomotor Domain Assessment Rubric-Level P3					
Skill Sets	Extent of Achievement				
	0	1	2	3	4
Equipment Identification Sensory skill to ***identify*** equipment and/or its component for a lab work.	Not able to identify the equipment.	--	--	--	Able to identify equipment as well as its components.
Equipment Use Sensory skills to ***demonstrate*** the use of the equipment for the lab work.	Doesn't demonstrate the use of equipment.	Slightly demonstrates the use of equipment.	Somewhat demonstrates the use of equipment.	Moderately demon strates the use of equipment.	Fully demonstrates the use of equipment.
Procedural Skills ***Displays*** skills to act upon sequence of steps in lab work.	Not able to either learn or perform lab work procedure.	Able to slightly understand lab work procedure and perform lab work.	Able to somewhat understand lab work procedure and perform lab work.	Able to moderately understand lab work procedure and perform lab work.	Able to fully understand lab work procedure and perform lab work.
Response Ability to ***imitate*** the lab work on his/her own.	Not able to imitate the lab work.	Able to slightly imitate the lab work.	Able to somewhat imitate the lab work.	Able to moderately imitate the lab work.	Able to fully imitate the lab work.
Observation's Use ***Displays*** skills to use the observations from lab work for experimental verifications and illustrations.	Not able to use the observations from lab work for experimental verifications and illustrations.	Slightly able to use the observations from lab work for experimental verifications and illustrations.	Somewhat able to use the observations from lab work for experimental verifications and illustrations.	Moderately able to use the observations from lab work for experimental verifications and illustrations.	Fully able to use the observations from lab work for experimental verifications and illustrations.
Safety Adherence Adherence to ***safety*** procedures.	Doesn't adhere to safety procedures.	Slightly adheres to safety procedures.	Somewhat adheres to safety procedures.	Moderately adheres to safety procedures.	Fully adheres to safety procedures.
Equipment Handling ***Equipment care*** during the use.	Doesn't handle equipment with required care.	Rarely handles equipment with required care.	Occasionally handles equipment with required care.	Often handles equipment with required care.	Handles equipment with required care.
Group Work ***Contributes*** in a group based lab work.	Doesn't participate and contribute.	Slightly participates and contributes.	Somewhat participates and contributes.	Moderately participates and contributes.	Fully participates and contributes.

Laboratory Session No. ____03_______ Date: ______________________

Weighted CLO (Psychomotor Score)	
Remarks	
Instructor's Signature with Date:	

LAB SESSION 04

Objective

To operate under supervision the 1-phase centertapped controlled rectifier circuit.

Components Required

- Diodes (2) –1N4001--7
- Resistor (5) –1 k Ω / 1/4 Watt
- Potentiometer (2) – 50 k Ω
- SCR (2) – C106
- Transformer (1) –12-12 V/ 400mA or 600mA with power cord properly attached
- Breadboard

Introduction

This lab is about single phase centertapped controlled rectifier. The circuit diagram of this rectifier is shown in Figure 4.1.

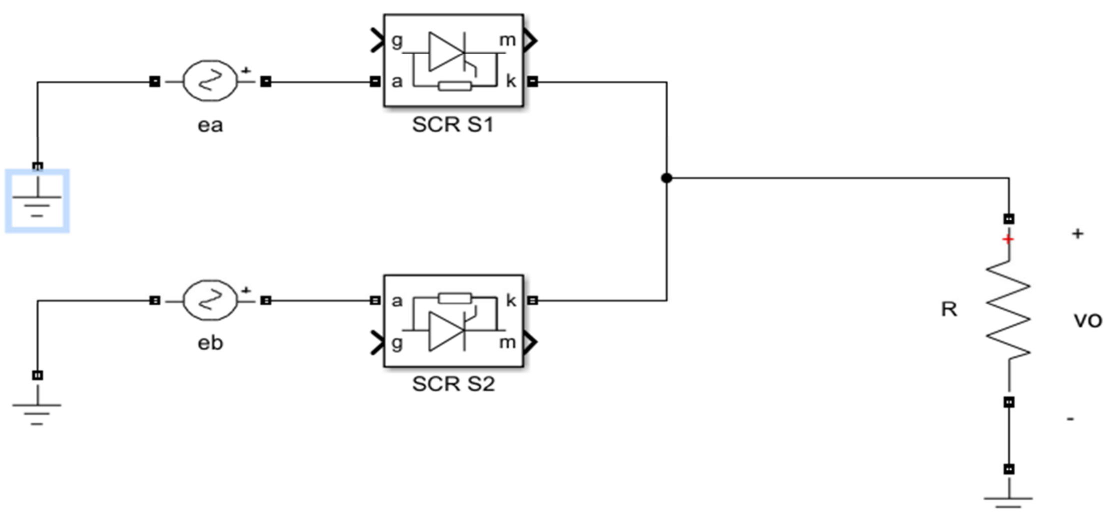

Figure 4.1: Single Phase Centertapped Controlled Rectifier

Here both the SCRs are connected in common cathode configuration. The SCR having highest potential at its anode will be forward biased. From 0 to180^0 ea is positive while eb is negative so SCR S1 will be forward biased while SCR S2 will be reverse biased and off/ open circuit. Although S1 is forward biased but it will wait for the gate pulse that will be applied at α. So from 0 to α both the SCRs are off/ open circuited and output voltage will be zero. As soon as S1 is fired, it will turn ON and will behave like short circuit. So, the output voltage will follow the input voltage (ea) from α to 180^0.

From 180^0 to 360^0 eb is positive while ea is negative so SCR S1 will be reverse biased and off/ open circuit while S2 will be forward biased. Although S2 is forward biased but it will wait for the gate pulse. So from 180^0 to (180^0+α) both the SCRs are off/ open circuited and output voltage will be zero. As soon as S2 is fired, it will turn ON and will behave like a short circuit. So, the output voltage will follow the input voltage (eb) from (180^0+α) to 360^0 as shown in the Figure 4.2.

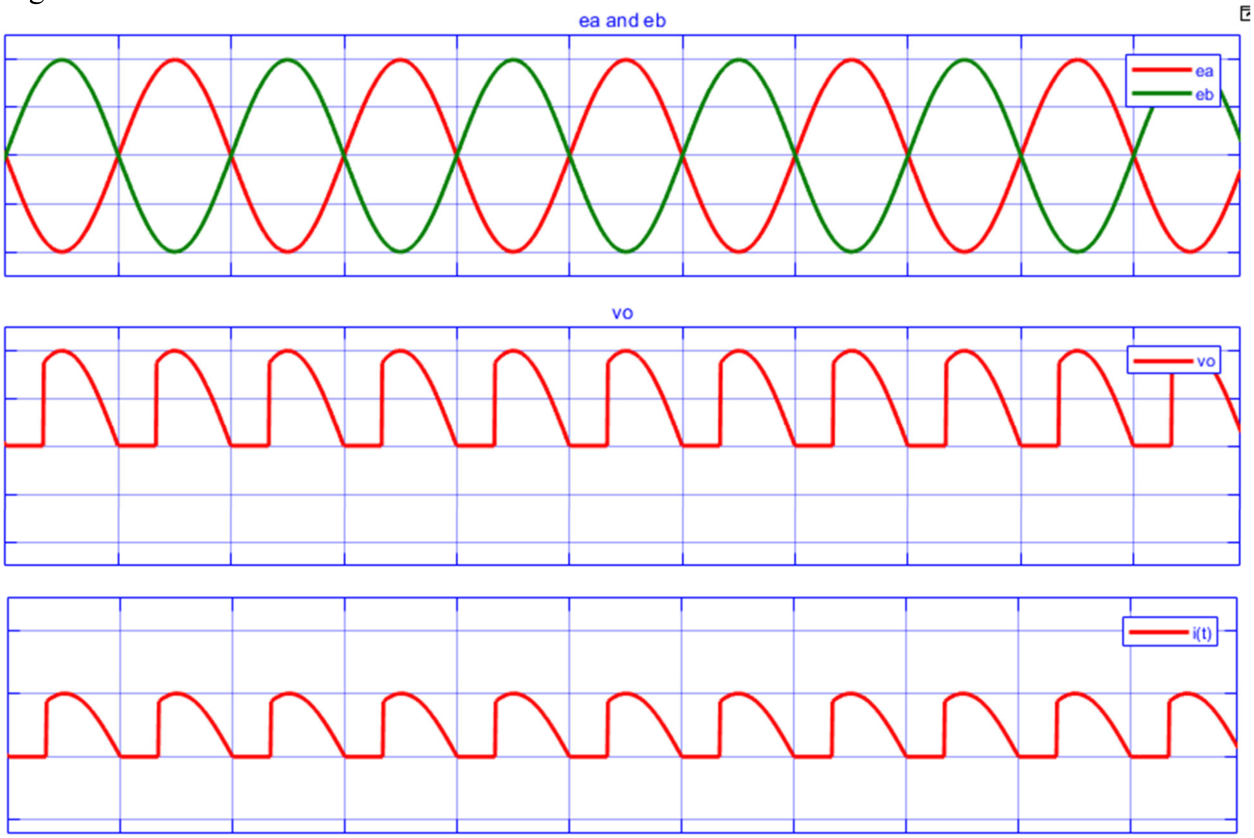

Figure 4.2: Single Phase Centertapped Controlled Rectifier Input and Output Waveforms

It can be noticed that output frequency is twice as of input frequency. As this rectifier generates output for complete cycle of input that's why it falls in fullwave rectifiers' category. In this lab resistive control method is used to trigger/ fire the SCR for simplicity. (Any gate triggering circuitry can be followed to fire the SCR). As resistive control method is used to fire the SCRs so α can vary between 0^0 and 90^0.
Remember that the explanation above is for single phase centertapped controlled rectifier with resistive load. The ON duration of SCR and thus the output waveform depends on the nature of load whether the load is resistive, RL on highly inductive.

Procedure

- Implement the single phase centertapped controlled rectifier circuit on breadboard, as shown in the Figure 4.3.

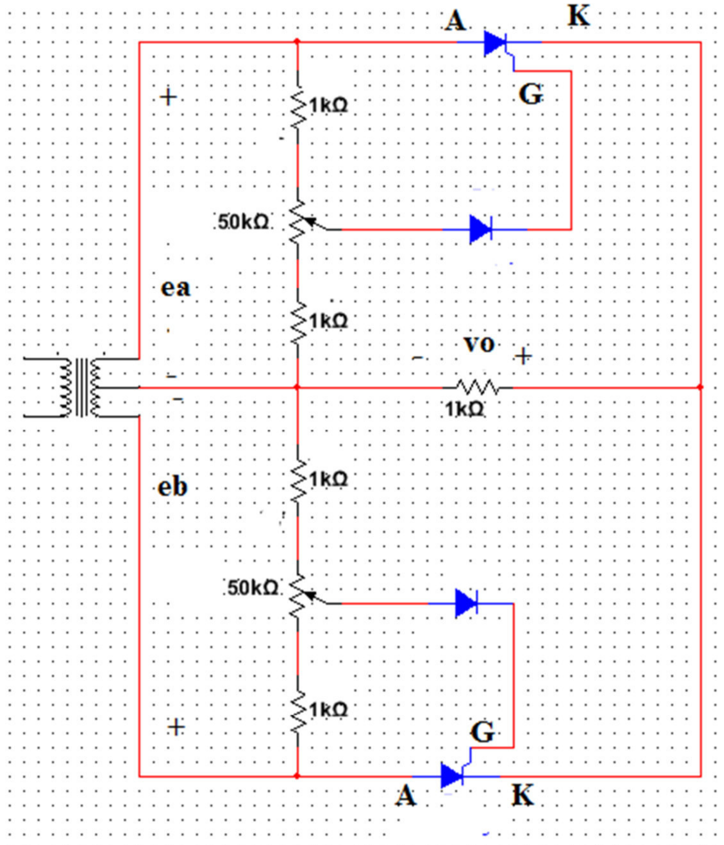

Figure 4.3: Single Phase Centertapped Controlled Rectifier and its Controlling Circuit

- Insert plug of transformer in the socket and turn the supply ON.
- Observe the waveform of input voltage ea (between one corner and center terminal of transformer). Measure its peak to peak, peak, frequency, mean and RMS voltage.

- Now observe the waveform of input voltage eb (between the other corner terminal and center terminal of the transformer. Measure its peak to peak, peak, frequency, mean and RMS voltage.

- Now observe both the waveforms ea and eb simultaneously and check the phase difference between the two waveforms.

- Now adjust all the potentiometers, by observing the output waveform. There should be a waveform at the output (not a straight line) as shown in the Figure 4.4. Adjust potentiometers to a position that firing angles for both the SCRs approximately be the same.

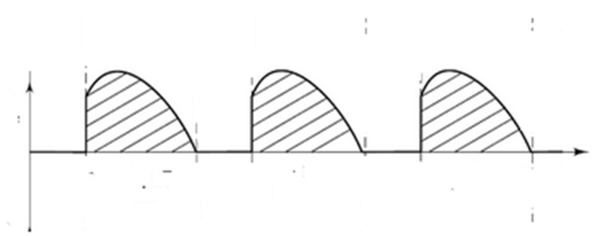

Figure 4.4: Output waveform for Single Phase Centertapped Controlled Rectifier

- Observe the output voltage waveform (across the load) on oscilloscope. Measure its peak to peak, peak, frequency, mean and RMS voltage.
- Measure the value of Δt using cursor option in the oscilloscope as shown in the Figure 4.5.

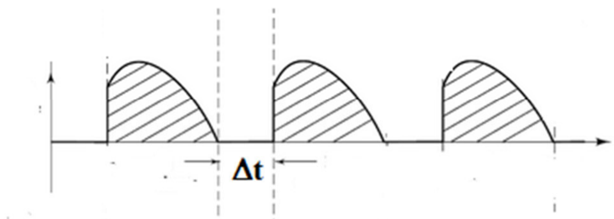

Figure 4.5: Measuring Δt for Single Phase Centertapped Controlled Rectifier

- By using the value of Δt calculate the value of α.
- Verify the output mean voltage and frequency via calculations.

Observation and Calculation Chart:

Input Voltage (obs.)	e_a • V_{pk-pk}= • V_{pk}= • Freq= • Mean= • RMS= • Waveform (Attach the waveform)
Input Voltage (obs.)	e_b • V_{pk-pk}= • V_{pk}= • Freq= • Mean= • RMS= • Waveform (Attach the waveform)
Input Voltage (obs.)	Phase difference between e_a and e_b=
Output Voltage (obs)	V_o • V_{pk-pk}= • V_{pk}=

	• Freq= • Mean= • Waveform (Attach the waveform)
Output Voltage (obs)	V_o • Δt =
Output Voltage (cal)	V_o • $\alpha = \frac{180}{10m} * \Delta t$
Output Voltage (cal)	V_o • Mean= $\frac{2Vpk}{\pi}(1 - sin^2 \frac{\alpha}{2})$ // where Vpk is Vpk of e_a • Freq= 2* Freq of e_a

Post Lab:

Simulate the 1-phase centertapped controlled rectifier circuit with

a) Resistive load
b) RL load
c) Highly Inductive load

and observe all the input and output parameters by keeping $\alpha = 60^0$

F/OBEM 01/05/00

NED University of Engineering & Technology
Department of ____**ELECTRONIC**__ Engineering
Course Code and Title: ____**EL-344 POWER ELECTRONICS**______

Psychomotor Domain Assessment Rubric-Level P3					
Skill Sets	Extent of Achievement				
	0	1	2	3	4
Equipment Identification Sensory skill to ***identify*** equipment and/or its component for a lab work.	Not able to identify the equipment.	--	--	--	Able to identify equipment as well as its components.
Equipment Use Sensory skills to ***demonstrate*** the use of the equipment for the lab work.	Doesn't demonstrate the use of equipment.	Slightly demonstrates the use of equipment.	Somewhat demonstrates the use of equipment.	Moderately demon strates the use of equipment.	Fully demonstrates the use of equipment.
Procedural Skills ***Displays*** skills to act upon sequence of steps in lab work.	Not able to either learn or perform lab work procedure.	Able to slightly understand lab work procedure and perform lab work.	Able to somewhat understand lab work procedure and perform lab work.	Able to moderately understand lab work procedure and perform lab work.	Able to fully understand lab work procedure and perform lab work.
Response Ability to ***imitate*** the lab work on his/her own.	Not able to imitate the lab work.	Able to slightly imitate the lab work.	Able to somewhat imitate the lab work.	Able to moderately imitate the lab work.	Able to fully imitate the lab work.
Observation's Use ***Displays*** skills to use the observations from lab work for experimental verifications and illustrations.	Not able to use the observations from lab work for experimental verifications and illustrations.	Slightly able to use the observations from lab work for experimental verifications and illustrations.	Somewhat able to use the observations from lab work for experimental verifications and illustrations.	Moderately able to use the observations from lab work for experimental verifications and illustrations.	Fully able to use the observations from lab work for experimental verifications and illustrations.
Safety Adherence Adherence to ***safety*** procedures.	Doesn't adhere to safety procedures.	Slightly adheres to safety procedures.	Somewhat adheres to safety procedures.	Moderately adheres to safety procedures.	Fully adheres to safety procedures.
Equipment Handling ***Equipment care*** during the use.	Doesn't handle equipment with required care.	Rarely handles equipment with required care.	Occasionally handles equipment with required care.	Often handles equipment with required care.	Handles equipment with required care.
Group Work ***Contributes*** in a group based lab work.	Doesn't participate and contribute.	Slightly participates and contributes.	Somewhat participates and contributes.	Moderately participates and contributes.	Fully participates and contributes.

Laboratory Session No. ____04_______ Date: ______________________

Weighted CLO (Psychomotor Score)	
Remarks	
Instructor's Signature with Date:	

LAB SESSION 05

Objective

To imitate the 3-phase half wave uncontrolled rectifier circuit on breadoard.

Components Required

- Diodes (3) –1N4001--7
- Resistor (1) –100 Ω/ 10 Watt
- Transformer (3) –12-12 V/ 1 A
- Breadboard

Introduction

This practical is about three phase halfwave uncontrolled rectifier. Three phase wye connected AC supply (shown in Figure 5.1) will be used as input to the rectifier circuit.

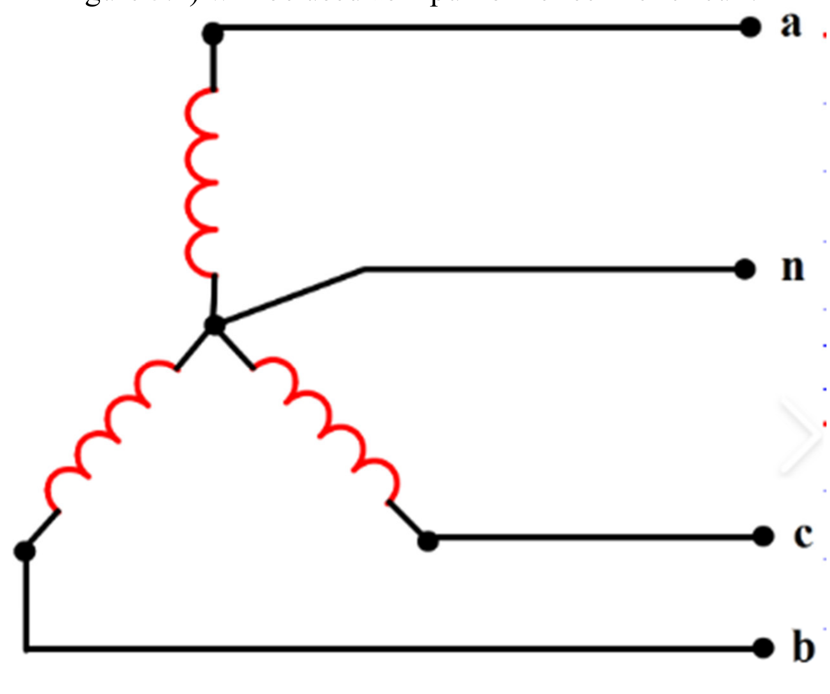

Figure 5.1: Three Phase Wye Connected AC Supply

So first have a quick review of 3 phase wye connected supply. It has three 3 phase terminal namely ***a***, ***b*** and ***c*** (having potentials ea, eb and ec respectively) and one neutral terminal ***n***. All phases have sinusoidal waveform that are equal in magnitude and frequency but 120^0 phase shifted from its precede as shown in Figure 5.2.

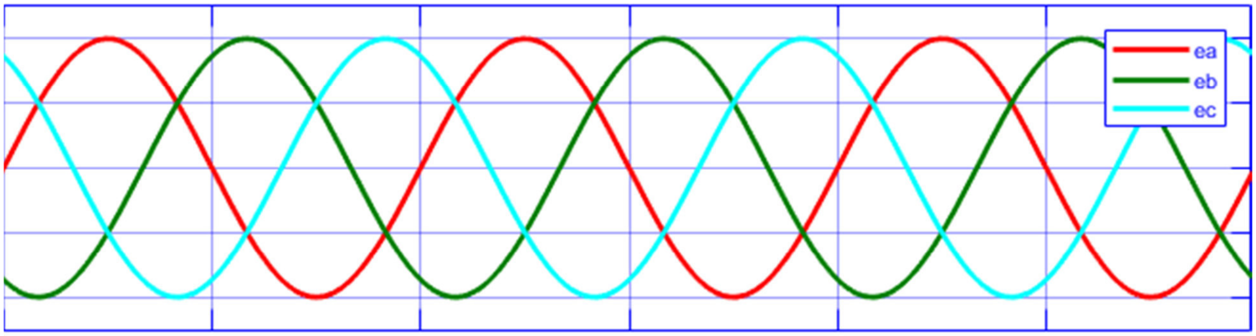

Figure 5.2: Three Phase AC Supply Waveforms

Three phase halfwave uncontrolled rectifier is shown in Figure 5.3.

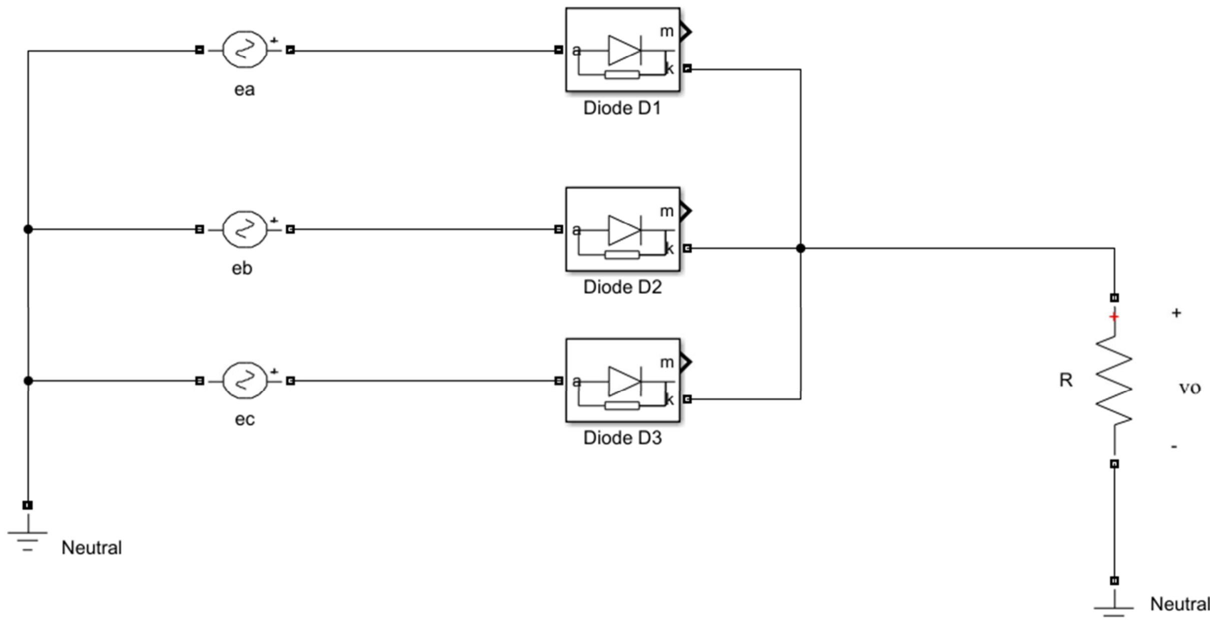

Figure 5.3: Three Phase Halfwave Uncontrolled Rectifier

Diodes are connected in common cathode configuration with their anodes are individually tied with the phase terminals of wye connected supply. One end of the load resistor is attached with common cathode terminal while the other end of the load is connected with the neutral of wye connected supply. As the diodes are in common cathode configuration, so the diode having highest potential at its anode will be forward biased/ ON. So, from 30^0 to 150^0 ea is highest. D1 is connected with ea so D1 will be forward biased and the rest two diodes will be reverse biased. D1 will be replaced with short circuit, thus output voltage will follow ea from 30^0 to 150^0. From 150^0 to 270^0 eb is highest. D2 is connected with eb so D2 will be forward biased and the rest two diodes will be reverse biased. D2 will be replaced with short circuit, thus output voltage will follow eb from 150^0 to 270^0. From 270^0 to 360^0 and 0 to 30^0 ec is highest. D3 is connected with ec so D3 will be forward biased and the rest two diodes will be reverse biased. D3 will be replaced with short circuit, thus output voltage will follow ec from 270^0 to 360^0 and 0 to 30^0 as shown in Figure 5.4.

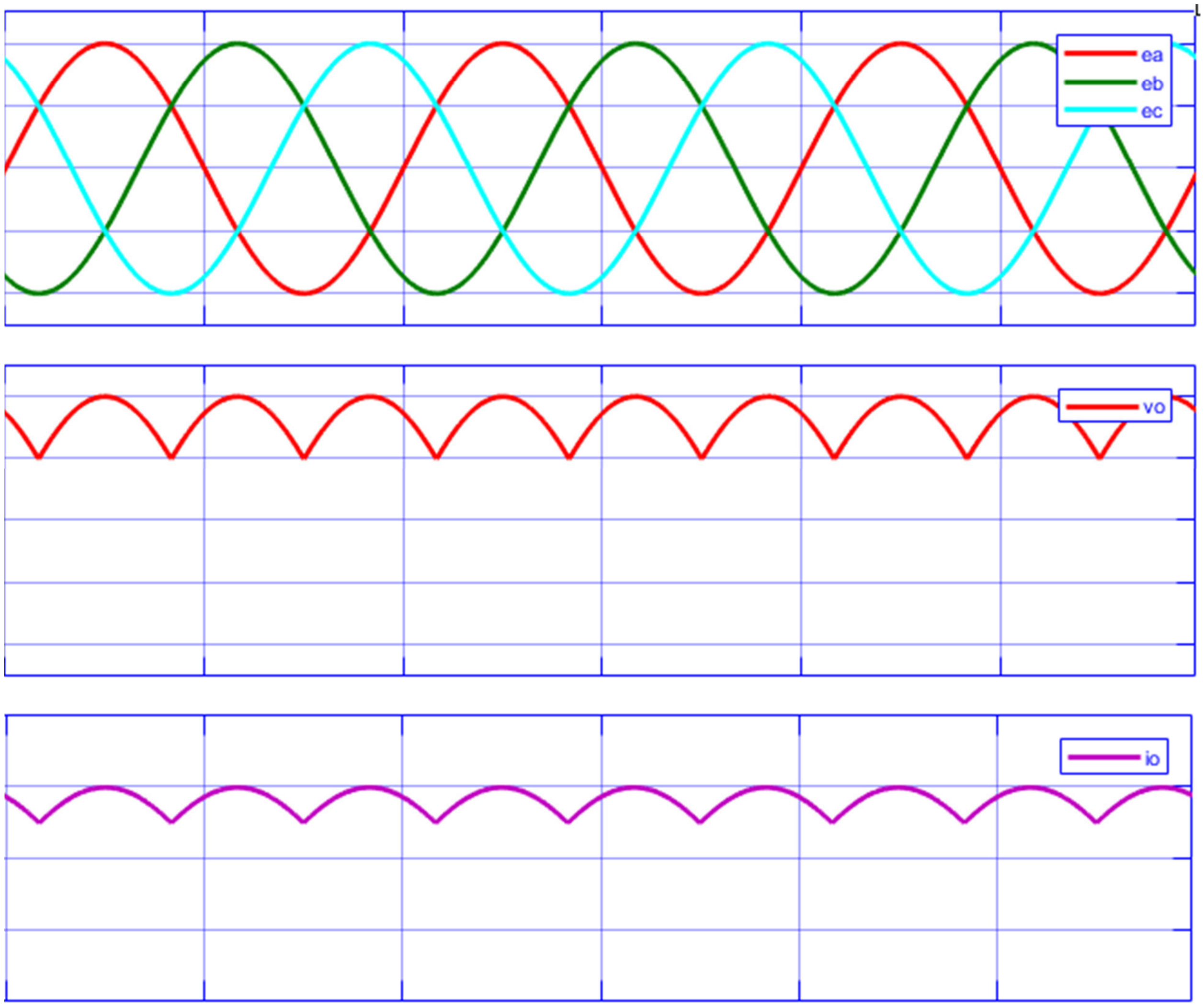

Figure 5.4: Three Phase Halfwave Uncontrolled Rectifier Input and Output Waveforms

Procedure

- Delta connection is available in the lab. Convert this delta into wye, by using transformer configuration shown in Figure 5.5. Step down transformers will be used in order to work at low voltage levels.

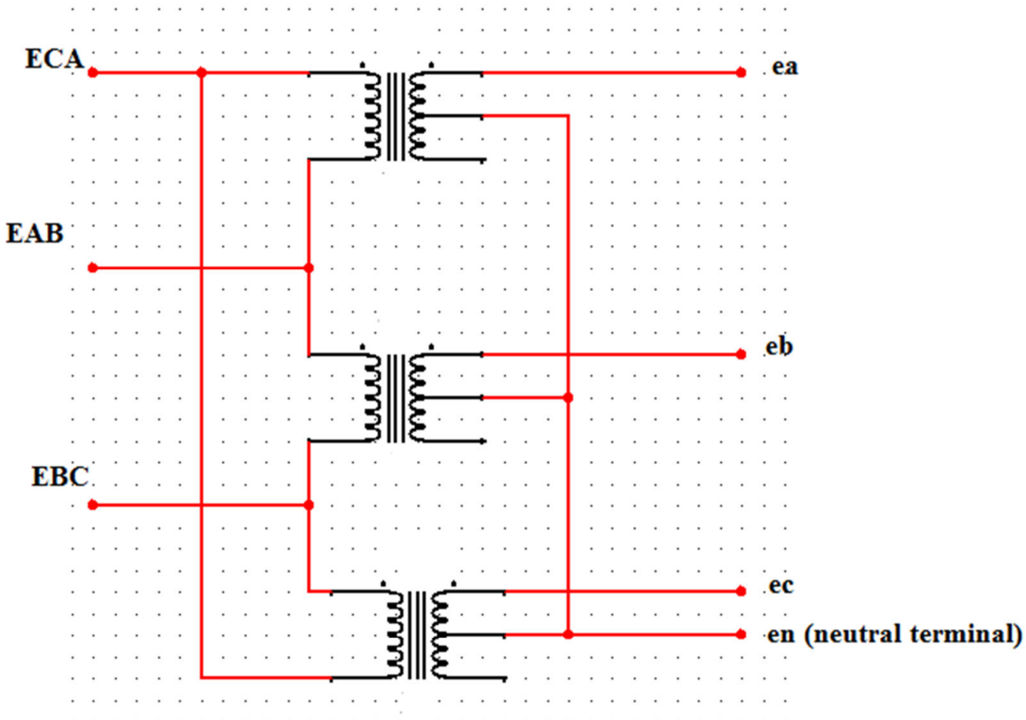

Figure 5.5: Delta to Wye Conversion

- Implement the circuit shown in Figure 5.6 on breadboard and attach the anodes of diodes with with secondary side of the transformer (**e_a, e_b and e_c**). One end of the resistor is attached with common cathode terminal while the other end with neutral.

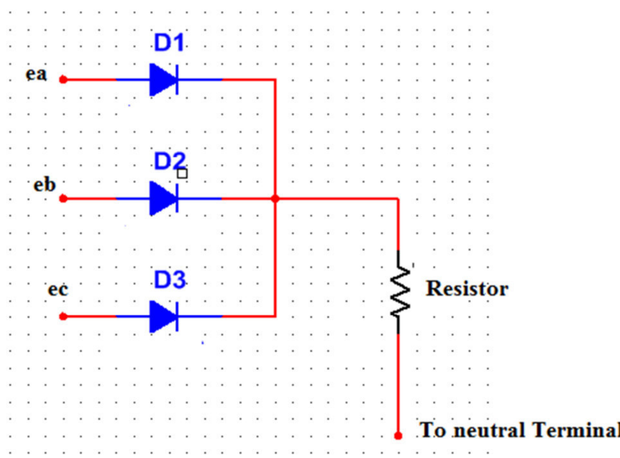

Figure 5.6: Three Phase Halfwave Uncontrolled Rectifier

- Now turn ON the Delta supply breaker.
- Measure the voltages at delta side via multimeter. (These will be the RMS voltages).

- Now measure the phase voltages at wye side via multimeter. (These will be the RMS voltages).
- Observe any of the phase voltage, at wye side, on oscilloscope and measure its peak to peak, peak, frequency and mean voltage.

- Observe any two phase voltages, of wye side, on oscilloscope and find out phase difference between these two whether 120^0 or 240^0.

- Now observe the output waveform across the load on oscilloscope (between common cathode terminal and neutral). Measure its peak to peak, peak, frequency and mean voltage.
- Verify the results via calculations.

Observation and Calculation Chart:

Delta Side (obs)	E_{AB} (RMS Voltage)= E_{BC} (RMS Voltage)= E_{CA} (RMS Voltage)=
Wye Side (obs)	e_{an} (RMS Voltage)= e_{bn} (RMS Voltage)= e_{cn} (RMS Voltage)=
Wye Side (obs)	e_{an} • $V_{pk\text{-}pk}$= • V_{pk}= • Freq= • Mean= • Waveform (Attach the waveform)
Wye Side (obs)	Phase difference between e_{an} and e_{bn}=
Output Voltage (obs)	V_o • $V_{pk\text{-}pk}$= • V_{pk}= • Freq= • Mean= • Waveform (Attach the waveform)
Output Voltage (cal)	V_o • Mean= $\frac{3(\sqrt{3})Vpk}{2\pi}$ // where Vpk is Vpk of e_{an}

	• Freq= 3* Freq of e_{an}

Post Lab:

Simulate the 3-phase half wave uncontrolled rectifier circuit and observe all the input and output parameters.

F/OBEM 01/05/00

NED University of Engineering & Technology
Department of ____**ELECTRONIC**__ Engineering
Course Code and Title: ____**EL-344 POWER ELECTRONICS**______

Psychomotor Domain Assessment Rubric-Level P3					
Skill Sets	Extent of Achievement				
	0	1	2	3	4
Equipment Identification Sensory skill to ***identify*** equipment and/or its component for a lab work.	Not able to identify the equipment.	--	--	--	Able to identify equipment as well as its components.
Equipment Use Sensory skills to ***demonstrate*** the use of the equipment for the lab work.	Doesn't demonstrate the use of equipment.	Slightly demonstrates the use of equipment.	Somewhat demonstrates the use of equipment.	Moderately demon strates the use of equipment.	Fully demonstrates the use of equipment.
Procedural Skills ***Displays*** skills to act upon sequence of steps in lab work.	Not able to either learn or perform lab work procedure.	Able to slightly understand lab work procedure and perform lab work.	Able to somewhat understand lab work procedure and perform lab work.	Able to moderately understand lab work procedure and perform lab work.	Able to fully understand lab work procedure and perform lab work.
Response Ability to ***imitate*** the lab work on his/her own.	Not able to imitate the lab work.	Able to slightly imitate the lab work.	Able to somewhat imitate the lab work.	Able to moderately imitate the lab work.	Able to fully imitate the lab work.
Observation's Use ***Displays*** skills to use the observations from lab work for experimental verifications and illustrations.	Not able to use the observations from lab work for experimental verifications and illustrations.	Slightly able to use the observations from lab work for experimental verifications and illustrations.	Somewhat able to use the observations from lab work for experimental verifications and illustrations.	Moderately able to use the observations from lab work for experimental verifications and illustrations.	Fully able to use the observations from lab work for experimental verifications and illustrations.
Safety Adherence Adherence to ***safety*** procedures.	Doesn't adhere to safety procedures.	Slightly adheres to safety procedures.	Somewhat adheres to safety procedures.	Moderately adheres to safety procedures.	Fully adheres to safety procedures.
Equipment Handling ***Equipment care*** during the use.	Doesn't handle equipment with required care.	Rarely handles equipment with required care.	Occasionally handles equipment with required care.	Often handles equipment with required care.	Handles equipment with required care.
Group Work ***Contributes*** in a group based lab work.	Doesn't participate and contribute.	Slightly participates and contributes.	Somewhat participates and contributes.	Moderately participates and contributes.	Fully participates and contributes.

Laboratory Session No. ____05_______ Date: ______________________

Weighted CLO (Psychomotor Score)	
Remarks	
Instructor's Signature with Date:	

LAB SESSION 06

Objective

To practice the 3-phase uncontrolled bridge rectifier circuit on breadboard.

Components Required

- Diodes (3) –1N4001--7
- Resistor (2) –100 Ω/ 10 Watt
- Transformer (3) –12-12 V/ 1 A
- Breadboard

Introduction

This practical is about three phase uncontrolled bridge rectifier. Circuit diagram of three phase uncontrolled bridge rectifier is shown in Figure 6.1.

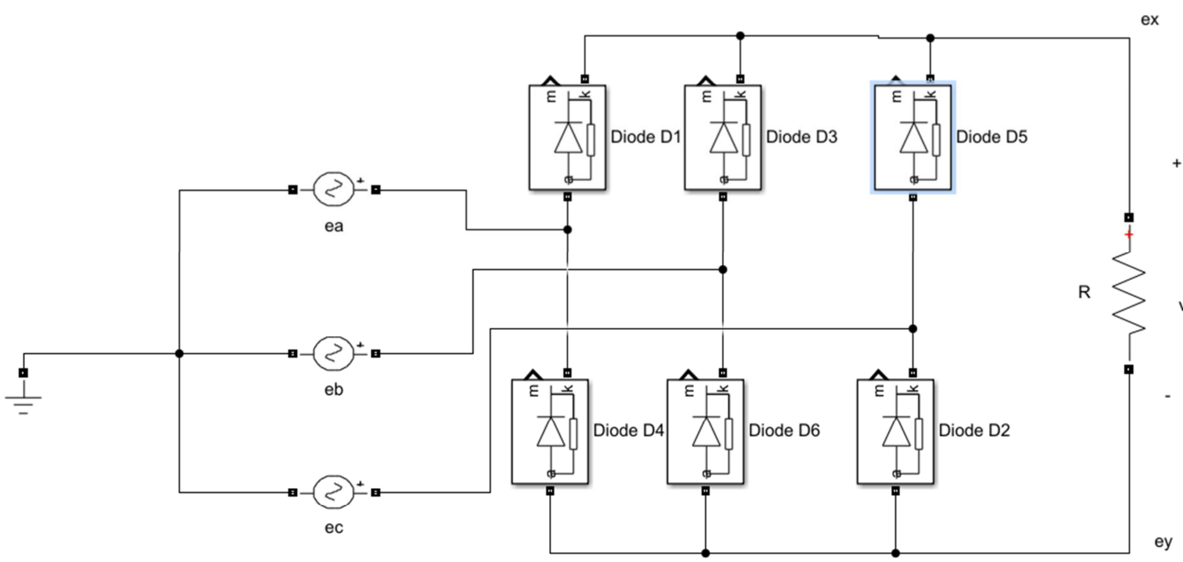

Figure 6.1: Three Phase Uncontrolled Bridge Rectifier

Out of six diodes used in three phase uncontrolled bridge rectifier, three (namely D1, D3 and D5) are connected in common cathode configuration (x terminal) while the other three (namely D2, D4 and D6) are connected in common anode configuration (y terminal). Load is attached in between common anode and common cathode terminal. The other end of each diode is connected to a phase of wye connected supply. D1 and D4 are connected with phase a, D3 and D6 are connected with phase b while D5 and D2 are connected with phase c.

As the diodes D1, D3 and D5 are in common cathode configuration so the diode having highest potential at its anode will be forward biased/ ON. So, from 30^0 to 150^0 ea is highest. D1 is connected with ea so D1 will be forward biased and the rest two diodes will be reverse biased. D1 will be replaced with short circuit, thus potential at x terminal will follow ea from 30^0 to 150^0. From 150^0 to 270^0 eb is highest. D3 is connected with eb so D3 will be forward biased and the rest two diodes will be reverse biased. D3 will be replaced with short circuit, thus the potential at x terminal will follow eb from 150^0 to 270^0. From 270^0 to 360^0 and 0 to 30^0 ec is highest. D5 is connected with ec so D5 will be forward biased and the rest two diodes will be reverse biased. D5 will be replaced with short circuit, thus potential at x terminal will follow ec from 270^0 to 360^0 and 0 to 30^0.

As the diodes D2, D4 and D6 are in common anode configuration so the diode having least potential at its cathode will be forward biased/ ON. So, from 90^0 to 210^0 ec is lowest. D2 is connected with ec so D2 will be forward biased and the rest two diodes will be reverse biased. D2 will be replaced with short circuit, thus potential at y terminal will follow ec from 90^0 to 210^0. From 210^0 to 330^0 ea is lowest. D4 is connected with ea so D4 will be forward biased and the rest two diodes will be reverse biased. D4 will be replaced with short circuit, thus the potential at y terminal will follow ea from 210^0 to 330^0. From 330^0 to 360^0 and 0 to 90^0 eb is lowest. D6 is connected with eb so D6 will be forward biased and the rest two diodes will be reverse biased. D6 will be replaced with short circuit, thus potential at y terminal will follow eb from 330^0 to 360^0 and 0 to 90^0.

It can be observed at each instant one diode at common cathode terminal (x terminal) and one diode at common anode terminal (y terminal) is ON, so current always flow from terminal x to terminal y. Frequency of each of ex and ey will be thrice as of input frequency. If the output is observed in between terminal x and y, it will be the difference of two phase i.e. line voltage. Output will follow eab from 30^0 to 90^0, eac from 90^0 to 150^0, ebc from 150^0 to 210^0, eba from 210^0 to 270^0, eca from 270^0 to 330^0, ecb from 330^0 to 360^0 and 0^0 to 30^0 as shown in Figure 6.2. So, the frequency of output voltage will be six times as of input frequency.

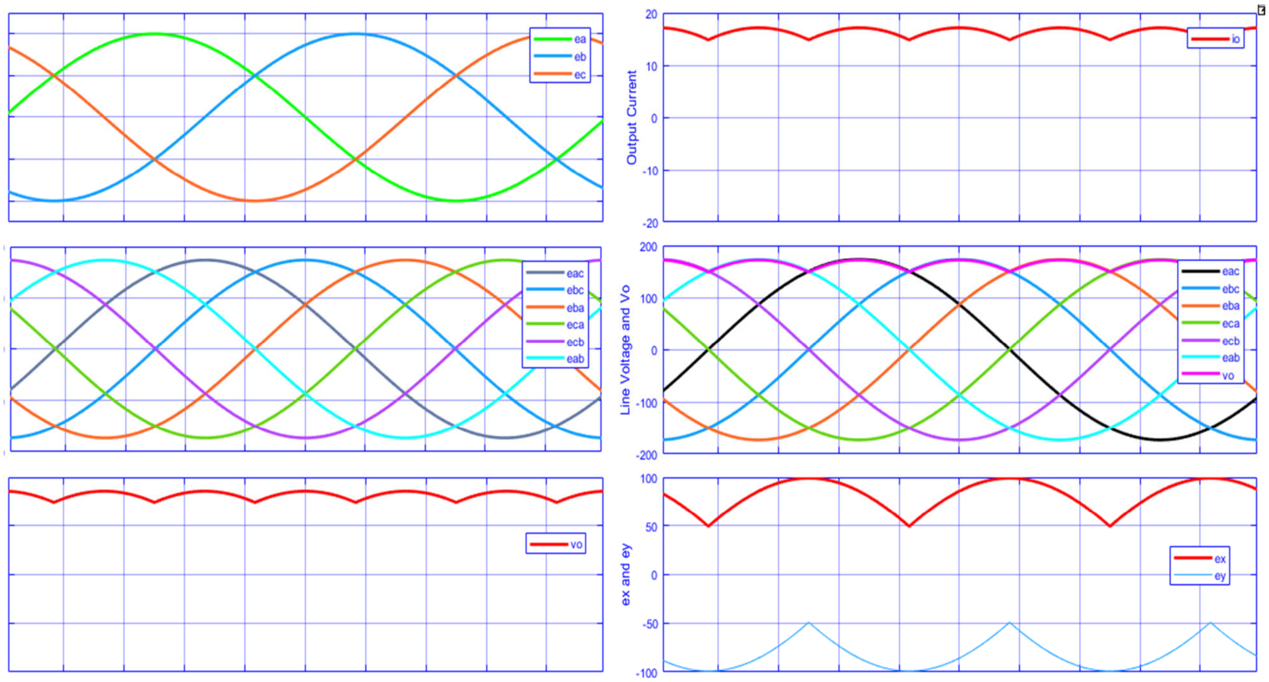

Figure 6.2: Three Phase Uncontrolled Bridge Rectifier Input and Output Waveforms

Procedure

- Delta connection is available in the lab. Convert this delta into wye, by using transformer configuration shown in Figure 6.3. Step down transformers will be used in order to work at low voltage levels.

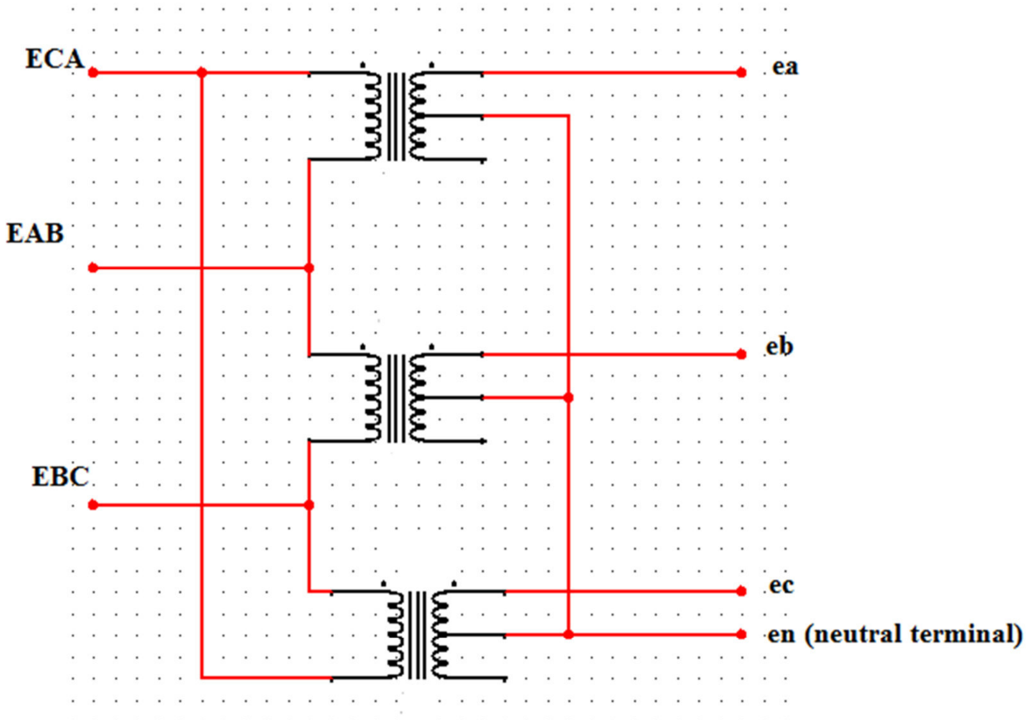

Figure 6.3: Delta to Wye Conversion

- Implement the circuit shown in Figure 6.4 on breadboard. Remember the neutral at wye side is not connected to any circuit node.

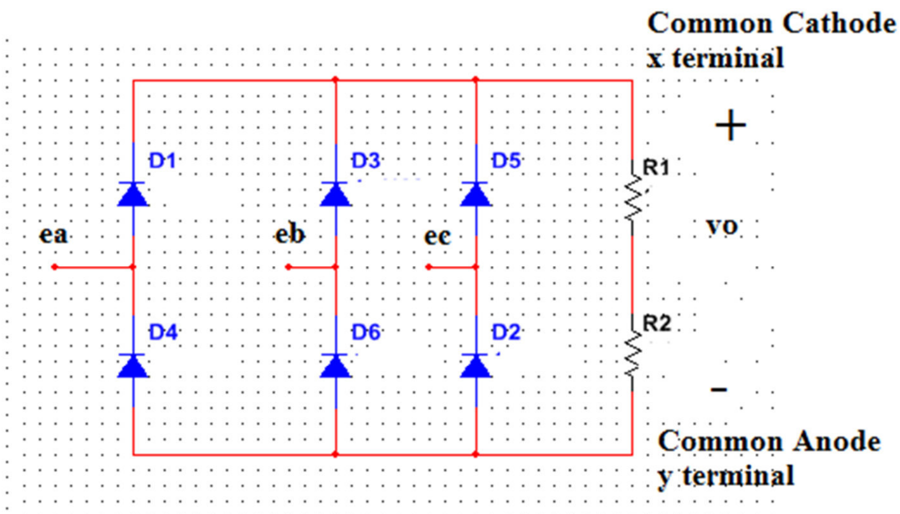

Figure 6.4: Three Phase Uncontrolled Bridge Rectifier

- Now turn ON the Delta supply breaker.
- Measure the voltages at delta side via multimeter. (These will be the RMS voltages.)
- Now measure the phase voltages at wye side via multimeter. (These will be the RMS voltages.)
- Observe any of the phase voltage, at wye side, on oscilloscope and measure its peak to peak, peak, frequency and mean voltage.
- Observe any two phase voltages, at wye side, on oscilloscope and find out phase

difference between these two whether 120^0 or 240^0.

- Now observe the waveform at terminal x (between common cathode terminal and neutral) on oscilloscope. Measure its peak to peak, peak, frequency and mean voltage.
- Verify the mean voltage and frequency of terminal x waveform via calculations.

- Now observe the waveform at terminal y (between common anode terminal and neutral) on oscilloscope. Measure its peak to peak, peak, frequency and mean voltage.
- Verify the mean voltage and frequency of terminal y waveform via calculations.

- Observe both the waveforms (ex (between common cathode terminal and neutral) and ey (between common anode terminal and neutral)) simultaneously.

- Now observe the output waveform across the load on oscilloscope (between x terminal (common cathode) and y terminal (common anode)). Measure its peak to peak, peak, frequency and mean voltage.
- Verify the results via calculations.

Observation and Calculation Chart:

Delta Side (obs)	E_{AB} (RMS Voltage)= E_{BC} (RMS Voltage)= E_{CA} (RMS Voltage)=
Wye Side (obs)	e_{an} (RMS Voltage)= e_{bn} (RMS Voltage)= e_{cn} (RMS Voltage)=
Wye Side (obs)	e_{an} • $V_{\mathbf{pk-pk}}$= • $V_{\mathbf{pk}}$= • Freq= • Mean= • Waveform (Attach the waveform)
Wye Side (obs)	Phase difference between e_{an} and e_{bn}=
Voltage Common Cathode terminal (x terminal) (obs.)	e_x • $V_{\mathbf{pk-pk}}$= • $V_{\mathbf{pk}}$= • Freq=

	• Mean= Waveform (Attach the waveform)
Voltage Common Cathode terminal (x terminal) (cal.)	e_x • Mean= $\frac{3(\sqrt{3})Vpk}{2\pi}$ // where Vpk is Vpk of e_{an} • Freq= 3* Freq of e_{an}
Voltage Common Anode terminal (y terminal) (obs.)	e_y • $V_{pk\text{-}pk}$= • V_{pk}= • Freq= • Mean= Waveform (Attach the waveform)
Voltage Common Anode terminal (y terminal) (cal.)	e_y • Mean= $-\frac{3(\sqrt{3})Vpk}{2\pi}$ // where Vpk is Vpk of e_{an} • Freq= 3* Freq of e_{an}
Voltage Common Cathode terminal (x terminal) and Voltage Common Anode terminal (y terminal) (obs.)	e_x and e_y simultaneously • Waveform (Attach the waveform)
Output Voltage (obs.)	V_o • $V_{pk\text{-}pk}$=

	• V_{pk}= • Freq= • Mean= • Waveform (Attach the waveform)
Output Voltage (cal.)	V_o • Mean= $\frac{3(\sqrt{3})Vpk}{\pi}$ // where Vpk is Vpk of e_{an} • Freq= 6* Freq of e_{an}

Post Lab:

Simulate the 3-phase uncontrolled bridge rectifier circuit and observe all the input and output parameters.

F/OBEM 01/05/00

NED University of Engineering & Technology
Department of ____**ELECTRONIC**__ Engineering
Course Code and Title: ____**EL-344 POWER ELECTRONICS**______

Psychomotor Domain Assessment Rubric-Level P3					
Skill Sets	Extent of Achievement				
	0	1	2	3	4
Equipment Identification Sensory skill to ***identify*** equipment and/or its component for a lab work.	Not able to identify the equipment.	--	--	--	Able to identify equipment as well as its components.
Equipment Use Sensory skills to ***demonstrate*** the use of the equipment for the lab work.	Doesn't demonstrate the use of equipment.	Slightly demonstrates the use of equipment.	Somewhat demonstrates the use of equipment.	Moderately demon strates the use of equipment.	Fully demonstrates the use of equipment.
Procedural Skills ***Displays*** skills to act upon sequence of steps in lab work.	Not able to either learn or perform lab work procedure.	Able to slightly understand lab work procedure and perform lab work.	Able to somewhat understand lab work procedure and perform lab work.	Able to moderately understand lab work procedure and perform lab work.	Able to fully understand lab work procedure and perform lab work.
Response Ability to ***imitate*** the lab work on his/her own.	Not able to imitate the lab work.	Able to slightly imitate the lab work.	Able to somewhat imitate the lab work.	Able to moderately imitate the lab work.	Able to fully imitate the lab work.
Observation's Use ***Displays*** skills to use the observations from lab work for experimental verifications and illustrations.	Not able to use the observations from lab work for experimental verifications and illustrations.	Slightly able to use the observations from lab work for experimental verifications and illustrations.	Somewhat able to use the observations from lab work for experimental verifications and illustrations.	Moderately able to use the observations from lab work for experimental verifications and illustrations.	Fully able to use the observations from lab work for experimental verifications and illustrations.
Safety Adherence Adherence to ***safety*** procedures.	Doesn't adhere to safety procedures.	Slightly adheres to safety procedures.	Somewhat adheres to safety procedures.	Moderately adheres to safety procedures.	Fully adheres to safety procedures.
Equipment Handling ***Equipment care*** during the use.	Doesn't handle equipment with required care.	Rarely handles equipment with required care.	Occasionally handles equipment with required care.	Often handles equipment with required care.	Handles equipment with required care.
Group Work ***Contributes*** in a group based lab work.	Doesn't participate and contribute.	Slightly participates and contributes.	Somewhat participates and contributes.	Moderately participates and contributes.	Fully participates and contributes.

Laboratory Session No. ____06_______ Date: ______________________

Weighted CLO (Psychomotor Score)	
Remarks	
Instructor's Signature with Date:	

LAB SESSION 07

Objective

To operate under supervision the 3-phase half wave controlled rectifier circuit.

Components Required

- Transformer (3) –12-12 V/ 1 A
- Resistor (6) –1k Ω/ 1Watt
- Potentiometer (3) – 50k Ω
- Diodes (3) –1N4001--7
- SCR (3) – C106
- Resistor (1) –100 Ω/ 10 Watt
- Breadboard

Introduction

Three phase halfwave controlled rectifier is shown in Figure 7.1.

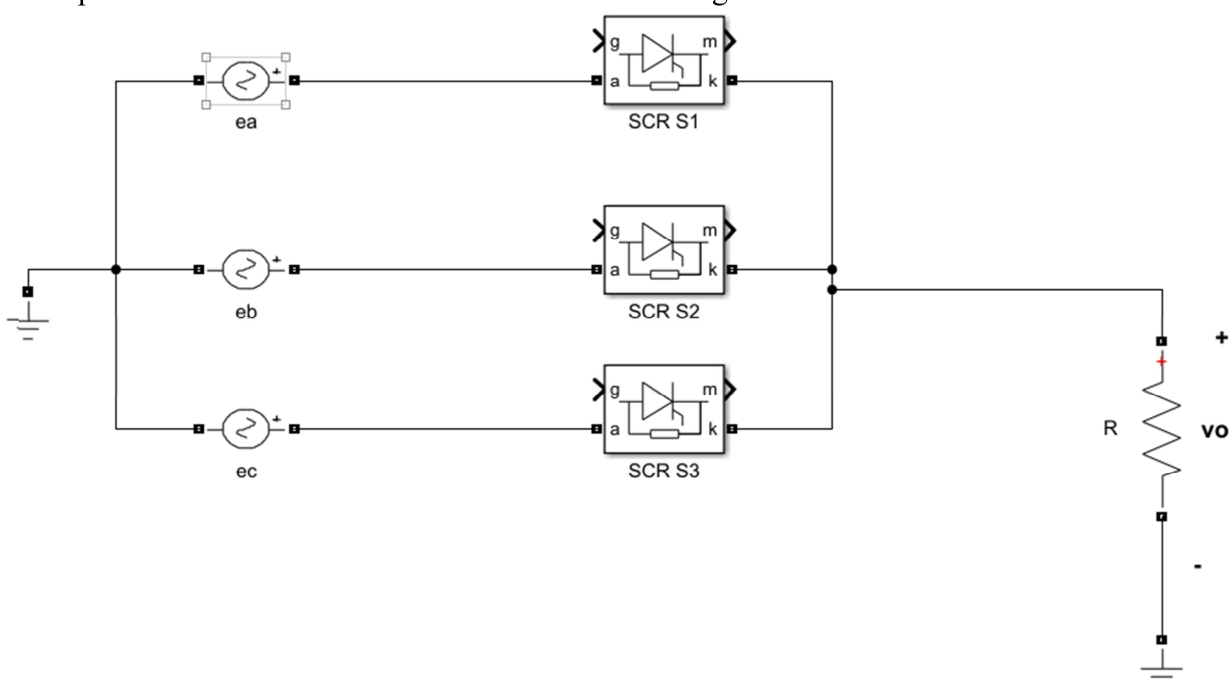

Figure 7.1: Three Phase Halfwave Controlled Rectifier

SCRs are connected in common cathode configuration with their anodes individually tied with the phase terminals of wye connected supply. One end of the load resistor is attached with common cathode terminal while the other end of the load is connected with the neutral of wye connected supply. As the SCRs are attached in common cathode configuration so the SCR having highest potential at its anode will be forward biased. So, at 30^0 ea is highest. S1 is connected with ea so S1 will be forward biased but it will wait for gate pulse. Lets assume the firing angle of all the SCRs $\alpha=30^0$. So, at $30^0 + 30^0 = 60^0$ S1 will be fired and it will turn ON. Rest two SCRs will be reverse biased/ off. S1 will be replaced with short circuit, thus output voltage will start to follow ea from 60^0. At 150^0 eb is highest. S2 is connected with eb so S2 will be forward biased but it will wait for gate pulse. So at $150^0 + 30^0 = 180^0$ S2 will be fired and it will turn ON. Rest two SCRs will be reverse biased/ off. S2 will be replaced with short circuit, thus output voltage will start to follow eb from 180^0. At 270^0 ec is highest. S3 is connected with ec so S3 will be forward biased but it will wait for gate pulse. So at $270^0 + 30^0 = 300^0$ S3 will be fired and it will turn ON. Rest two SCRs will be reverse biased/ off. S3 will be replaced with short circuit, thus output voltage will start to follow ec from 300^0 as shown in Figure 7.2. As resistive control method is used in this lab to fire the SCRs so α can vary between 0^0 and 90^0.

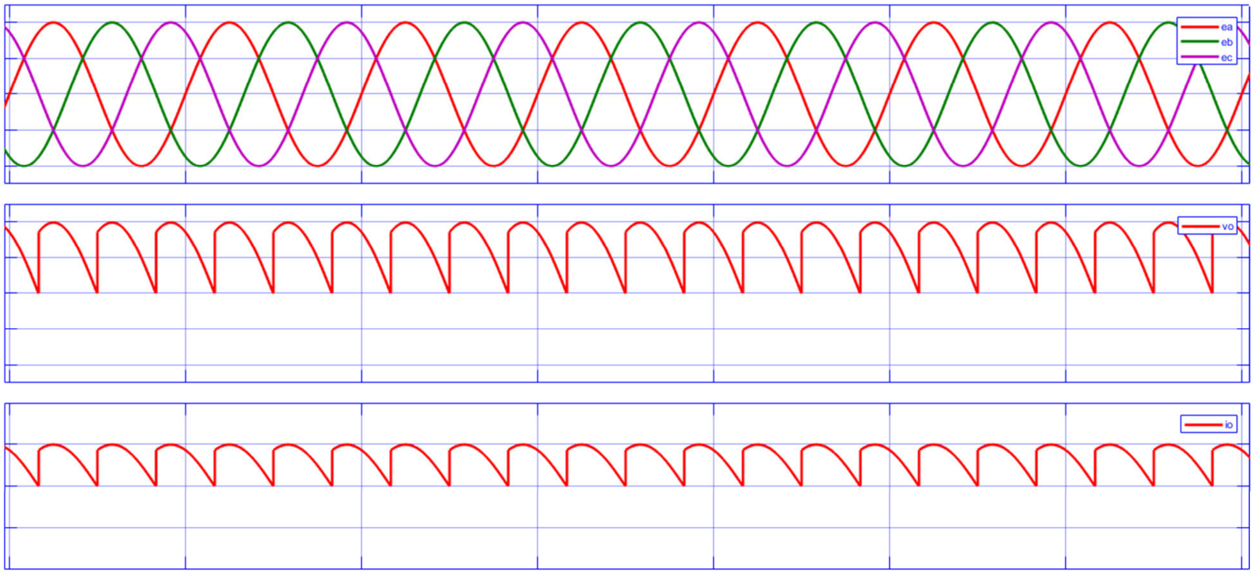

Figure 7.2: Three Phase Halfwave Controlled Rectifier Input and Output Waveforms

How long the previous device (SCR) will remain ON before the firing of upcoming device (SCR)? It totally depends on the nature of load. e.g. for resistive load the SCR S1 can remain ON upto maximum 180^0. After 180^0 as ea becomes negative, so S1 will get reverse biased irrespective of the fact whether S2 has fired or not. So, for that case from 180^0 till the firing of S2 no SCR will be ON and we will get zero voltage at the output. Thus for the **resistive load** either positive voltage or zero will appear at the output. As firing angle increases above 30^0 the zero voltage duration will appear at output as shown in Figure 7.3.

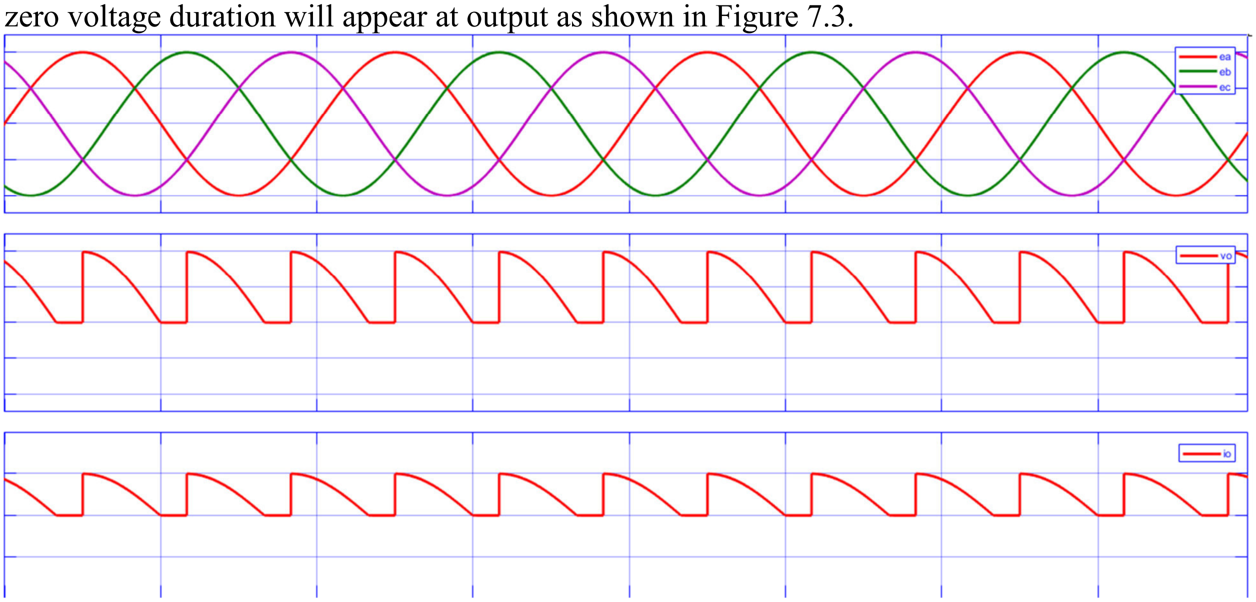

Figure 7.3: Three Phase Halfwave Controlled Rectifier Input and Output Waveforms for Resistive Load (α > 30^0)

However, for RL loads and highly inductive loads, turning ON of previous SCR can even prolong till the firing of the upcoming SCR and for that case output voltage can be negative.

Procedure

- Delta connection is available in the lab. Convert this delta into wye, by using transformer configuration shown in Figure 7.4. Step down transformers will be used in order to work at low voltage levels.

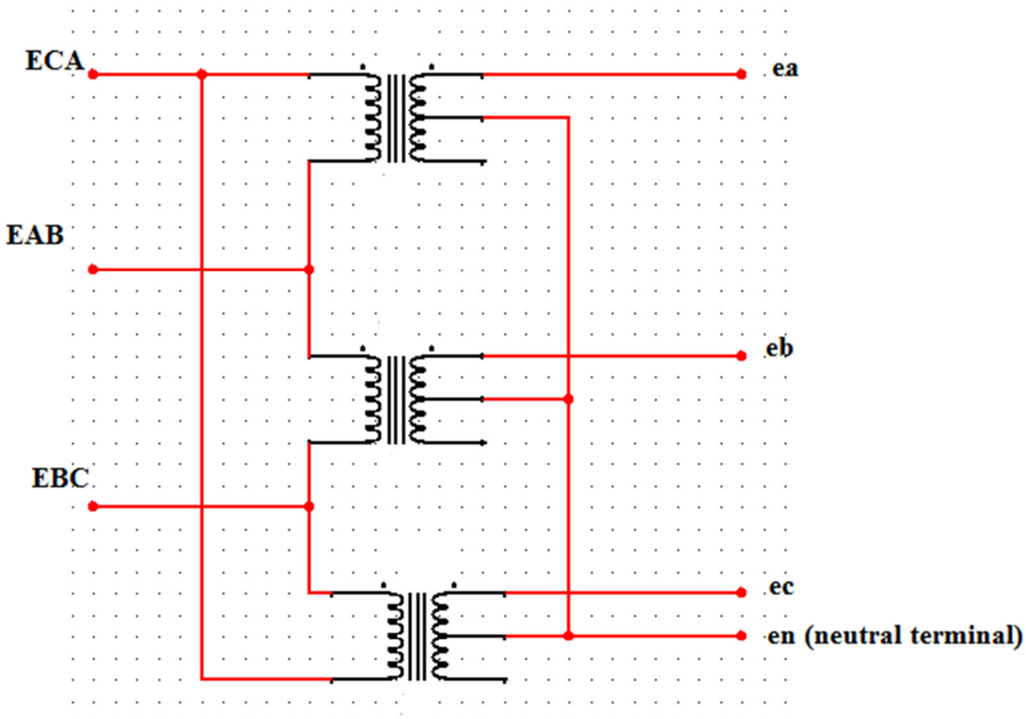

Figure 7.4: Delta to Wye Conversion

- Implement the firing circuitry shown in Figure 7.5 on breadboard.

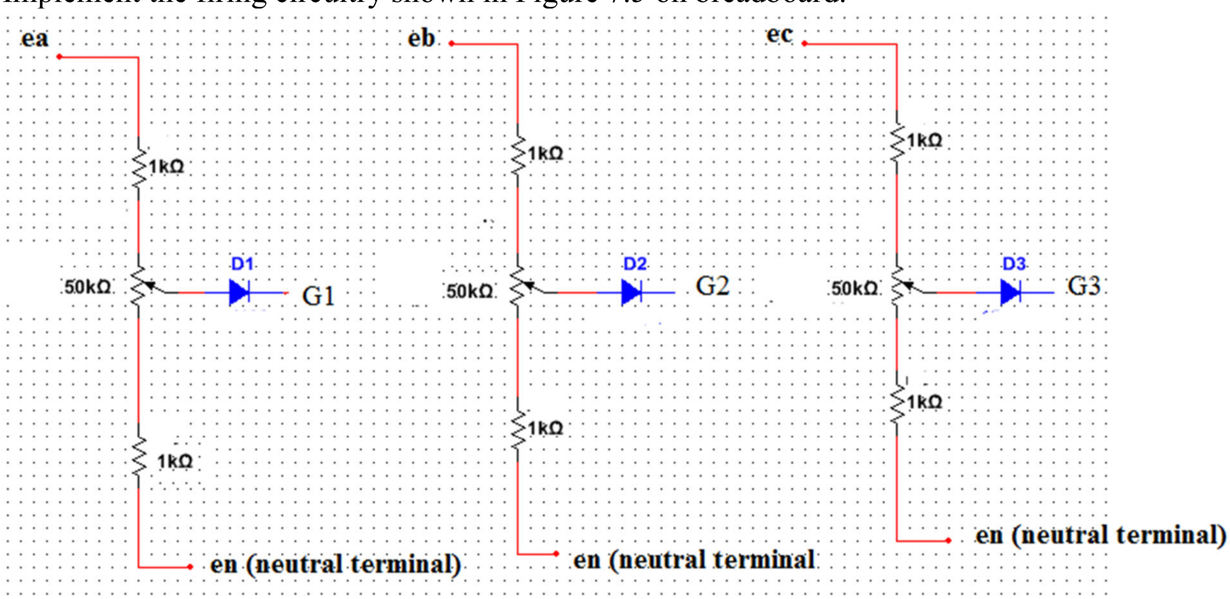

Figure 7.5: Firing Circuit for Three Phase Halfwave Controlled Rectifier

- Implement the rectifier circuit shown in Figure 7.6 on breadboard. Attach the anodes of

SCRs with secondary side of the transformer (**e_a, e_b and e_c respectively**). While the gate terminals of SCRs are connected with (G1, G2 and G3 respectively) terminals of firing circuitry. One end of the load resistor (100 Ω/ 10 Watt) is attached with common cathode terminal while the other end with the neutral.

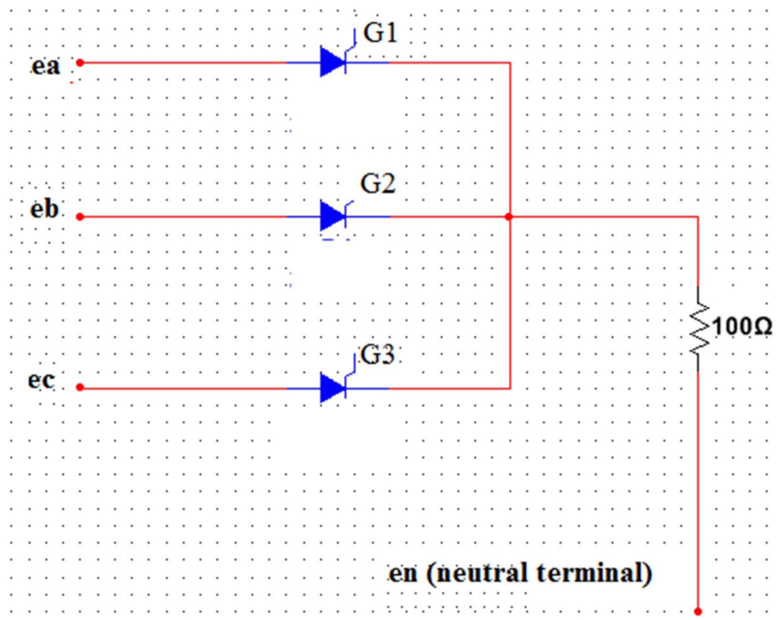

Figure 7.6: Three Phase Halfwave Controlled Rectifier

- Now turn ON the Delta supply breaker.
- Measure the voltages at delta side via multimeter. (These will be the RMS voltages.)

- Now measure the phase voltages at wye side via multimeter. (These will be the RMS voltages.)
- Observe any of the phase voltage, at wye side, on oscilloscope and measure its peak to peak, peak, frequency and mean voltage.

- Observe any two phase voltages, of wye side, on oscilloscope and find out phase difference between these two whether 120^0 or 240^0.

- Now adjust all the potentiometers, by observing the output waveform, to a position that all firing angles (α) of all SCRs be the same and output waveform is above 0 level ($\alpha<30^0$) as shown in the Figure 7.7.

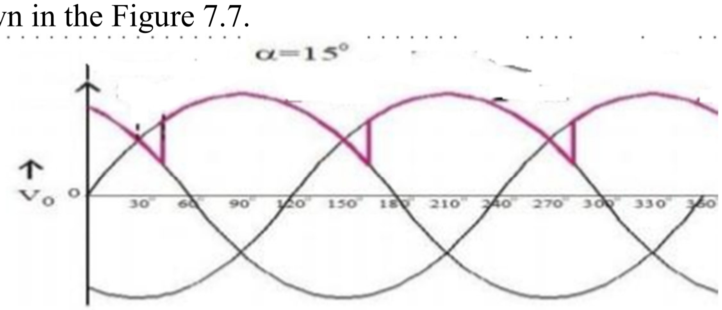

Figure 7.7: Output Waveform For Three Phase Halfwave Controlled Rectifier

- Now observe the output waveform across the load on oscilloscope (between common cathode terminal and neutral). Measure its peak to peak, peak, frequency and mean voltage.

- Measure the value of Δt using cursor option in the oscilloscope as shown in the Figure 7.8.

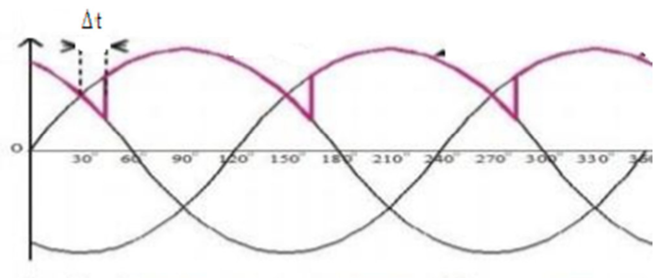

Figure 7.8: Measuring Δt for Three Phase Halfwave Controlled Rectifier

- By using the value of Δt calculate the value of α.
- Verify the mean value and frequency via calculations

Observation and Calculation Chart:

Delta Side (obs)	E_{AB} (RMS Voltage)= E_{BC} (RMS Voltage)= E_{CA} (RMS Voltage)=
Wye Side (obs)	e_{an} (RMS Voltage)= e_{bn} (RMS Voltage)= e_{cn} (RMS Voltage)=
Wye Side (obs)	e_{an} • $V_{pk\text{-}pk}$= • V_{pk}= • Freq= • Mean= • Waveform (Attach the waveform)
Wye Side (obs)	Phase difference between ean and ebn=
Output Voltage (obs)	V_o • $V_{pk\text{-}pk}$= • V_{pk}= • Freq=

	• Mean= • Waveform (Attach the waveform)
Output Voltage (obs)	V_o • Δt =
Output Voltage (cal)	V_o • $\alpha = \frac{180}{10m} * \Delta t$
Output Voltage (cal)	V_o • Mean= $\frac{3(\sqrt{3})Vpk}{2\pi}(1 - 2sin^2\frac{\alpha}{2})$ // where Vpk is Vpk of e_{an} • Freq= 3* Freq of $e_{\mathbf{an}}$
Rotate the potentiometers such that resistances increase (α increase). What's your observation regarding the output waveform? Minimum output voltage is positive or negative or zero? Why?	

Post Lab:

Simulate the 3-phase halfwave controlled rectifier circuit with

a) Resistive load
b) RL Load
c) Highly inductive load

and observe all the input and output parameters by keeping

- $\alpha = 30^0$
- $\alpha = 90^0$

F/OBEM 01/05/00

NED University of Engineering & Technology
Department of ____**ELECTRONIC**__ Engineering
Course Code and Title: ____**EL-344 POWER ELECTRONICS**______

Psychomotor Domain Assessment Rubric-Level P3					
Skill Sets	Extent of Achievement				
	0	1	2	3	4
Equipment Identification Sensory skill to ***identify*** equipment and/or its component for a lab work.	Not able to identify the equipment.	--	--	--	Able to identify equipment as well as its components.
Equipment Use Sensory skills to ***demonstrate*** the use of the equipment for the lab work.	Doesn't demonstrate the use of equipment.	Slightly demonstrates the use of equipment.	Somewhat demonstrates the use of equipment.	Moderately demon strates the use of equipment.	Fully demonstrates the use of equipment.
Procedural Skills ***Displays*** skills to act upon sequence of steps in lab work.	Not able to either learn or perform lab work procedure.	Able to slightly understand lab work procedure and perform lab work.	Able to somewhat understand lab work procedure and perform lab work.	Able to moderately understand lab work procedure and perform lab work.	Able to fully understand lab work procedure and perform lab work.
Response Ability to ***imitate*** the lab work on his/her own.	Not able to imitate the lab work.	Able to slightly imitate the lab work.	Able to somewhat imitate the lab work.	Able to moderately imitate the lab work.	Able to fully imitate the lab work.
Observation's Use ***Displays*** skills to use the observations from lab work for experimental verifications and illustrations.	Not able to use the observations from lab work for experimental verifications and illustrations.	Slightly able to use the observations from lab work for experimental verifications and illustrations.	Somewhat able to use the observations from lab work for experimental verifications and illustrations.	Moderately able to use the observations from lab work for experimental verifications and illustrations.	Fully able to use the observations from lab work for experimental verifications and illustrations.
Safety Adherence Adherence to ***safety*** procedures.	Doesn't adhere to safety procedures.	Slightly adheres to safety procedures.	Somewhat adheres to safety procedures.	Moderately adheres to safety procedures.	Fully adheres to safety procedures.
Equipment Handling ***Equipment care*** during the use.	Doesn't handle equipment with required care.	Rarely handles equipment with required care.	Occasionally handles equipment with required care.	Often handles equipment with required care.	Handles equipment with required care.
Group Work ***Contributes*** in a group based lab work.	Doesn't participate and contribute.	Slightly participates and contributes.	Somewhat participates and contributes.	Moderately participates and contributes.	Fully participates and contributes.

Laboratory Session No. ____07_______ Date: ______________________

Weighted CLO (Psychomotor Score)	
Remarks	
Instructor's Signature with Date:	

LAB SESSION 08

Objective

To manipulate with guidance the 3-phase half controlled bridge rectifier circuit.

Components Required

- Transformer (3) –12-12 V/ 1 A
- Resistor (6) –1k Ω/ 1Watt
- Potentiometer (3) – 50k Ω
- Diodes (6) –1N4001--7
- SCR (3) – C106
- Resistor (2) –100 Ω/ 10 Watt
- Breadboard

Introduction

This practical is about three phase half controlled bridge rectifier. Three phase half controlled bridge rectifier is shown in Figure 8.1.

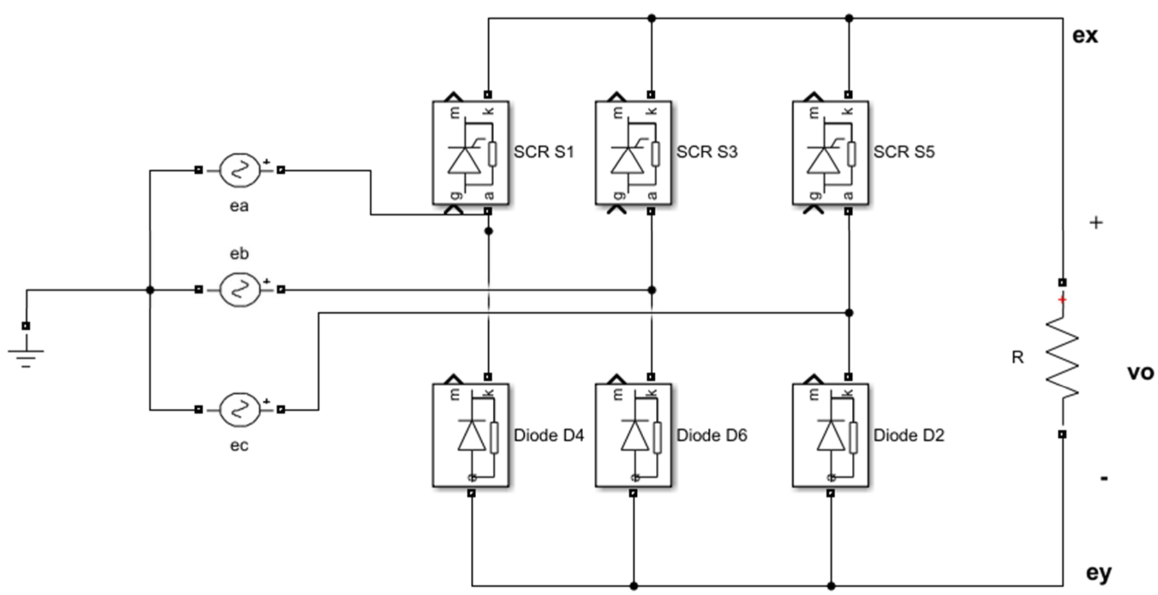

Figure 8.1: Three Phase Half Controlled Bridge Rectifier

Six devices are used in three phase half controlled bridge rectifier. Three of them are SCRs (namely S1, S3 and S5) that are connected in common cathode configuration (x terminal) while the rest three are diodes (namely D2, D4 and D6) that are connected in common anode configuration (y terminal). Load is attached in between common anode and common cathode terminal. The other end of each device is attached to a phase of wye connected supply. S1 and D4 are connected with phase a, S3 and D6 are connected with phase b while S5 and D2 are connected with phase c.

As the SCRs are attached in common cathode configuration so the SCR having highest potential at its anode will be forward biased. So, at 30^0 ea is highest. S1 is connected with ea so S1 will be forward biased but it will wait for gate pulse. Let's assume the firing angle for all the SCRs $\alpha=30^0$. So at $30^0 + 30^0 = 60^0$ S1 will be fired and it will turn ON. Rest two SCRs will be reverse biased/ off. S1 will be replaced with short circuit, thus potential at terminal x will start to follow ea from 60^0. At 150^0 eb is highest. S3 is connected with eb so S3 will be forward biased but it will wait for gate pulse. So at $150^0 + 30^0 = 180^0$ S3 will be fired and it will turn ON. Rest two SCRs will be reverse biased/ off. S3 will be replaced with short circuit, thus potential at terminal x will start to follow eb from 180^0. At 270^0 ec is highest. S5 is connected with ec so S5 will be forward biased but it will wait for gate pulse. So at $270^0 + 30^0 = 300^0$ S5 will be fired and it will turn ON. Rest two SCRs will be reverse biased/ off. S5 will be replaced with short circuit, thus potential at terminal x will start to follow ec from 300^0. Previous device will remain ON before the firing of upcoming device. As resistive control method is used to fire the SCRs so α can vary between 0 and 90^0.

As the diodes are attached in common anode configuration so the diode having least potential at its cathode will be forward biased/ ON. So, from 90^0 to 210^0 ec is lowest. D2 is connected with ec so D2 will be forward biased and the rest two diodes will be reverse biased/off . D2 will be replaced with short circuit, thus potential at y terminal will follow ec from 90^0 to 210^0. From 210^0 to 330^0 ea is lowest. D4 is connected with ea so D4 will be forward biased and the rest two diodes will be reverse biased. D4 will be replaced with short circuit, thus the potential at y terminal will follow ea from 210^0 to 330^0. From 330^0 to 360^0 and 0 to 90^0 eb is lowest. D6 is connected with eb so D6 will be forward biased and the rest two diodes will be reverse biased/ off. D6 will be replaced with short circuit, thus potential at y terminal will follow eb from 330^0 to 360^0 and 0 to 90^0, as shown in Figure 8.2.

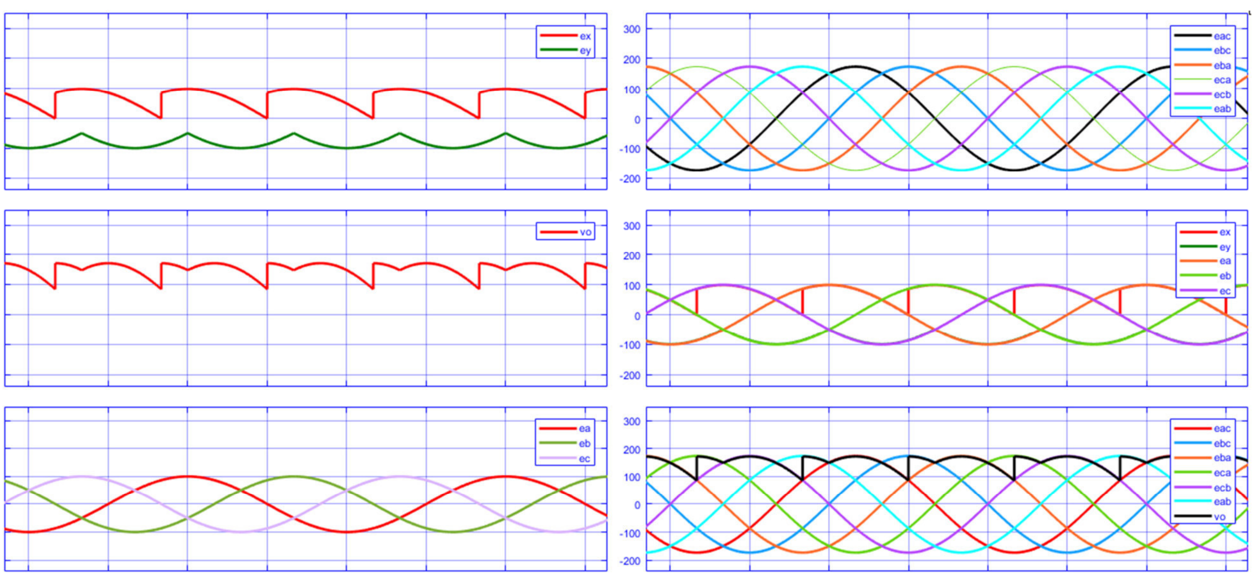

Figure 8.2: Three Phase Half Controlled Bridge Rectifier Input and Output Waveforms

It can be observed that at each instant one SCR at common cathode terminal (x terminal) and one diode at common anode terminal (y terminal) is ON, so current always flow from terminal x to terminal y. Frequency of each of ex and ey will be thrice as of input frequency.

If the output is observed in between terminal x and y, it will either be the difference of two phases i.e. line voltage (here the line voltage will always be always positive) or zero (in case at particular instant the ON devices of both common cathode terminal and common anode terminal are attached to the same phase). If α is set greater than 60^0, zero volts intervals appear in the output waveform. The overall output voltage can never be negative for half controlled bridge rectifier irrespective of the nature of the load.

Procedure

- Delta connection is available in the lab. Convert this delta into wye, by using transformer configuration shown in Figure 8.3. Step down transformers will be used in order to work at low voltage levels.

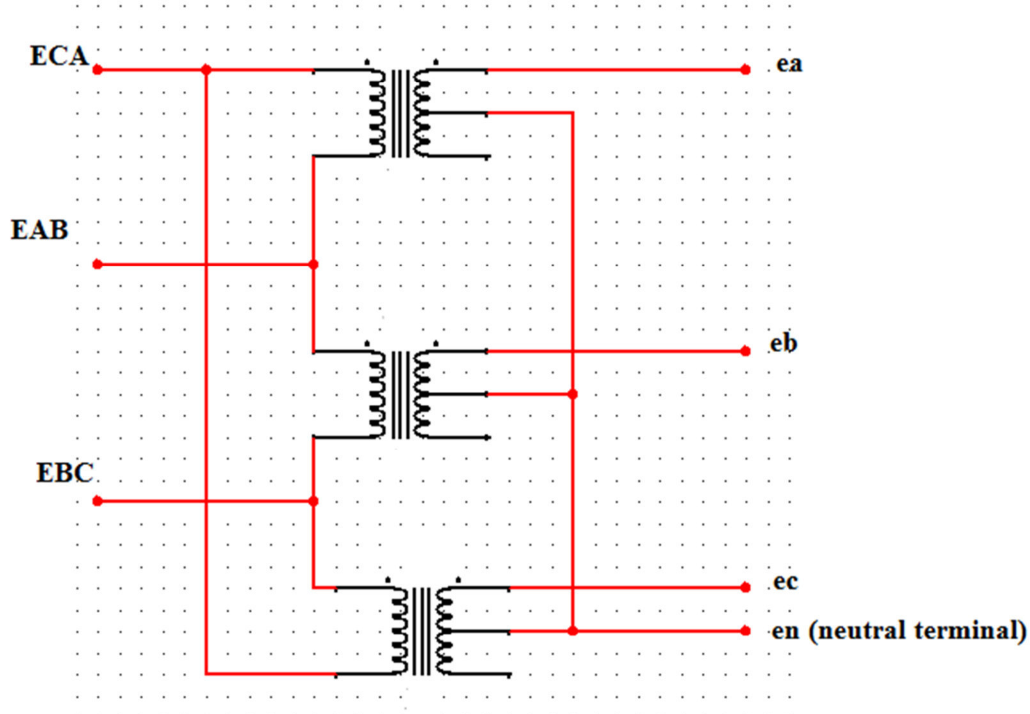

Figure 8.3: Delta to Wye Conversion

- Implement the firing circuitry shown in Figure 8.4 on breadboard.

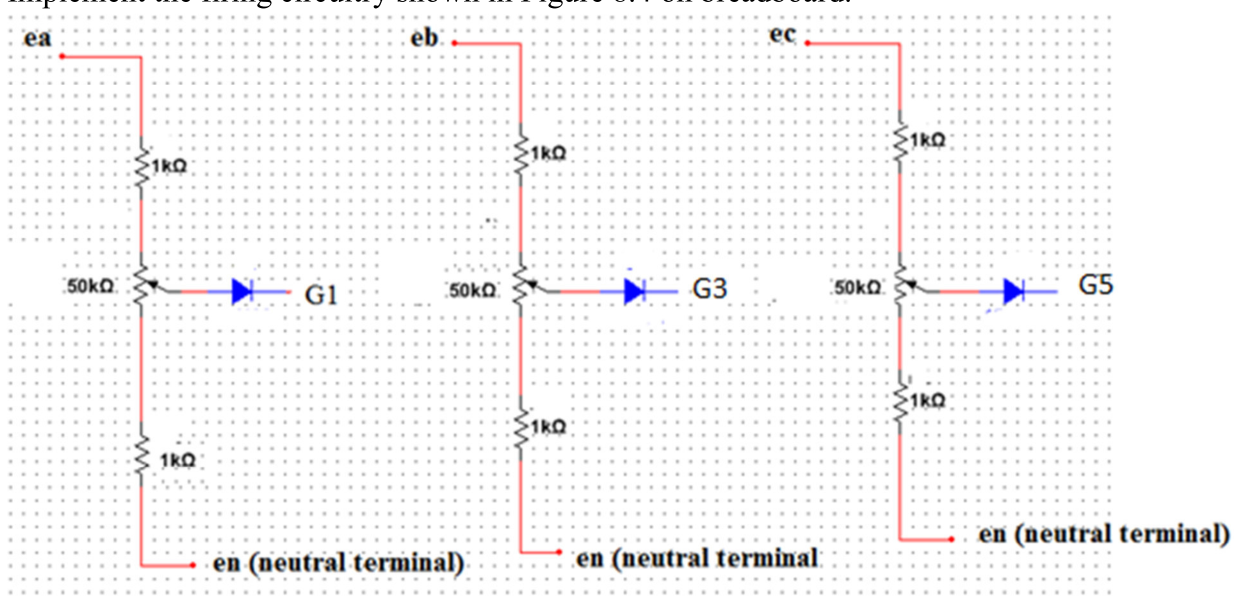

Figure 8.4: Firing Circuit of SCRs

- Implement the rectifier circuit shown in Figure 8.5 on breadboard. The gate terminals of SCR are connected with (G1, G3 and G5 respectively) terminals of firing circuitry. One end of the series connected two load resistors (100 Ω/ 10 Watt) is attached with common cathode terminal while the other end with common anode terminal. Remember the neutral at wye side is not connected to any circuit node.

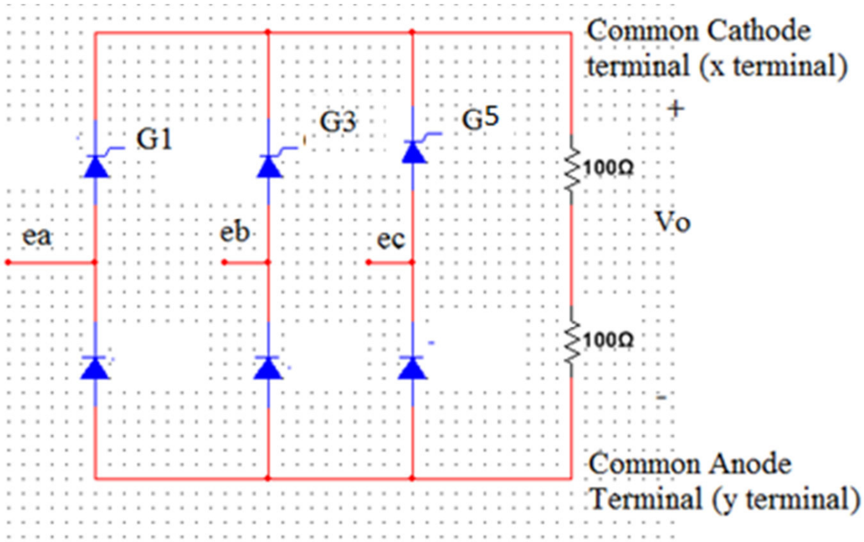

Figure 8.5: Three Phase Half Controlled Bridge Rectifier

- Now turn ON the Delta supply breaker.
- Measure the voltages at delta side via multimeter. (These will be the RMS voltages.)

- Now measure the phase voltages at wye side via multimeter. (These will be the RMS voltages).
- Observe any of the phase voltage, at wye side, on oscilloscope and measure its peak to peak, peak, frequency and mean voltage.

- Observe any two phase voltages, of wye side, on oscilloscope and find out phase difference between these two whether 120^0 or 240^0.

- Now adjust all the potentiometers, by observing the waveform at terminal x (between common cathode terminal and neutral), to a position that all firing angles (α) be the same and waveform at terminal x is above 0 level ($\alpha<30^0$) as shown in the Figure 8.6

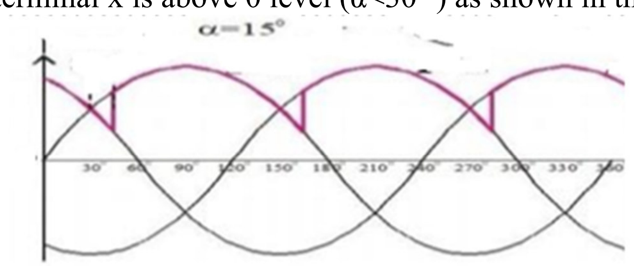

Figure 8.6: Waveform at Terminal x of Half Controlled Bridge Rectifier

- Now observe the waveform at terminal x (between common cathode terminal and neutral) on oscilloscope. Measure its peak to peak, peak, frequency and mean voltage.
- Measure the value of Δt using cursor option in the oscilloscope as shown in the Figure 8.7.

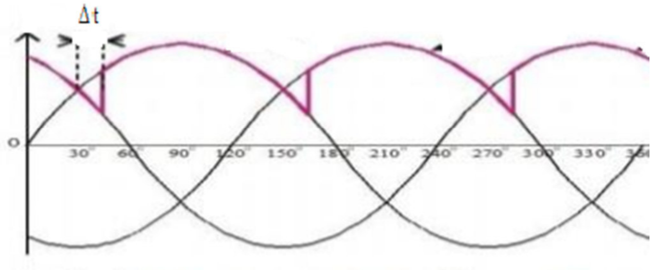

Figure 8.7: Measuring Δt for Half Controlled Bridge Rectifier

- By using the value of Δt calculate the value of α.
- Verify the mean value and frequency via calculations.

- Now observe the waveform at terminal y (between common anode terminal and neutral) on oscilloscope. Measure its peak to peak, peak, frequency and mean voltage.
- Verify the mean value and frequency via calculations

- Observe both the waveforms (ex (between common cathode terminal and neutral) and ey (between common anode terminal and neutral)) simultaneously.

- Now observe the output waveform across the load on oscilloscope (between x terminal (common cathode) and y terminal (common anode)). Measure its peak to peak, peak, and mean voltage.
- Verify the mean voltage via calculations.

Observation and Calculation Chart:

Delta Side (obs)	E_{AB} (RMS Voltage)= E_{BC} (RMS Voltage)= E_{CA} (RMS Voltage)=
Wye Side (obs)	e_{an} (RMS Voltage)= e_{bn} (RMS Voltage)= e_{cn} (RMS Voltage)=
Wye Side (obs)	e_{an} • $V_{\mathbf{pk\text{-}pk}}$= • $V_{\mathbf{pk}}$= • Freq= • Mean= • Waveform (Attach the waveform)

Wye Side (obs)	Phase difference between ean and ebn=
Voltage Common Cathode terminal (x terminal) (obs)	e_x • V_{pk-pk}= • V_{pk}= • Freq= • Mean= Waveform (Attach the waveform)
Voltage Common Cathode terminal (x terminal) (obs)	e_x • Δt =
Voltage Common Cathode terminal (x terminal) (cal.)	e_x • $\alpha = \frac{180}{10m} * \Delta t$
Voltage Common Cathode terminal (x terminal) (cal.)	e_x • Mean= $\frac{3(\sqrt{3})Vpk}{2\pi}(1 - 2sin^2\frac{\alpha}{2})$ // where Vpk is Vpk of e_{an} • Freq= 3* Freq of e_{an}
Voltage Common Anode terminal (y terminal) (obs.)	e_y • V_{pk-pk}= • V_{pk}= • Freq= • Mean= • Waveform (Attach the waveform)

Voltage Common Anode terminal (y terminal) (cal.)	e_y • Mean= $-\frac{3(\sqrt{3})Vpk}{2\pi}$ // where Vpk is Vpk of e_{an} • Freq= 3* Freq of e_{an}
Voltage Common Cathode terminal (x terminal) and Voltage Common Anode terminal (y terminal) (obs.)	e_x and e_y simultaneously • Waveform (Attach the waveform)
Output Voltage (obs.)	V_o • $V_{pk\text{-}pk}$= • V_{pk}= • Mean= • Waveform (Attach the waveform)
Output Voltage (cal.)	V_o • Mean= $\frac{3(\sqrt{3})Vpk}{\pi}(1 - sin^2\frac{\alpha}{2})$ // where Vpk is Vpk of e_{an}

Rotate the potentiometers such that resistances increase (α increases). Whats your observation regarding the e_x, e_y and output waveform? Minimum voltage of e_x and output waveform is positive or negative or zero? Why?

Post Lab:

Simulate the 3-phase half controlled bridge rectifier circuit with

a) Resistive load
b) Highly inductive load

and observe all the input and output parameters by keeping

- $\alpha = 30^0$
- $\alpha = 90^0$

F/OBEM 01/05/00

NED University of Engineering & Technology
Department of ____**ELECTRONIC**__ Engineering
Course Code and Title: ____**EL-344 POWER ELECTRONICS**______

Psychomotor Domain Assessment Rubric-Level P3					
Skill Sets	Extent of Achievement				
	0	1	2	3	4
<u>Equipment</u> <u>Identification</u> Sensory skill to ***identify*** equipment and/or its component for a lab work.	Not able to identify the equipment.	--	--	--	Able to identify equipment as well as its components.
<u>Equipment Use</u> Sensory skills to ***demonstrate*** the use of the equipment for the lab work.	Doesn't demonstrate the use of equipment.	Slightly demonstrates the use of equipment.	Somewhat demonstrates the use of equipment.	Moderately demon strates the use of equipment.	Fully demonstrates the use of equipment.
<u>Procedural Skills</u> ***Displays*** skills to act upon sequence of steps in lab work.	Not able to either learn or perform lab work procedure.	Able to slightly understand lab work procedure and perform lab work.	Able to somewhat understand lab work procedure and perform lab work.	Able to moderately understand lab work procedure and perform lab work.	Able to fully understand lab work procedure and perform lab work.
<u>Response</u> Ability to ***imitate*** the lab work on his/her own.	Not able to imitate the lab work.	Able to slightly imitate the lab work.	Able to somewhat imitate the lab work.	Able to moderately imitate the lab work.	Able to fully imitate the lab work.
<u>Observation's Use</u> ***Displays*** skills to use the observations from lab work for experimental verifications and illustrations.	Not able to use the observations from lab work for experimental verifications and illustrations.	Slightly able to use the observations from lab work for experimental verifications and illustrations.	Somewhat able to use the observations from lab work for experimental verifications and illustrations.	Moderately able to use the observations from lab work for experimental verifications and illustrations.	Fully able to use the observations from lab work for experimental verifications and illustrations.
<u>Safety Adherence</u> Adherence to ***safety*** procedures.	Doesn't adhere to safety procedures.	Slightly adheres to safety procedures.	Somewhat adheres to safety procedures.	Moderately adheres to safety procedures.	Fully adheres to safety procedures.
<u>Equipment Handling</u> ***Equipment care*** during the use.	Doesn't handle equipment with required care.	Rarely handles equipment with required care.	Occasionally handles equipment with required care.	Often handles equipment with required care.	Handles equipment with required care.
<u>Group Work</u> ***Contributes*** in a group based lab work.	Doesn't participate and contribute.	Slightly participates and contributes.	Somewhat participates and contributes.	Moderately participates and contributes.	Fully participates and contributes.

Laboratory Session No. ____08_______ Date: ______________________

Weighted CLO (Psychomotor Score)	
Remarks	
Instructor's Signature with Date:	

LAB SESSION 09

Objective

To operate under supervision the buck converter circuit.

Pre Lab:

Reading Material:

- Book (Power Electronics by Daniel W. Hart)
- Chapter 6 (DC-DC Converters)
- Topic 6.3 (The Buck Converter)
- Topic 6.4 (Design Considerations)

Components Required

- 555 Timer IC (1)
- Diode (3) – 1N4001--7
- Potentiometer – 100 k Ω
- Resistor (1) – 10 k Ω
- Resistor (1) – 1 k Ω
- Capacitor (2) –10 ηF
- Capacitor (1) – 1μF
- BJT (1) – 2N2222A
- Inductor (1) – Solo winding/ You can also use your transformer's winding
- Resistor (1) – As per your calculated value and rating
- Capacitor (1)– As per your calculated value
- Breadboard

Introduction

This practical is about buck converter. Buck Converter is a type of DC-DC converter. So, first have an overview of DC-DC converter. DC-DC converter is a power electronic circuit that converts a fixed dc voltage to a different dc voltage level, often providing a regulated output. This output can be fixed or variable dc voltage. DC-DC converters can be divided into four categories namely

- Buck Converters
- Boost Converters
- Buck-Boost Converters
- Cuck Converter

Buck converter converts high input dc voltage (supply voltage) into low output dc voltage. It is also known as step down converter. The circuit diagram of buck converter is shown in Figure 9.1.

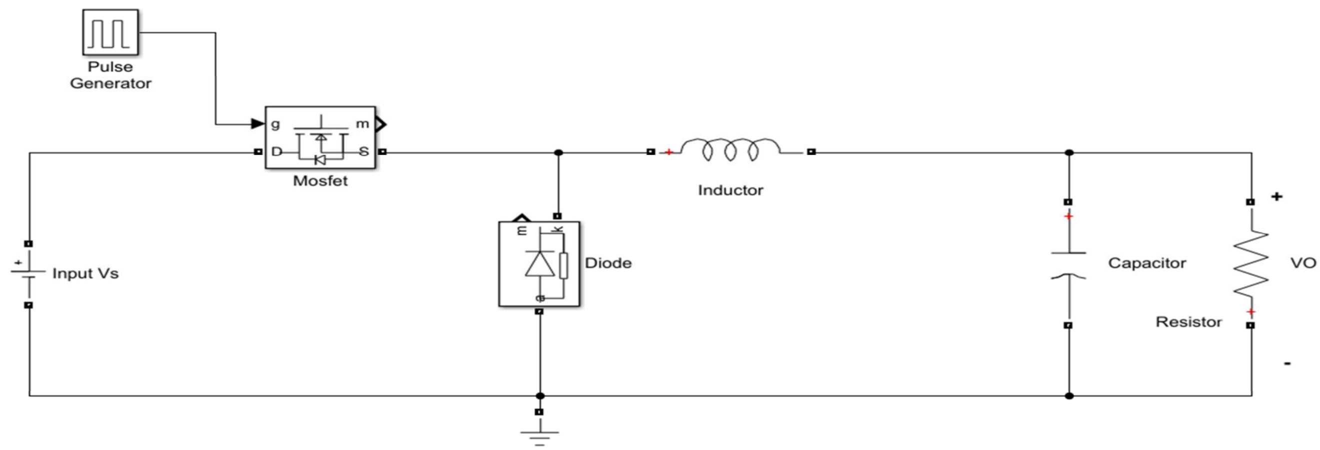

Figure 9.1: Buck Converter

BJT/ MOSFET is used as a switch that will periodically turn ON (for duration $\boldsymbol{t_1}$) and OFF (for duration $\boldsymbol{t_2}$). Total switching time is $\boldsymbol{T}$ and switching frequency is $\boldsymbol{f} = {}^{\mathbf{1}}/_{\boldsymbol{T}}$. It is assumed that

- continuous and positive current flows through the inductor
- the output current $(\boldsymbol{I_o})$ through the load is constant
- output voltage $(\boldsymbol{V_o})$ across the load is constant

When a high switching signal is applied to the base of BJT (or gate of MOSFET), it will turn on/ close and will be replaced with short circuit as shown in Figure 9.2. Supply voltage Vs will appear at the cathode of diode, thus the diode will become reverse biased and open circuited. Voltage across the inductor will be Vs- Vo. As inductor's voltage is positive and constant so it will store the energy and its current will increase linearly. As the output current is constant, so the capacitor's current will also change linearly and change in capacitor current will be equal to the change in inductor current. As average capacitor current is zero, capacitor will both discharge and charge during this duration.

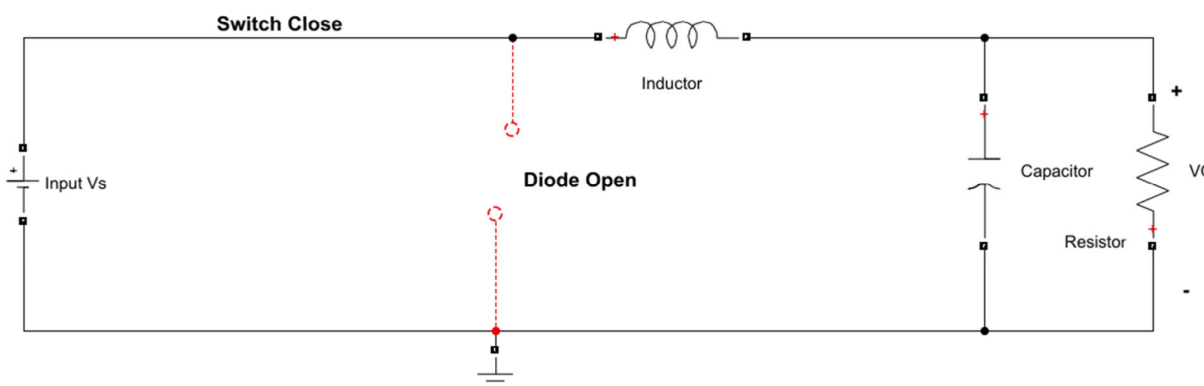

Figure 9.2: Buck Converter in Closed Switch Mode

When a low switching signal is applied to the base of BJT (or gate of MOSFET), it will turn off and will be replaced with open circuit as shown in Figure 9.3.

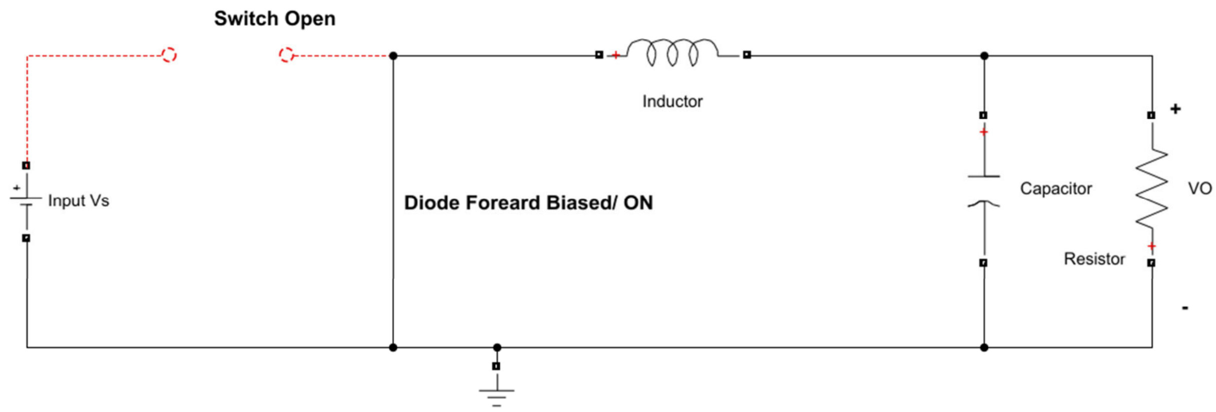

Figure 9.3: Buck Converter in Open Switch Mode

Now there will be no connection between supply and load and source current will be zero. As some current was flowing through the inductor before the switch (BJT/ MOSFET) turned off and inductor current can't abruptly be changed to zero, so inductor will reverse its polarity making the diode forward biased. Thus, the diode will turn on and will be replaced with short circuit. Now inductor polarity has reversed which is equal to **-**Vo so it will release its energy and its current will reduce linearly. As the output current is constant, so the capacitor's current will also change linearly and change in capacitor current will be equal to the change in inductor current. As average capacitor current is zero, capacitor will both charge and discharge during this duration as shown in Figure 9.4.

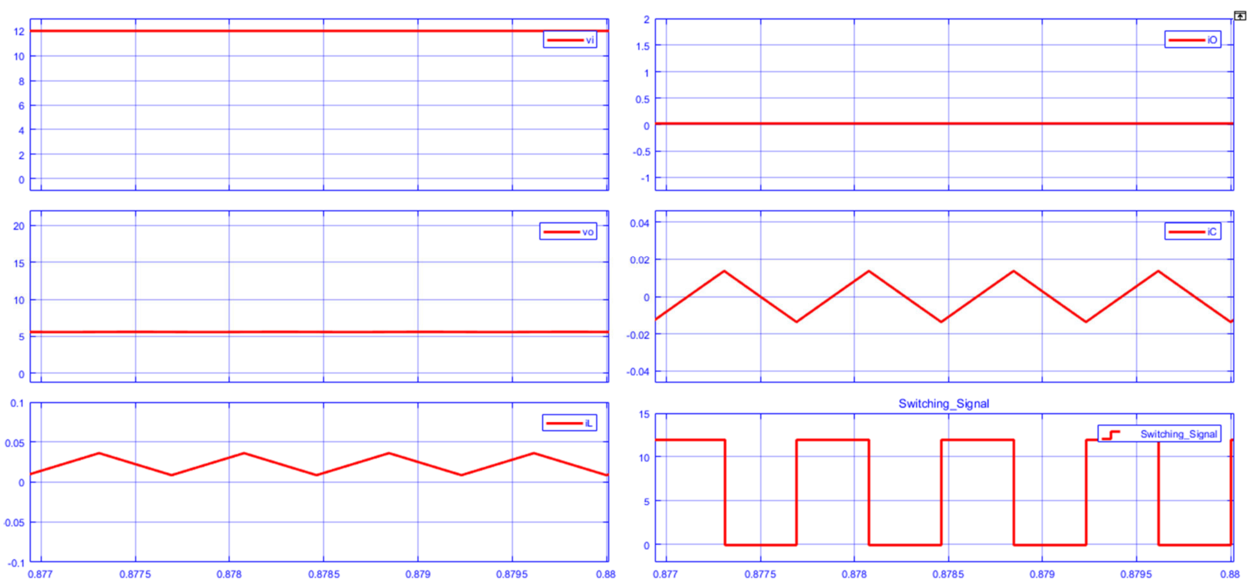

Figure 9.4: Switching Signal, Input and Output Voltage, Inductor, Capacitor and Output Current for Buck Converter

Switching signal, to turn the BJT/ MOSFET ON and OFF, can be generated from 555 timer by using it as astable multivibrator. For this practical switching signal of fixed frequency and variable duty cycle has generated. It can also be generated via programming an Arduino.

Due to the periodic nature of inductor current the output voltage can relate with the input voltage as

$$V_o = kV_s$$

where k is the duty cycle which is defined as "Ratio between high time of a switching signal and total time of the switching signal" i.e.

$$k = \frac{t_1}{t_1 + t_2}$$

Inductance and capacitance for a buck converter can be calculated as

$$L = \frac{V_s(1-k)k}{f * \Delta i_L}$$

$$C = \frac{1-k}{8 * L * f^2 * (\frac{\Delta V}{V_o})}$$

The minimum inductance that allows continuous current flow through the inductor is represented by L_{min}. Mostly to guarantee continuous inductor current designers keep $L = 1.25 * L_{min}$.

Buck converters are very power efficient as compared to the voltage regulator that perform the same dc voltage conversion operation but dissipate excess amount of energy in the form of heat. That's why buck converters are preferred over normal voltage regulators.

Procedure

- Implement the astable multivibrator circuit using 555 timer IC on breadboard, to generate switching signal as shown in Figure 9.5, on breadboard.

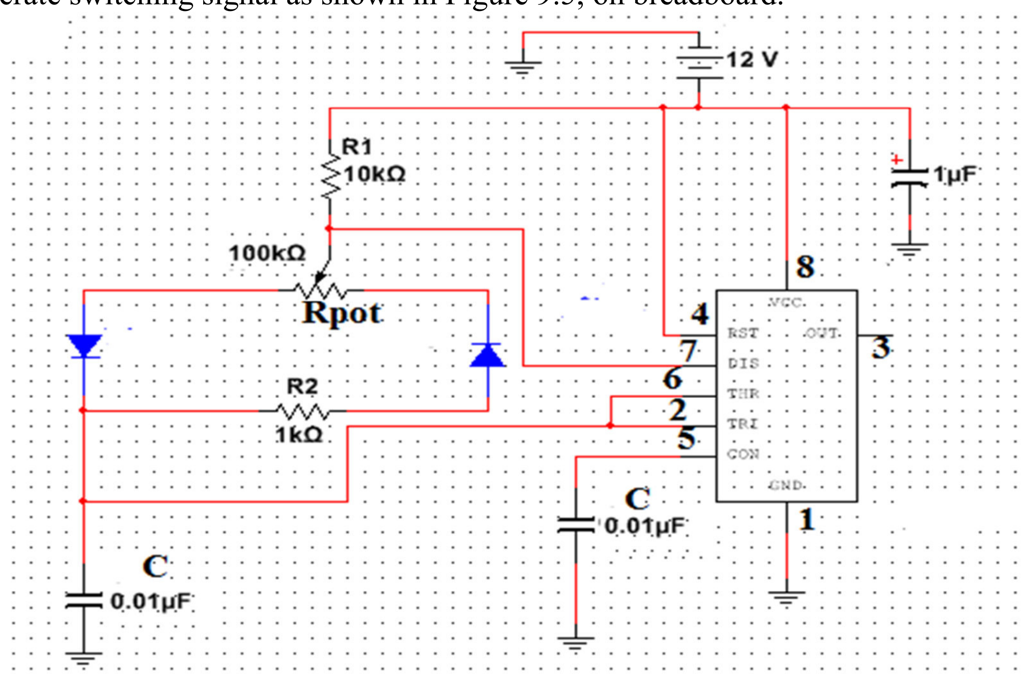

Figure 9.5: 555 Timer As Astable Multivibrator to Generate Fixed Frequency and Variable Duty Cycle Signal

- Supply voltage will be kept 12V throughout the practical.
- Observe the output waveform at pin 3 of IC on oscilloscope and measure its frequency.
- Now vary the potentiometer and observe the change in duty cycle and frequency.
- Variation in duty cycle will be kept between 25% and 75%.
  Note: The same signal can also be generated through arduino. By varying the delay in HIGH and LOW signal duty cycle can be adjusted to any desired value.

- Measure the Inductance of the inductor you are using via LCR meter.
- Calculate the minimum inductance.
- Using the range of duty cycle, minimum inductance and frequency calculate the value of resistance that works well/ is acceptable throughout the range of duty cycle.
- Calculate the maximum power rating of the load (resistance).
- By keeping output voltage variation less than 0.5% and using the range of duty cycle, inductance and frequency calculate the value of capacitance that doesn't allow output voltage variation to exceed the defined limit.
- Now you have values for all the components of your buck converter.

- Implement the buck converter, using the component values that you have just calculated, as shown in the Figure 9.6. Remember base terminal of the BJT will be attached to pin 3 of 555 timer IC.

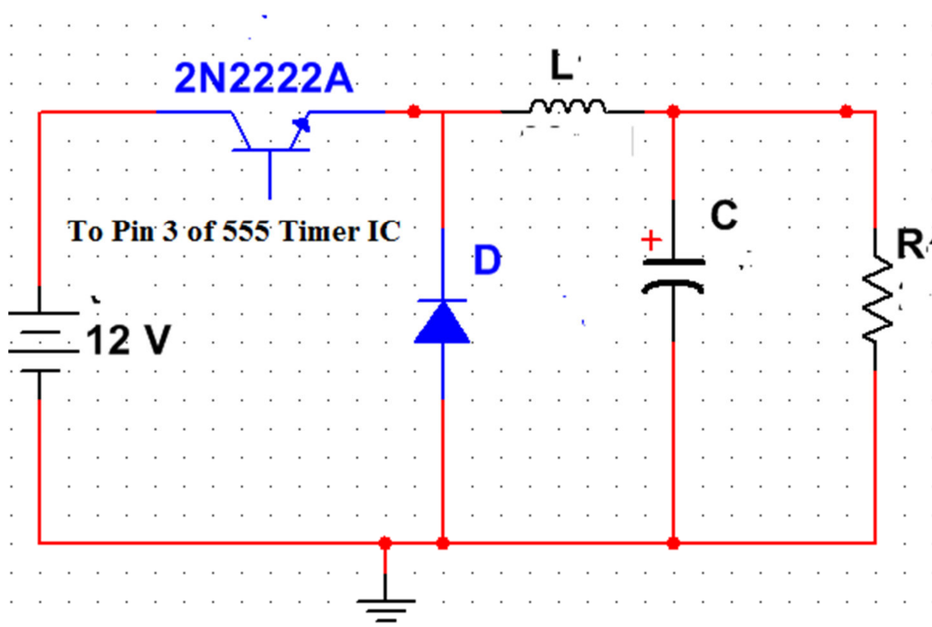

Figure 9.6: Buck Converter

- Adjust the duty cycle at 25% by varying the potentiometer attached with 555 timer IC and observing output voltage on oscilloscope at pin 3 of 555 timer IC. Measure the voltage across the output resistor in buck converter via multimeter or oscilloscope.
- Verify the result through calculation.

- Adjust the duty cycle at 50% by varying the potentiometer attached with 555 timer IC and observing output voltage at pin 3 of 555 timer IC on oscilloscope.
- Measure the voltage across the output resistor in buck converter via multimeter or oscilloscope.

- Verify the result through calculation.

- Adjust the duty cycle at 75% by varying the potentiometer attached with 555 timer IC and observing output voltage at pin 3 of 555 timer IC on oscilloscope.
- Measure the voltage across the output resistor in buck converter via multimeter or oscilloscope.
- Verify the result through calculation.

Designing, Observation and Calculation Chart:

555 timer as astable multivibrator/ Generation of switching signal	
555 timer output (obs.)	At pin 3 • Frequency=
555 timer output (cal.)	At pin 3 • Frequency= $\frac{1}{0.693\,(R_1+R_{pot}+R_2)C}$
555 timer output (obs.)	Variation in duty cycle by varying potentiometer • Yes/ No
555 timer output (obs.)	Variation in frequency by varying potentiometer • Yes/ No
Designing of buck Converter	
Inductance (obs.)	Inductance • **L=**
Minimum Inductance (cal.)	Minimum Inductance • $L_{min} = \frac{L}{1.25}$

Resistance (cal.)	Resistance • $\boldsymbol{R = \frac{2*f*L_{min}}{1-k}}$
Resistor Wattage (cal.)	Resistance • $\boldsymbol{P = \frac{{V_o}^2}{R}}$
Capacitance (cal.)	Capacitance • $\boldsymbol{C = \frac{1-k}{8*L*f^2*(\frac{\Delta V}{V_o})}}$

Observations and Calculations of buck Converter	
Duty Cycle (25%) Output voltage (obs.)	Output Voltage • V_o=
Duty Cycle (25%) Output voltage (cal.)	Output Voltage • V_o= kV_s
Duty Cycle (50%) Output voltage (obs.)	Output Voltage • V_o=

Duty Cycle (50%) Output voltage (cal.)	Output Voltage • V_o= kV_s
Duty Cycle (75%) Output voltage (obs.)	Output Voltage • V_o=
Duty Cycle (75%) Output voltage (cal.)	Output Voltage • V_o= kV_s

Post Lab:

Simulate the buck converter circuit using the circuit parameters that you have just calculated and observe all the input and output parameters.

F/OBEM 01/05/00

NED University of Engineering & Technology
Department of ____**ELECTRONIC**__ Engineering
Course Code and Title: ____**EL-344 POWER ELECTRONICS**______

Psychomotor Domain Assessment Rubric-Level P3					
Skill Sets	Extent of Achievement				
	0	1	2	3	4
Equipment Identification Sensory skill to ***identify*** equipment and/or its component for a lab work.	Not able to identify the equipment.	--	--	--	Able to identify equipment as well as its components.
Equipment Use Sensory skills to ***demonstrate*** the use of the equipment for the lab work.	Doesn't demonstrate the use of equipment.	Slightly demonstrates the use of equipment.	Somewhat demonstrates the use of equipment.	Moderately demon strates the use of equipment.	Fully demonstrates the use of equipment.
Procedural Skills ***Displays*** skills to act upon sequence of steps in lab work.	Not able to either learn or perform lab work procedure.	Able to slightly understand lab work procedure and perform lab work.	Able to somewhat understand lab work procedure and perform lab work.	Able to moderately understand lab work procedure and perform lab work.	Able to fully understand lab work procedure and perform lab work.
Response Ability to ***imitate*** the lab work on his/her own.	Not able to imitate the lab work.	Able to slightly imitate the lab work.	Able to somewhat imitate the lab work.	Able to moderately imitate the lab work.	Able to fully imitate the lab work.
Observation's Use ***Displays*** skills to use the observations from lab work for experimental verifications and illustrations.	Not able to use the observations from lab work for experimental verifications and illustrations.	Slightly able to use the observations from lab work for experimental verifications and illustrations.	Somewhat able to use the observations from lab work for experimental verifications and illustrations.	Moderately able to use the observations from lab work for experimental verifications and illustrations.	Fully able to use the observations from lab work for experimental verifications and illustrations.
Safety Adherence Adherence to ***safety*** procedures.	Doesn't adhere to safety procedures.	Slightly adheres to safety procedures.	Somewhat adheres to safety procedures.	Moderately adheres to safety procedures.	Fully adheres to safety procedures.
Equipment Handling ***Equipment care*** during the use.	Doesn't handle equipment with required care.	Rarely handles equipment with required care.	Occasionally handles equipment with required care.	Often handles equipment with required care.	Handles equipment with required care.
Group Work ***Contributes*** in a group based lab work.	Doesn't participate and contribute.	Slightly participates and contributes.	Somewhat participates and contributes.	Moderately participates and contributes.	Fully participates and contributes.

Laboratory Session No. ____09_______ Date: _______________________

Weighted CLO (Psychomotor Score)	
Remarks	
Instructor's Signature with Date:	

LAB SESSION 10

Objective

To practice the boost converter circuit on breadboard.

Pre Lab

Reading Material:
- Book (Power Electronics by Daniel W. Hart)
- Chapter 6 (DC-DC Converters)
- Topic 6.5 (The Boost Converter)

Components Required

- 555 Timer IC (1)
- Diode (3) – 1N4001--7
- Potentiometer – 100 k Ω
- Resistor (1) – 10 k Ω
- Resistor (1) – 1 k Ω
- Capacitor (2) –10 nF
- Capacitor (1) – 1µF
- BJT (1) – 2N2222A
- Inductor (1) – Solo winding/ You can also use your transformer's winding
- Resistor (1)– As per your calculated value and rating
- Capacitor (1)– As per your calculated value
- Breadboard

Introduction

Boost converter converts low input dc voltage (supply voltage) into high output dc voltage. It is also known as step up converter. The circuit diagram of boost converter is shown in Figure 10.1.

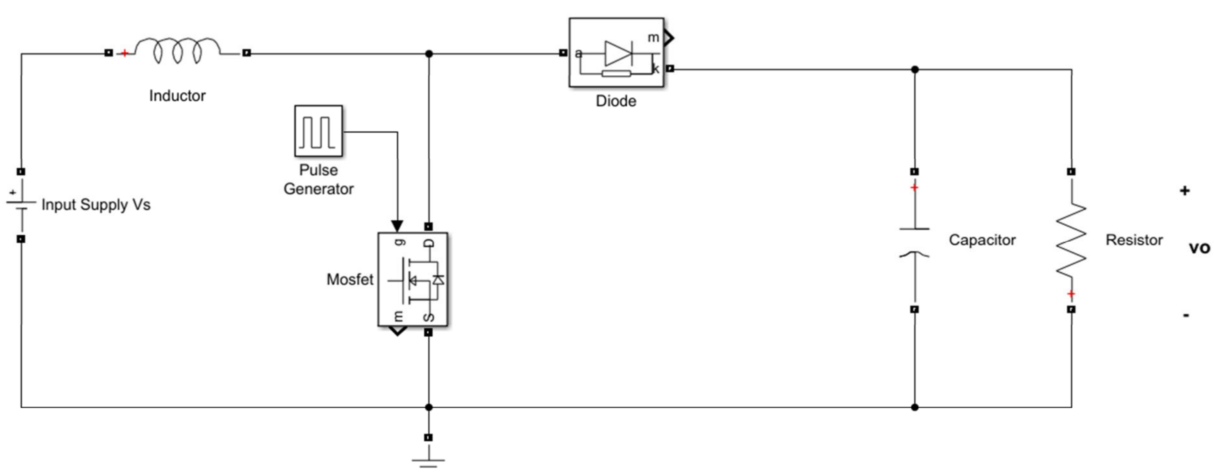

Figure 10.1: Boost Converter

BJT/ MOSFET is used as a switch that will periodically turn ON (for duration $\boldsymbol{t_1}$) and OFF (for duration $\boldsymbol{t_2}$). Total switching time is $\boldsymbol{T}$ and switching frequency is $\boldsymbol{f} = {}^{\boldsymbol{1}}/_{\boldsymbol{T}}$. It is assumed that

- continuous and positive current flows through the inductor
- the output current $(\boldsymbol{I_o})$ through the load is constant
- output voltage $(\boldsymbol{V_o})$ across the load is constant

When a high switching signal is applied to the base of BJT (or gate of MOSFET), it will turn on and will be replaced with short circuit as shown in Figure 10.2. So, anode of diode will be connected to ground and thus the diode will become reverse biased and open circuited. Voltage across the inductor will be Vs. As inductor's voltage is positive and constant so it will store the energy and its current will increase linearly. As the output current is constant, so the capacitor's current will also be the constant and equal in magnitude to the output current. As the capacitor current is negative, so it will discharge linearly.

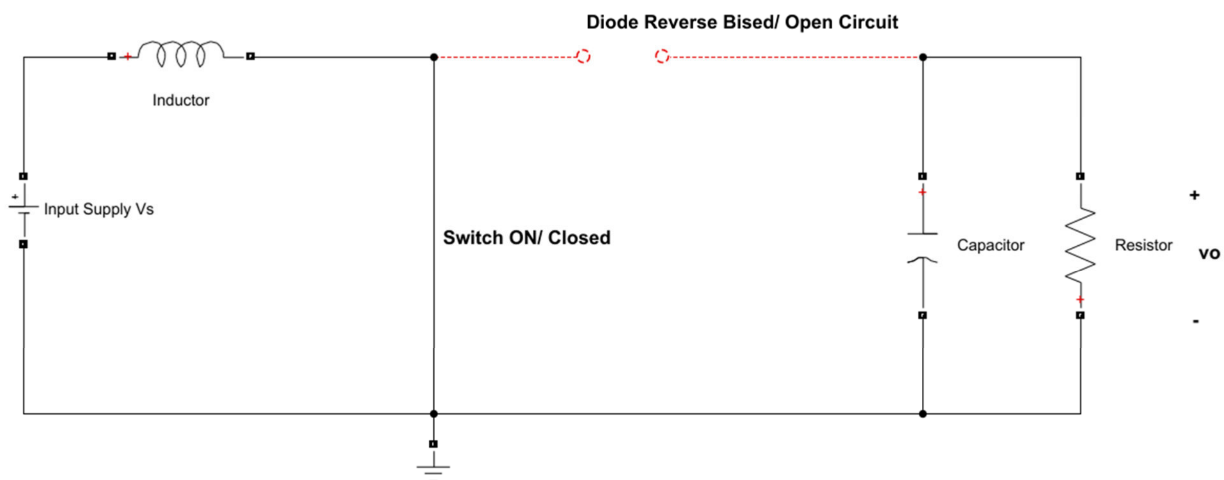

Figure 10.2: Boost Converter in Closed Switch Mode

When a low switching signal is applied to the base of BJT (or gate of MOSFET), it will turn off and will be replaced with open circuit as shown in Figure 10.3.

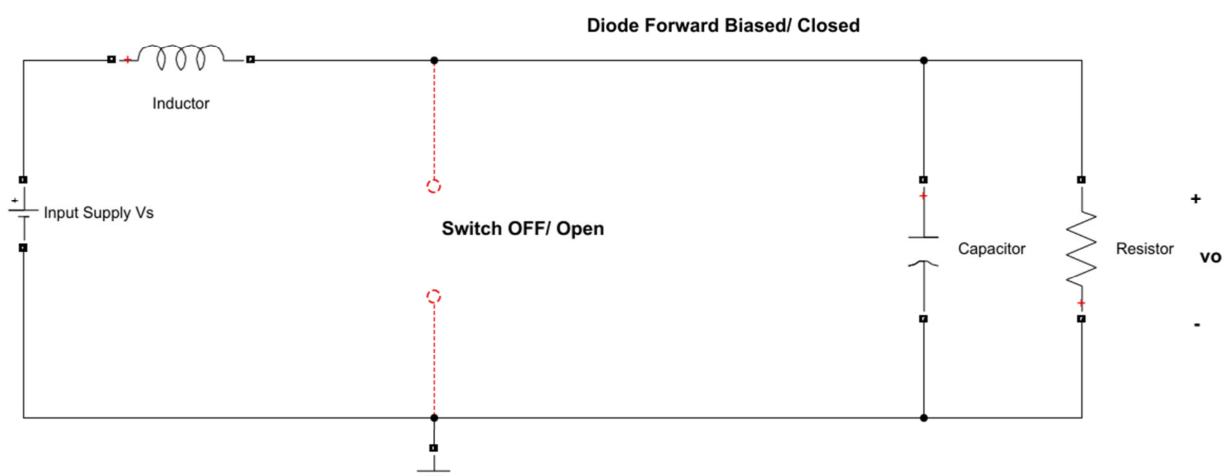

Figure 10.3: Boost Converter in Open Switch Mode

As some current was flowing through the inductor before the switch (BJT/ MOSFET) turned off and inductor current can't abruptly be changed to zero, so inductor will reverse its polarity making the diode forward biased. As diode is forward biased so it will turn on and will be replaced with short circuit. Voltage across the inductor will be Vs-Vo. Inductor voltage (Vs-Vo) is negative means Vo is greater than Vs. As inductor's voltage is negative so it will release its energy and its current will reduce linearly. As the output current is constant, so the capacitor's current will also change linearly and change in capacitor current during this duration will be equal to the change in inductor current as shown in Figure 10.4.

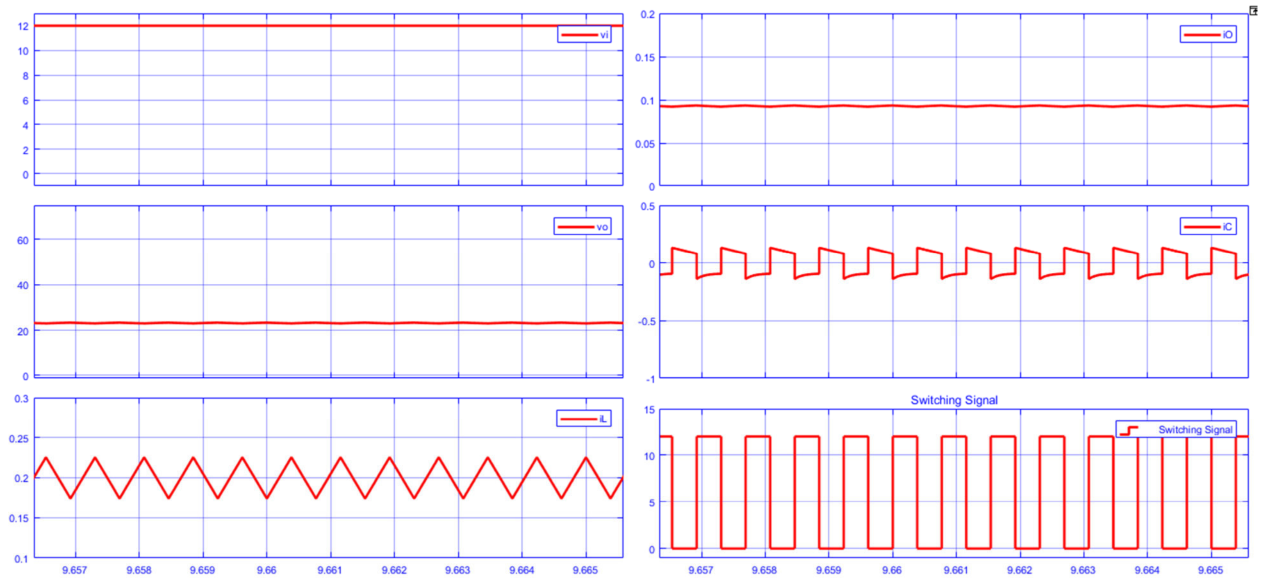

Figure 10.4: Switching Signal, Input and Output Voltage, Inductor, Capacitor and Output Current for Boost Converter

Switching signal, to turn the BJT/ MOSFET ON and OFF, can be generated from 555 timer IC by using it as astable multivibrator. For this practical switching signal of fixed frequency and variable duty cycle has generated. It can also be generated via programming an Arduino.

Due to the periodic inductor current the output voltage can relate with the input voltage as

$$\boldsymbol{V_o = \frac{V_s}{1-k}}$$

where k is the duty cycle which is defined as "Ratio between high time of a switching signal and total time of the switching signal" i.e.

$$\boldsymbol{k = \frac{t_1}{t_1 + t_2}}$$

Inductance and capacitance for a buck converter can be calculated as

$$\boldsymbol{L = \frac{V_s * k}{f * \Delta i_L}}$$

$$\boldsymbol{C = \frac{k}{R * f * (\frac{\Delta V}{V_o})}}$$

The minimum inductance that allows continuous current flow through the inductor is represented by L_{min}. Mostly to guarantee continuous inductor current the designers keep $L = 1.25 * L_{min}$.

Procedure

- Implement the astable multivibrator circuit using 555 timer IC on breadboard, to generate switching signal as shown in Figure 10.5 on breadboard.

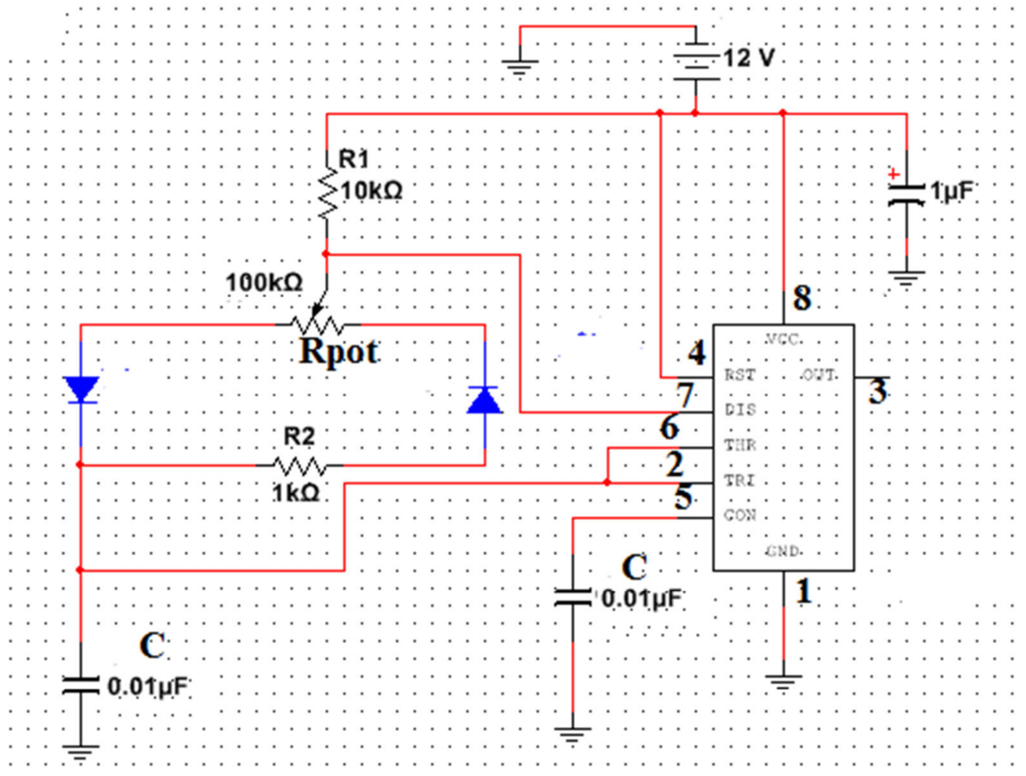

Figure 10.5: 555 Timer As Astable Multivibrator to Generate Fixed Frequency and Variable Duty Cycle Signal

- Supply voltage will be kept 12V throughout the practical.
- Observe the output waveform at pin 3 of IC on oscilloscope and measure its frequency.
- Now vary the potentiometer and observe the change in duty cycle and frequency.
- Variation in duty cycle will be kept between 25% and 75%.
  Note: The same signal can also be generated through arduino. By varying the delay in HIGH and LOW signal duty cycle can be adjusted to any desired value.

- Measure the Inductance of the inductor you are using via LCR meter.
- Calculate the minimum inductance.
- Using the range of duty cycle, minimum inductance and frequency calculate the value of resistance that work well/ is acceptable throughout the range of duty cycle.
- Calculate the maximum power rating of the load (resistance).
- By keeping the output voltage variation less than 0.5% and using the range of duty cycle, resistance and frequency calculate the value of capacitance that doesn't allow output voltage variation to exceed the defined limit.
- Now you have values for all the components of your boost converter.

- Implement the boost converter as shown in the Figure 10.6. Remember base terminal of the BJT will be attached to pin 3 of 555 timer IC.

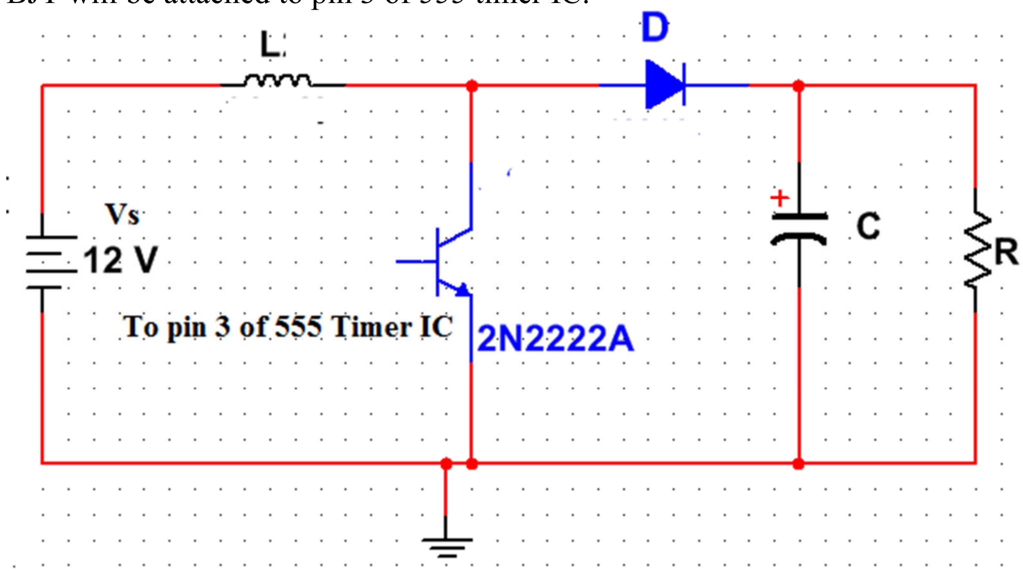

Figure 10.6: Boost Converter

- Adjust the duty cycle at 25% by varying the potentiometer attached with 555 timer IC and observing output voltage on oscilloscope at pin 3 of 555 timer IC.
- Measure the voltage across the output resistor in boost converter via multimeter or oscilloscope.
- Verify the result through calculation.

- Adjust the duty cycle at 50% by varying the potentiometer attached with 555 timer IC and observing output voltage on oscilloscope at pin 3 of 555 timer IC.
- Measure the voltage across the output resistor in boost converter via multimeter or oscilloscope.
- Verify the result through calculation.

- Adjust the duty cycle at 75% by varying the potentiometer attached with 555 timer IC and observing output voltage on oscilloscope at pin 3 of 555 timer IC.
- Measure the voltage across the output resistor in boost converter via multimeter or oscilloscope.
- Verify the result through calculation.

Designing, Observation and Calculation Chart:

555 timer as astable multivibrator/ Generation of switching signal	
555 timer output (obs.)	At pin 3 • Frequency=

555 timer output (cal.)	At pin 3 • Frequency= $\frac{1}{0.693\ (R_1+R_{pot}+R_2)C}$
555 timer output (obs.)	Variation in duty cycle by varying potentiometer • Yes/ No
555 timer output (obs.)	Variation in frequency by varying potentiometer • Yes/ No
<u>Designing of boost Converter</u>	
Inductance (obs.)	Inductance • **L=**
Minimum Inductance (cal.)	Minimum Inductance • $L_{min} = \frac{L}{1.25}$
Resistance (cal.)	Resistance • $R = \frac{2*f*L_{min}}{k*(1-k)^2}$

Resistor Wattage (cal.)	Resistance • $P = \frac{V_o^2}{R}$

Capacitance (cal.)	Capacitance • $\boldsymbol{C = \frac{k}{R * f * (\frac{\Delta V}{V_o})}}$

Observations and Calculations of boost Converter	
Duty Cycle (25%) Output voltage (obs.)	Output Voltage • V_o=
Duty Cycle (25%) Output voltage (cal.)	Output Voltage • $V_o = \frac{Vs}{(1-k)}$
Duty Cycle (50%) Output voltage (obs.)	Output Voltage • V_o=
Duty Cycle (50%) Output voltage (cal.)	Output Voltage • $V_o = \frac{Vs}{(1-k)}$
Duty Cycle (75%) Output voltage (obs.)	Output Voltage • V_o=
Duty Cycle (75%) Output voltage (cal.)	Output Voltage • $V_o = \frac{Vs}{(1-k)}$

Post Lab:

Simulate the boost converter circuit using the circuit parameters that you have just calculated and observe all the input and output parameters.

F/OBEM 01/05/00

NED University of Engineering & Technology
Department of ____**ELECTRONIC**__ Engineering
Course Code and Title: ____**EL-344 POWER ELECTRONICS**______

Psychomotor Domain Assessment Rubric-Level P3					
Skill Sets	Extent of Achievement				
	0	1	2	3	4
<u>Equipment</u> <u>Identification</u> Sensory skill to ***identify*** equipment and/or its component for a lab work.	Not able to identify the equipment.	--	--	--	Able to identify equipment as well as its components.
<u>Equipment Use</u> Sensory skills to ***demonstrate*** the use of the equipment for the lab work.	Doesn't demonstrate the use of equipment.	Slightly demonstrates the use of equipment.	Somewhat demonstrates the use of equipment.	Moderately demon strates the use of equipment.	Fully demonstrates the use of equipment.
<u>Procedural Skills</u> ***Displays*** skills to act upon sequence of steps in lab work.	Not able to either learn or perform lab work procedure.	Able to slightly understand lab work procedure and perform lab work.	Able to somewhat understand lab work procedure and perform lab work.	Able to moderately understand lab work procedure and perform lab work.	Able to fully understand lab work procedure and perform lab work.
<u>Response</u> Ability to ***imitate*** the lab work on his/her own.	Not able to imitate the lab work.	Able to slightly imitate the lab work.	Able to somewhat imitate the lab work.	Able to moderately imitate the lab work.	Able to fully imitate the lab work.
<u>Observation's Use</u> ***Displays*** skills to use the observations from lab work for experimental verifications and illustrations.	Not able to use the observations from lab work for experimental verifications and illustrations.	Slightly able to use the observations from lab work for experimental verifications and illustrations.	Somewhat able to use the observations from lab work for experimental verifications and illustrations.	Moderately able to use the observations from lab work for experimental verifications and illustrations.	Fully able to use the observations from lab work for experimental verifications and illustrations.
<u>Safety Adherence</u> Adherence to ***safety*** procedures.	Doesn't adhere to safety procedures.	Slightly adheres to safety procedures.	Somewhat adheres to safety procedures.	Moderately adheres to safety procedures.	Fully adheres to safety procedures.
<u>Equipment Handling</u> ***Equipment care*** during the use.	Doesn't handle equipment with required care.	Rarely handles equipment with required care.	Occasionally handles equipment with required care.	Often handles equipment with required care.	Handles equipment with required care.
<u>Group Work</u> ***Contributes*** in a group based lab work.	Doesn't participate and contribute.	Slightly participates and contributes.	Somewhat participates and contributes.	Moderately participates and contributes.	Fully participates and contributes.

Laboratory Session No. ____10_______ Date: ______________________

Weighted CLO (Psychomotor Score)	
Remarks	
Instructor's Signature with Date:	

LAB SESSION 11

Objective

To manipulate with guidance the buck-boost converter circuit.

Pre Lab

Reading Material:

- Book (Power Electronics by Daniel W. Hart)
- Chapter 6 (DC-DC Converters)
- Topic 6.6 (The Buck-Boost Converter)

Components Required

- 555 Timer IC (1)
- Diode (3) – 1N4001--7
- Potentiometer – 100 k Ω
- Resistor (1) – 10 k Ω
- Resistor (1) – 1 k Ω
- Capacitor (2) –10 nF
- Capacitor (1) – 1μF
- BJT (1) – 2N2222A
- Inductor (1) – Solo winding/ You can also use your transformer's winding
- Resistor (1)– As per your calculated value and rating
- Capacitor (1)– As per your calculated value
- Breadboard

Introduction

Buck-Boost converter converts the input dc voltage (supply voltage) into either low or high output dc voltage depending on the value of duty cycle (k) of the switching signal. Polarity of the output voltage is reversed as of the input that's why it is also known as "**inverting regulator**". In this converter source is never connected directly to the load that's why it is also called as "**indirect regulator**". The circuit diagram of buck-boost converter is shown in Figure 11.1.

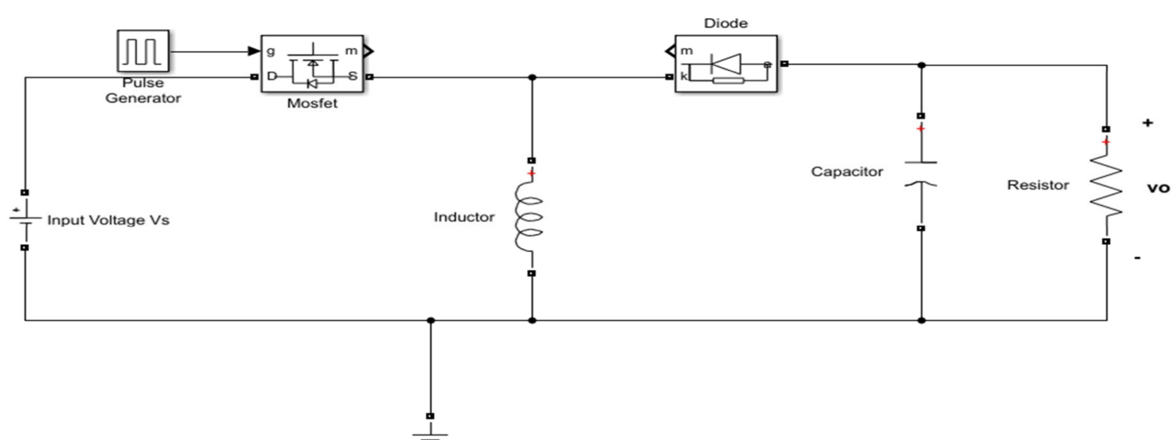

Figure 11.1: Buck-Boost Converter

BJT/ MOSFET is used as a switch that will periodically turn ON (for duration t_1) and OFF (for duration t_2). Total switching time is T and switching frequency is $f = {}^{1}/_{T}$. It is assumed that

- continuous and positive current flows through the inductor
- the output current (I_o) through the load is constant
- output voltage (V_o) across the load is constant

When a high switching signal is applied to the base of BJT (or gate of MOSFET), it will turn on and will be replaced with short circuit as shown in Figure 11.2. So, cathode of diode will be connected to the supply and thus the diode will become reverse biased and open circuited. Voltage across the inductor will be Vs. As inductor's voltage is positive and constant so it will store the energy and its current will increase linearly. As the output current is constant, so the capacitor's current will also be the constant and equal in magnitude to the output current. As the capacitor current is negative, so it will discharge linearly.

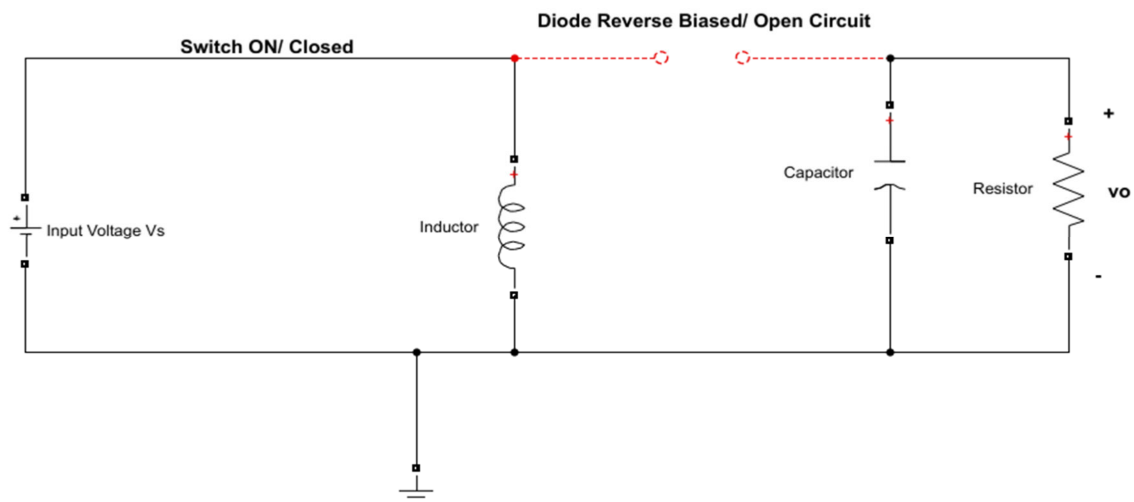

Figure 11.2: Buck-Boost Converter in Closed Switch Mode

When a low switching signal is applied to the base of BJT (or gate of MOSFET), it will turn off and will be replaced with open circuit as shown in Figure 11.3.

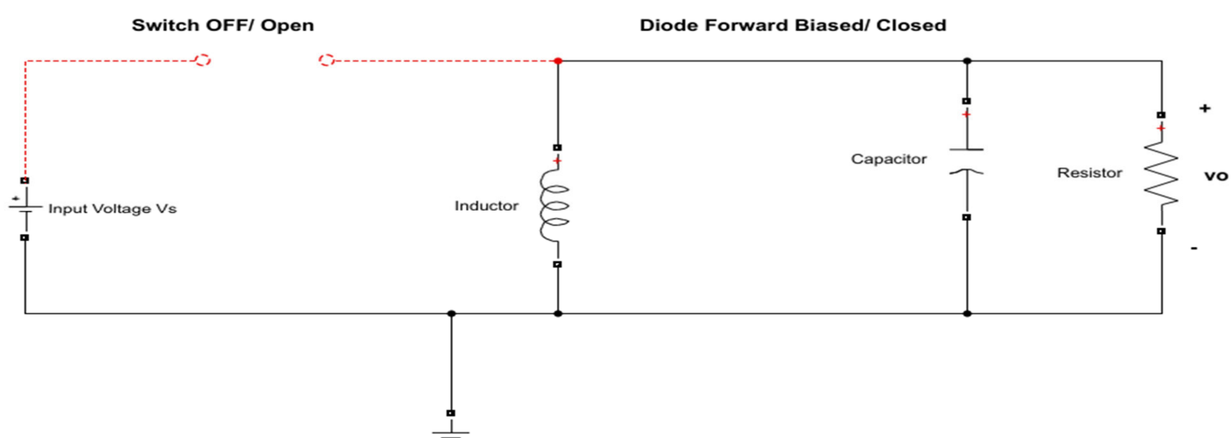

Figure 11.3: Buck-Boost Converter in Open Switch Mode

Source current will be zero during this duration. As some current was flowing through the inductor before the switch (BJT/ MOSFET) turned off and inductor current can't abruptly be changed to zero, so inductor will reverse its polarity making the diode forward biased. Thus, the diode will turn on and will be replaced with short circuit. Now inductor polarity has reversed which is equal to Vo, this means that the value of Vo is also negative. As inductor's voltage is negative so it will release its energy and its current will reduce linearly. As the output current is constant, so the capacitor's current will also change linearly and change in capacitor current will be equal to the change in inductor current as shown in Figure 11.4.

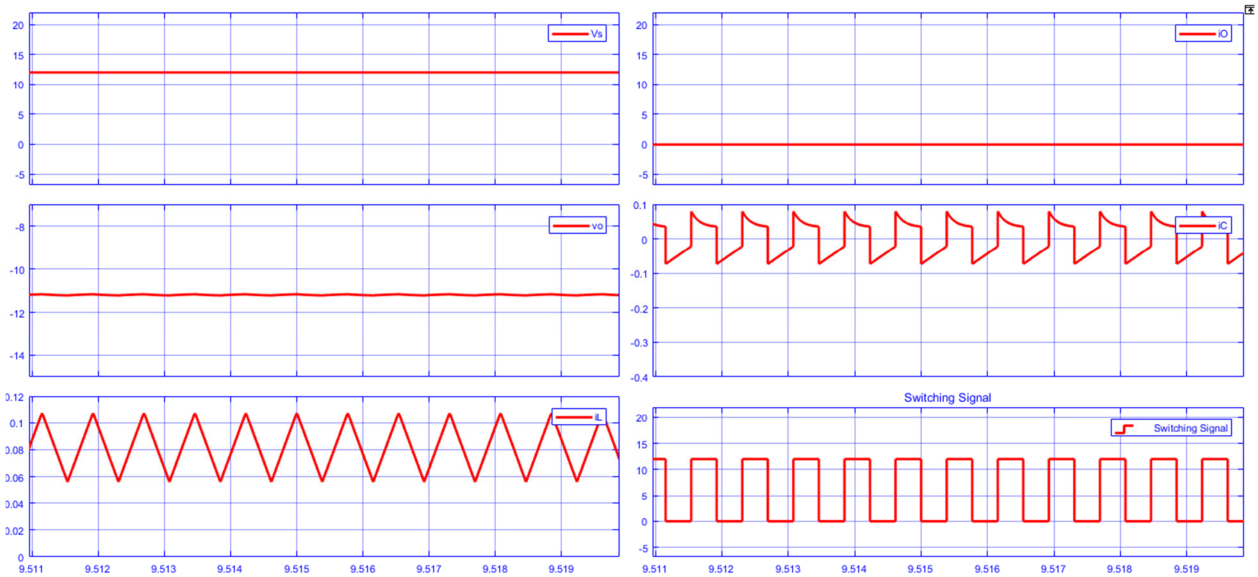

Figure 11.4: Switching Signal, Input and Output Voltage, Inductor, Capacitor and Output Current for Buck-Boost Converter

Switching signal, to turn the BJT/ MOSFET ON and OFF, can be generated from 555 timer by using it as astable multivibrator. For this practical switching signal of fixed frequency and variable duty cycle has generated. It can also be generated via programming an Arduino.

Due to the periodic nature of inductor current the output voltage can relate with the input voltage as

$$V_o = -V_s \frac{k}{1-k}$$

where k is the duty cycle which is defined as "Ratio between high time of a switching signal and total time of the switching signal" i.e.

$$k = \frac{t_1}{t_1 + t_2}$$

Inductance and capacitance for a buck-boost converter can be calculated as

$$L = \frac{V_s * k}{f * \Delta i_L}$$

$$C = \frac{k}{R * f * (\frac{\Delta V}{V_o})}$$

The minimum inductance that allows continuous current flow through the inductor is represented by L_{min}. Mostly to guarantee the continuous inductor current designers keep $L = 1.25 * L_{min}$.

Procedure

- Implement the astable multivibrator circuit using 555 timer IC on breadboard, to generate switching signal as shown in Figure 11.5 on breadboard.

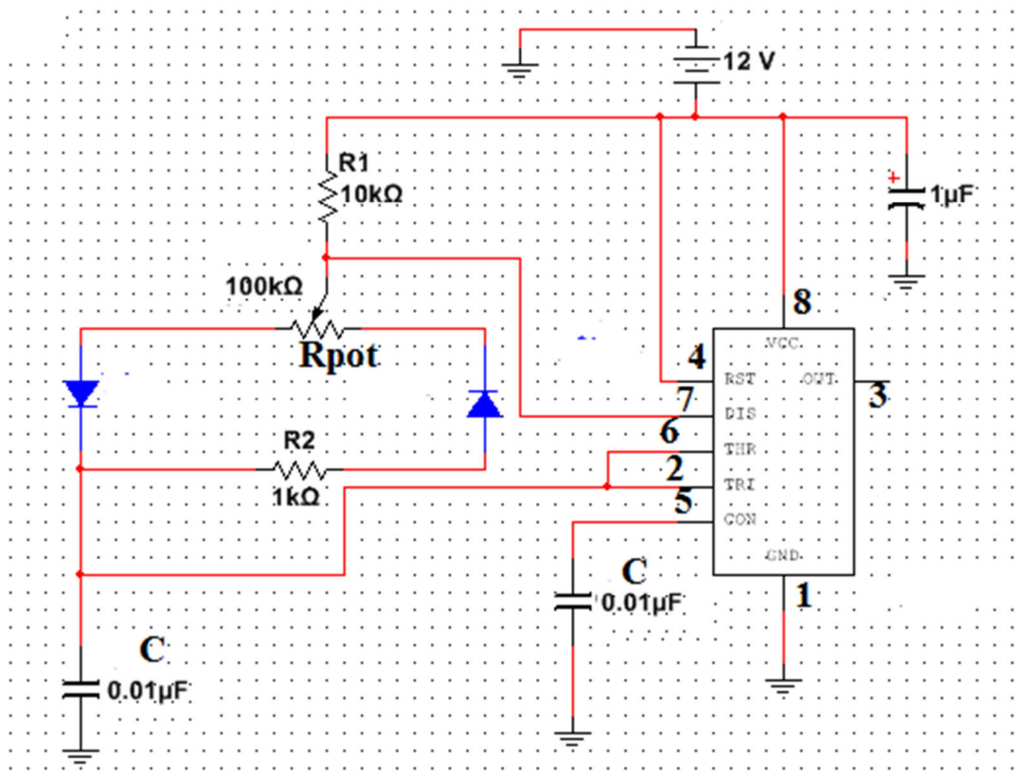

Figure 11.5: 555 Timer As Astable Multivibrator to Generate Fixed Frequency and Variable Duty Cycle Signal

- Supply voltage will be kept 12V throughout the practical.
- Observe the output waveform at pin 3 of IC on oscilloscope and measure its frequency.
- Now vary the potentiometer and observe the change in duty cycle and frequency.
- Variation in duty cycle will be kept between 25% and 75%.
  Note: The same signal can also be generated through arduino. By varying the delay in HIGH and LOW signal duty cycle can be adjusted to any desired value.

- Measure the Inductance of the inductor you are using via LCR meter.
- Calculate the minimum inductance.
- Using the range of duty cycle, minimum inductance and frequency calculate the value of resistance that work well/ is acceptable throughout the range of duty cycle.
- Calculate the maximum power rating of the load (resistance).
- By keeping the variation in output voltage less than 0.5% and using the range of duty cycle, resistance and frequency: calculate the value of capacitance that doesn't allow output voltage variation to exceed the defined limit.
- Now you have values for all the components of your buck-boost converter.

- Implement the buck-boost converter as shown in the Figure 11.5. Remember base terminal of the BJT will be attached to pin 3 of 555 timer IC.

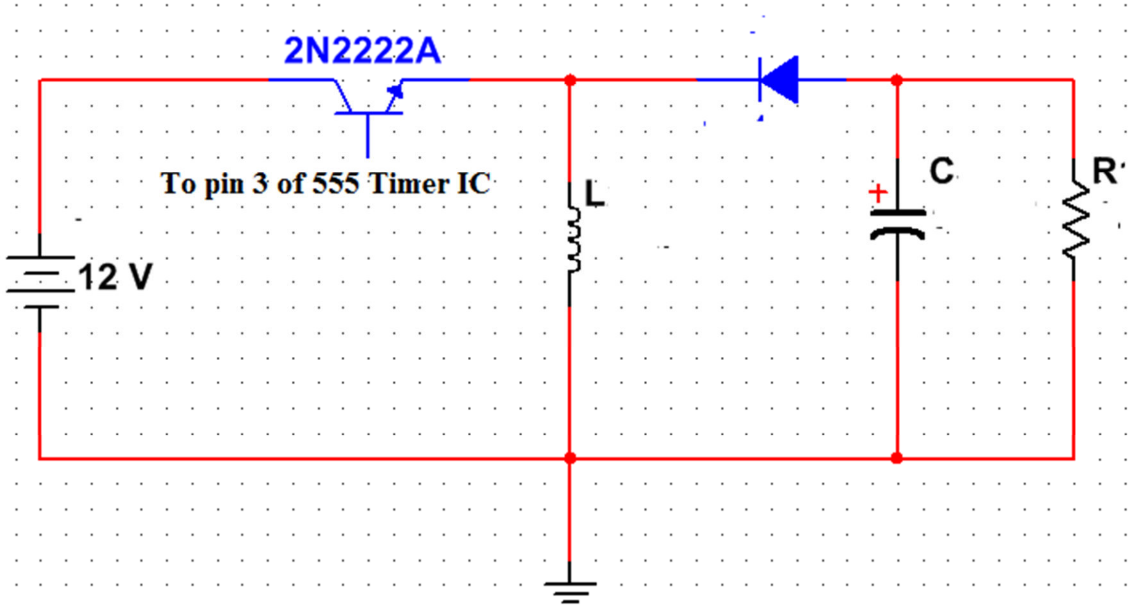

Figure 11.6: Buck-Boost Converter

- Adjust the duty cycle at 25% by varying the potentiometer attached with 555 timer IC and observing output voltage on oscilloscope at pin 3 of 555 timer IC.
- Measure the voltage across the output resistor in buck-boost converter via multimeter or oscilloscope.
- Verify the result through calculation.

- Adjust the duty cycle at 50% by varying the potentiometer attached with 555 timer IC and observing output voltage on oscilloscope at pin 3 of 555 timer IC.
- Measure the voltage across the output resistor in buck-boost converter via multimeter or oscilloscope.
- Verify the result through calculation.

- Adjust the duty cycle at 75% by varying the potentiometer attached with 555 timer IC and observing output voltage on oscilloscope at pin 3 of 555 timer IC.
- Measure the voltage across the output resistor in buck-boost converter via multimeter or oscilloscope.
- Verify the result through calculation.

Designing, Observation and Calculation Chart:

555 timer as astable multivibrator/ Generation of switching signal	
555 timer output (obs.)	At pin 3 • Frequency=

555 timer output (cal.)	At pin 3 • Frequency= $\frac{1}{0.693\,(R_1+R_{pot}+R_2)C}$
555 timer output (obs.)	Variation in duty cycle by varying potentiometer • Yes/ No
555 timer output (obs.)	Variation in frequency by varying potentiometer • Yes/ No
<u>Designing of buck-boost Converter</u>	
Inductance (obs.)	Inductance • **L=**
Minimum Inductance (cal.)	Minimum Inductance • $L_{min} = \frac{L}{1.25}$
Resistance (cal.)	Resistance • $R = \frac{2*f*L_{min}}{(1-k)^2}$

Resistor Wattage (cal.)	Resistance • $P = \frac{{V_o}^2}{R}$

Capacitance (cal.)	Capacitance • $C = \frac{k}{R * f * (\frac{\Delta V}{V_o})}$

Observations and Calculations of buck-boost Converter	
Duty Cycle (25%) Output voltage (obs.)	Output Voltage • $\mathbf{V_o}$=
Duty Cycle (25%) Output voltage (cal.)	Output Voltage • $\mathbf{V_o} = -\frac{k*Vs}{(1-k)}$
Duty Cycle (50%) Output voltage (obs.)	Output Voltage • $\mathbf{V_o}$=
Duty Cycle (50%) Output voltage (cal.)	Output Voltage • $\mathbf{V_o} = -\frac{k*Vs}{(1-k)}$
Duty Cycle (75%) Output voltage (obs.)	Output Voltage • $\mathbf{V_o}$=
Duty Cycle (75%) Output voltage (cal.)	Output Voltage • $\mathbf{V_o} = -\frac{k*Vs}{(1-k)}$

Post Lab:

Simulate the buck-boost converter circuit using the circuit parameters that you have just calculated and observe all the input and output parameters.

F/OBEM 01/05/00

NED University of Engineering & Technology
Department of ____**ELECTRONIC**__ Engineering
Course Code and Title: ____**EL-344 POWER ELECTRONICS**______

Psychomotor Domain Assessment Rubric-Level P3					
Skill Sets	Extent of Achievement				
	0	1	2	3	4
Equipment Identification Sensory skill to ***identify*** equipment and/or its component for a lab work.	Not able to identify the equipment.	--	--	--	Able to identify equipment as well as its components.
Equipment Use Sensory skills to ***demonstrate*** the use of the equipment for the lab work.	Doesn't demonstrate the use of equipment.	Slightly demonstrates the use of equipment.	Somewhat demonstrates the use of equipment.	Moderately demon strates the use of equipment.	Fully demonstrates the use of equipment.
Procedural Skills ***Displays*** skills to act upon sequence of steps in lab work.	Not able to either learn or perform lab work procedure.	Able to slightly understand lab work procedure and perform lab work.	Able to somewhat understand lab work procedure and perform lab work.	Able to moderately understand lab work procedure and perform lab work.	Able to fully understand lab work procedure and perform lab work.
Response Ability to ***imitate*** the lab work on his/her own.	Not able to imitate the lab work.	Able to slightly imitate the lab work.	Able to somewhat imitate the lab work.	Able to moderately imitate the lab work.	Able to fully imitate the lab work.
Observation's Use ***Displays*** skills to use the observations from lab work for experimental verifications and illustrations.	Not able to use the observations from lab work for experimental verifications and illustrations.	Slightly able to use the observations from lab work for experimental verifications and illustrations.	Somewhat able to use the observations from lab work for experimental verifications and illustrations.	Moderately able to use the observations from lab work for experimental verifications and illustrations.	Fully able to use the observations from lab work for experimental verifications and illustrations.
Safety Adherence Adherence to ***safety*** procedures.	Doesn't adhere to safety procedures.	Slightly adheres to safety procedures.	Somewhat adheres to safety procedures.	Moderately adheres to safety procedures.	Fully adheres to safety procedures.
Equipment Handling ***Equipment care*** during the use.	Doesn't handle equipment with required care.	Rarely handles equipment with required care.	Occasionally handles equipment with required care.	Often handles equipment with required care.	Handles equipment with required care.
Group Work ***Contributes*** in a group based lab work.	Doesn't participate and contribute.	Slightly participates and contributes.	Somewhat participates and contributes.	Moderately participates and contributes.	Fully participates and contributes.

Laboratory Session No. ____11_______ Date: _______________________

Weighted CLO (Psychomotor Score)	
Remarks	
Instructor's Signature with Date:	

LAB SESSION 12

Objective

To practice the phase controlled 1-phase ac voltage controller circuit on the breadboard.

Components Required

- Diode (4) –1N4001--7
- Resistor (2) –1 k Ω / 1/4 Watt
- Resistor (1) –2.2 k Ω / 1/4 Watt
- Potentiometer (1) – 50 k Ω
- SCR(2) – C106
- Transformer (1) –12-12 V/ 400mA or 600mA with power cord properly attached
- Breadboard

Introduction

This practical is about phase controlled single phase ac voltage controller. So first have a quick overview of ac voltage controller. An ac voltage controller accepts electrical power from one system/ source and vary its RMS voltage at same frequency for delivering it to another system/ load. AC voltage controllers are also known as ***ac regulators.*** Rember that for ac voltage controller both the input and output voltages are ac. There are single phase ac voltage controllers that are used to convert single phase ac supply as well as 3 phase ac voltage controllers for 3 phase ac supply.

Single phase ac voltage controller is shown in Figure 12.1.

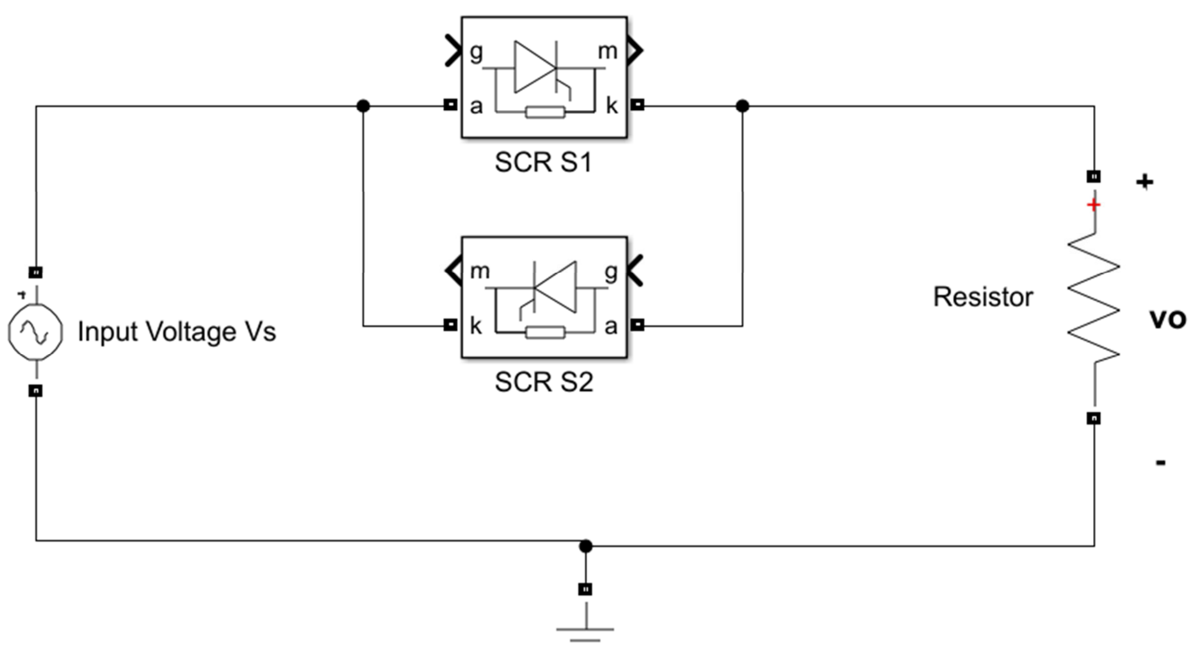

Figure 12.1: Single Phase AC Voltage Controller Circuit

The basic circuit is composed of a pair of SCRs connected back-to-back (also known as antiparallel) between the source and load. There are three different switching techniques/ methods of these SCRs, namely

- Phase Control Method
- Integral Cycle Control Method
- PWM AC Voltage Control Method

Here only phase controlled method will be discussed. With phase controlled method the switches conduct load current for a chosen period of each input cycle of voltage.

Assume that the firing angle of both the SCRs is same $\alpha_1 = \alpha_2 = \alpha$. During positive cycle of input S1 will be forward biased while S2 will be reverse biased thus will be off/ open circuit. Although S1 is forward biased but as it has not yet fired so it will also be off/ open circuit. So, from the instant 0 to α/ω both S1 and S2 will be off and output voltage will be zero. At t= α/ω S1 get fired, hence it will turn ON and behave as short circuit. So, the output will follow the input voltage from t= α/ω to t = π/ω.

During negative cycle of input S2 will be forward biased while S1 will be reverse biased thus will be off/ open circuit. Although S2 is forward biased but as it has not yet fired so it will also be off/ open circuit. So, from instant π/ω to $(\pi + \alpha)/\omega$ both S1 and S2 will be off and output voltage will be zero. At t = $(\pi + \alpha)/\omega$ S2 get fired, hence it will turn ON and behave as short circuit, So, the output voltage will follow the input voltage from t= $(\pi + \alpha)/\omega$ to t = $2\pi/\omega$ as shown in Figure 12.2.

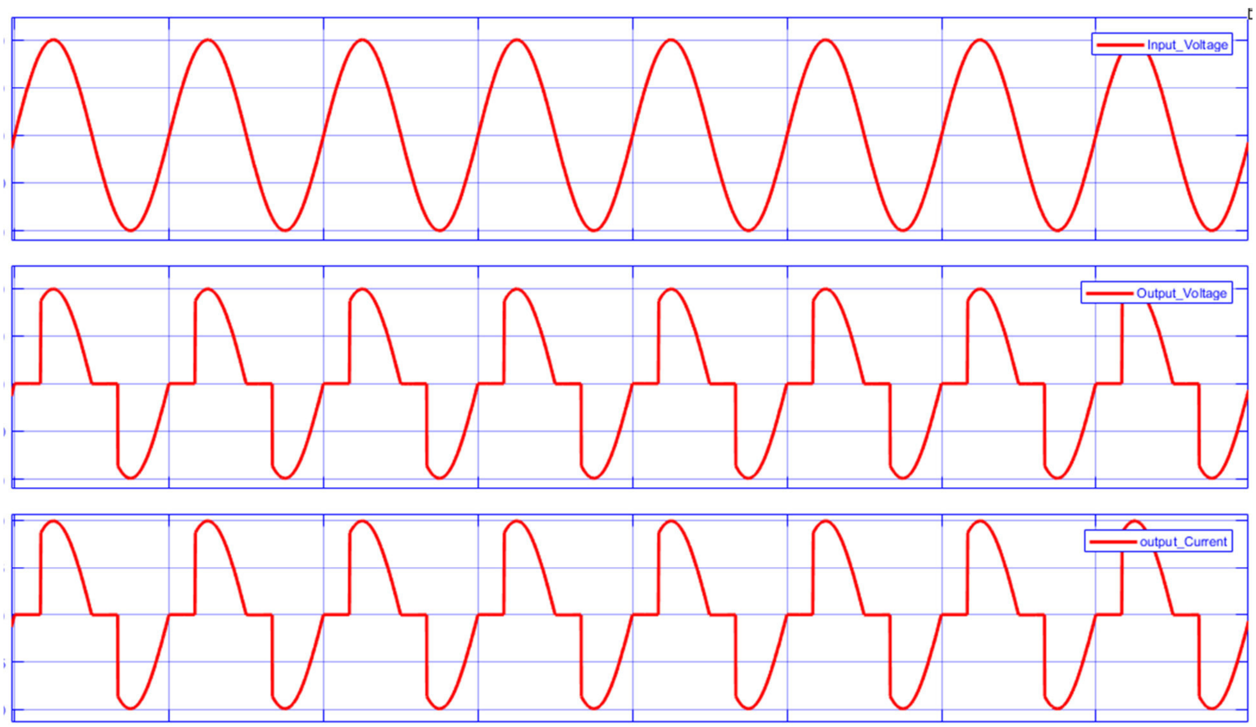

Figure 12.2: Phase Controlled Single Phase AC Voltage Controller Circuit Input and Output Waveforms with Resistive Load

For a resistive load the SCR turns off at the reversal of input i.e. S1 turns off at t = π/ω while S2 turns off at t = $2\pi/\omega$. Because for a resistive load the output current is in phase to the input voltage, if voltage reverses its polarity, then the current tries to reverse its direction which is not allowed as the SCR is a unidirectional device. So, SCR gets turn off as soon as the voltage polarity reverses.

For a RL load the current lags the voltage so the conduction time of each SCR can be extended depending on the value of inductance as shown in the Figure 12.3.

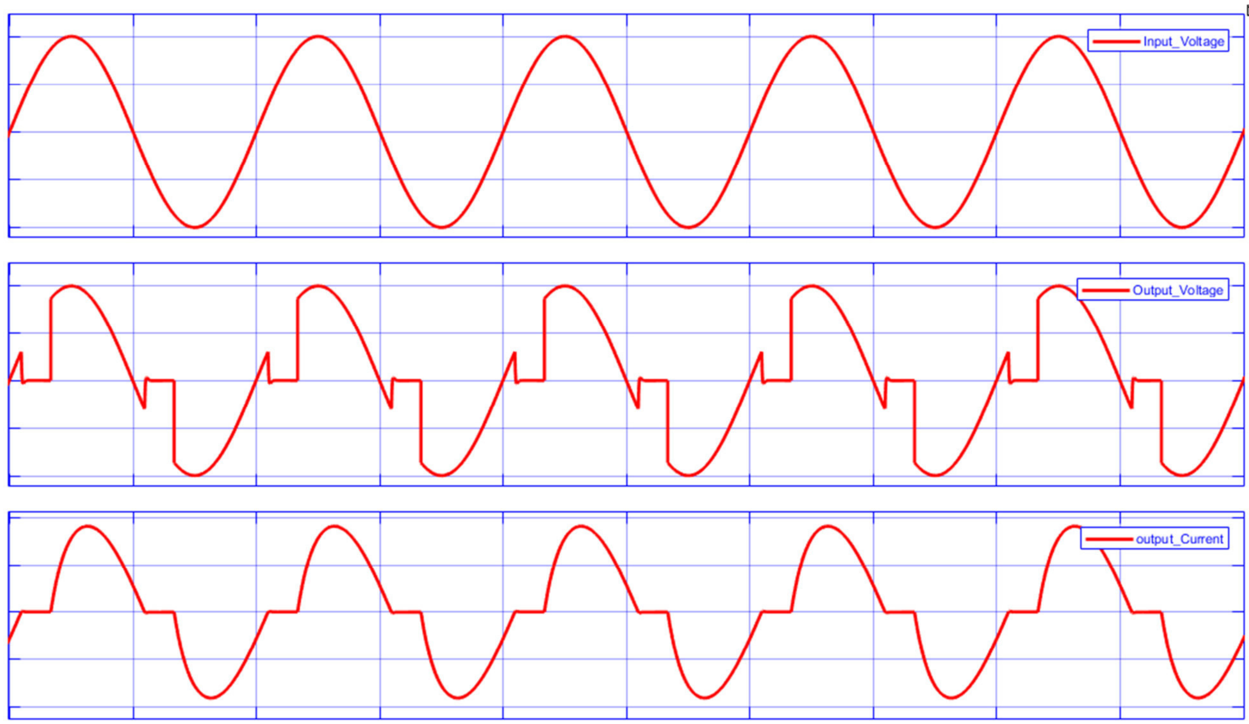

Figure 12.3: Phase Controlled Single Phase AC Voltage Controller Circuit Input and Output Waveforms with RL Load

For this practical phase controlled single phase ac voltage controller circuit having resistive load will be implemented as shown in Figure 12.4.

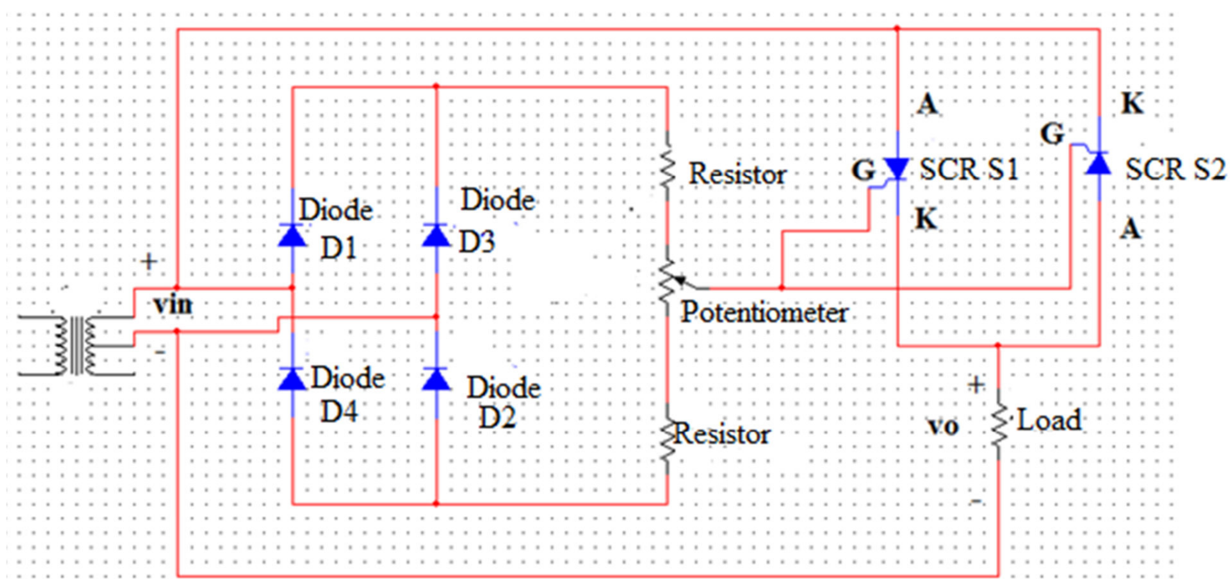

Figure 12.4: Phase Controlled Single Phase AC Voltage Controller

Resistive control method is used to trigger/ fire the SCR for simplicity. (Any gate triggering method can be followed to fire the SCR). As resistive control method is used to fire the SCRs, so α can vary between 0^0 and 90^0.

Two gate pulses are required for each cycle for input. The pulse during positive cycle of input will fire S1 while the pulse during negative cycle of input will fire S2. So, to generate these pulses, first the input is rectified through bridge rectifier then the output of this bridge rectifier (2 positive cycles for each input cycle) is applied to gate control circuit. As a result of this two pulses/ gate signals (positive gate signals) generate for each half cycle of input.

Procedure

- Implement the single phase ac controller circuit on breadboard as shown in the Figure 12.5.

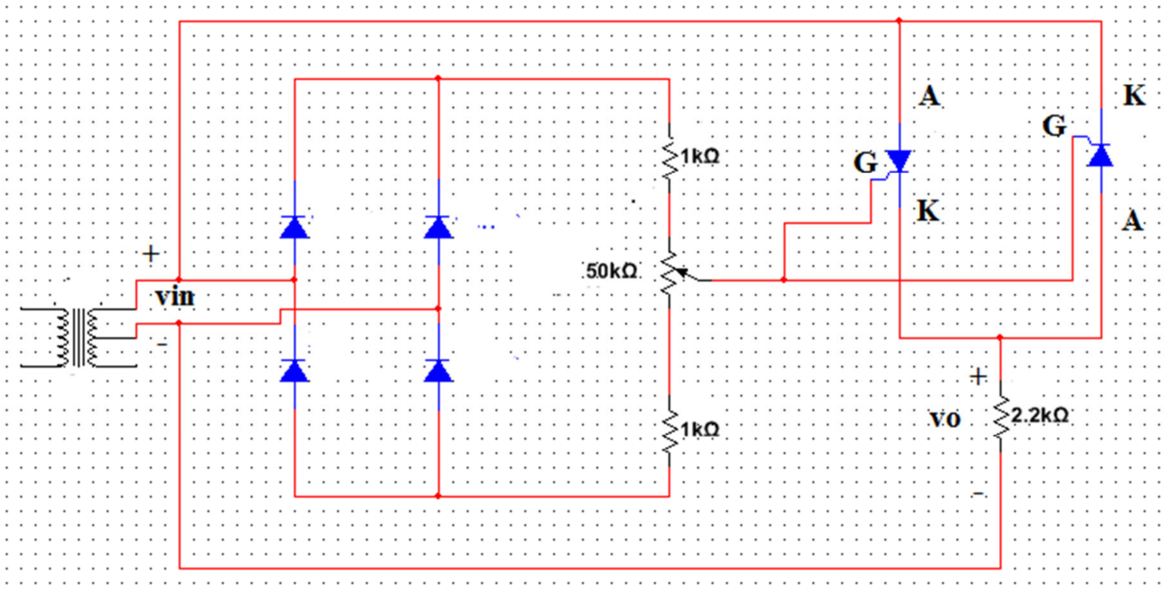

Figure 12.5: Phase Controlled Single Phase AC Voltage Controller Circuit

- Insert plug of transformer in the socket and turn the supply ON.
- Observe the input voltage waveform (between the transformer terminals that are attached with the circuit) on oscilloscope. Measure its peak to peak, peak, frequency, mean and RMS voltage.

- Now adjust the potentiometer by observing the output waveform, there should be a waveform at the output (not a straight line) as shown in the Figure 12.6.

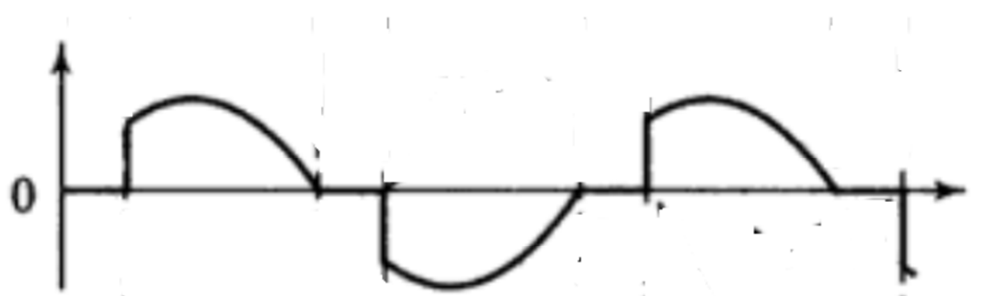

Figure 12.6: Output Waveform of Phase Controlled Single Phase AC Voltage Controller

- Observe the output voltage waveform (across the load) on oscilloscope. Measure its peak to peak, peak, frequency, mean and RMS voltage.
- Measure the value of Δt using cursor option in the oscilloscope as shown in the Figure 12.7

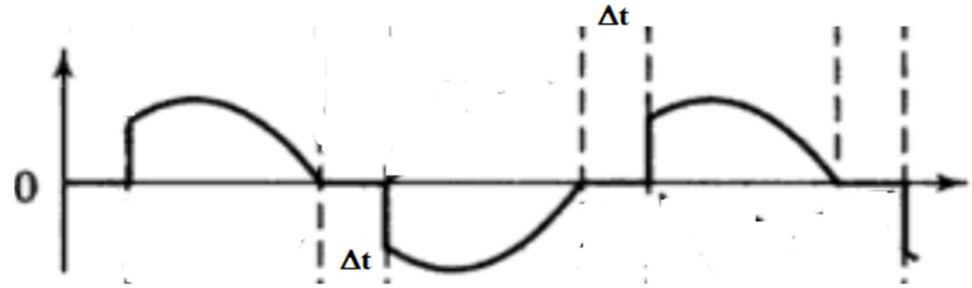

Figure 12.7: Measuring Δt for Phase Controlled Single Phase AC Voltage Controller

- By using the value of Δt calculate the value of α.
- Verify the output mean voltage, RMS voltage and frequency via calculations.

Observation and Calculation Chart:

Input Voltage (obs.)	v_{in} • $V_{pk\text{-}pk}$= • V_{pk}= • Freq= • Mean= • RMS= • Waveform (Attach the waveform)
Output Voltage (obs.)	v_o • $V_{pk\text{-}pk}$= • V_{pk}= • Freq= • Mean= • RMS= • Waveform (Attach the waveform)
Output Voltage (obs.)	v_o • Δt =

Output Voltage (cal.)	v_o • $\alpha = \frac{180}{10m} * \Delta t$
Output Voltage (cal.)	V_o • Mean= • Freq= • RMS = $\frac{Vpk}{\sqrt{2}}\left(1 - \frac{\alpha}{\pi} + \frac{sin2\alpha}{2\pi}\right)^{1/2}$ // where Vpk is Vpk of v_{in}

Post Lab:

Simulate the 1-phase ac controller circuit with

a) Resistive load
b) RL load

and observe all the input and output parameters by keeping $\alpha = 60^0$

F/OBEM 01/05/00

NED University of Engineering & Technology
Department of ____**ELECTRONIC**__ Engineering
Course Code and Title: ____**EL-344 POWER ELECTRONICS**______

Psychomotor Domain Assessment Rubric-Level P3					
Skill Sets	Extent of Achievement				
	0	1	2	3	4
Equipment Identification Sensory skill to ***identify*** equipment and/or its component for a lab work.	Not able to identify the equipment.	--	--	--	Able to identify equipment as well as its components.
Equipment Use Sensory skills to ***demonstrate*** the use of the equipment for the lab work.	Doesn't demonstrate the use of equipment.	Slightly demonstrates the use of equipment.	Somewhat demonstrates the use of equipment.	Moderately demon strates the use of equipment.	Fully demonstrates the use of equipment.
Procedural Skills ***Displays*** skills to act upon sequence of steps in lab work.	Not able to either learn or perform lab work procedure.	Able to slightly understand lab work procedure and perform lab work.	Able to somewhat understand lab work procedure and perform lab work.	Able to moderately understand lab work procedure and perform lab work.	Able to fully understand lab work procedure and perform lab work.
Response Ability to ***imitate*** the lab work on his/her own.	Not able to imitate the lab work.	Able to slightly imitate the lab work.	Able to somewhat imitate the lab work.	Able to moderately imitate the lab work.	Able to fully imitate the lab work.
Observation's Use ***Displays*** skills to use the observations from lab work for experimental verifications and illustrations.	Not able to use the observations from lab work for experimental verifications and illustrations.	Slightly able to use the observations from lab work for experimental verifications and illustrations.	Somewhat able to use the observations from lab work for experimental verifications and illustrations.	Moderately able to use the observations from lab work for experimental verifications and illustrations.	Fully able to use the observations from lab work for experimental verifications and illustrations.
Safety Adherence Adherence to ***safety*** procedures.	Doesn't adhere to safety procedures.	Slightly adheres to safety procedures.	Somewhat adheres to safety procedures.	Moderately adheres to safety procedures.	Fully adheres to safety procedures.
Equipment Handling ***Equipment care*** during the use.	Doesn't handle equipment with required care.	Rarely handles equipment with required care.	Occasionally handles equipment with required care.	Often handles equipment with required care.	Handles equipment with required care.
Group Work ***Contributes*** in a group based lab work.	Doesn't participate and contribute.	Slightly participates and contributes.	Somewhat participates and contributes.	Moderately participates and contributes.	Fully participates and contributes.

Laboratory Session No. ____12_______ Date: _______________________

Weighted CLO (Psychomotor Score)	
Remarks	
Instructor's Signature with Date:	

LAB SESSION 13 (OPEN ENDED LAB)

Objective:

To practice bridge inverter using Arduino for PWM generation.

Background:

Now a days lot of research is going on in generating electricity through renewable energy sources like solar energy, wind energy, hydro energy etc. The generated voltage through these sources is stored in the batteries. As we know that this stored voltage is DC while at home we use AC supply. So, the first step is to convert this DC voltage into AC voltage so that it can be utilized. This conversion is done by inverter.

There are two types of inverters namely single phase bridge inverters and three phase bridge inverters.

Single phase full bridge inverter circuit is shown in Figure 13.1 alongwith its output waveform.

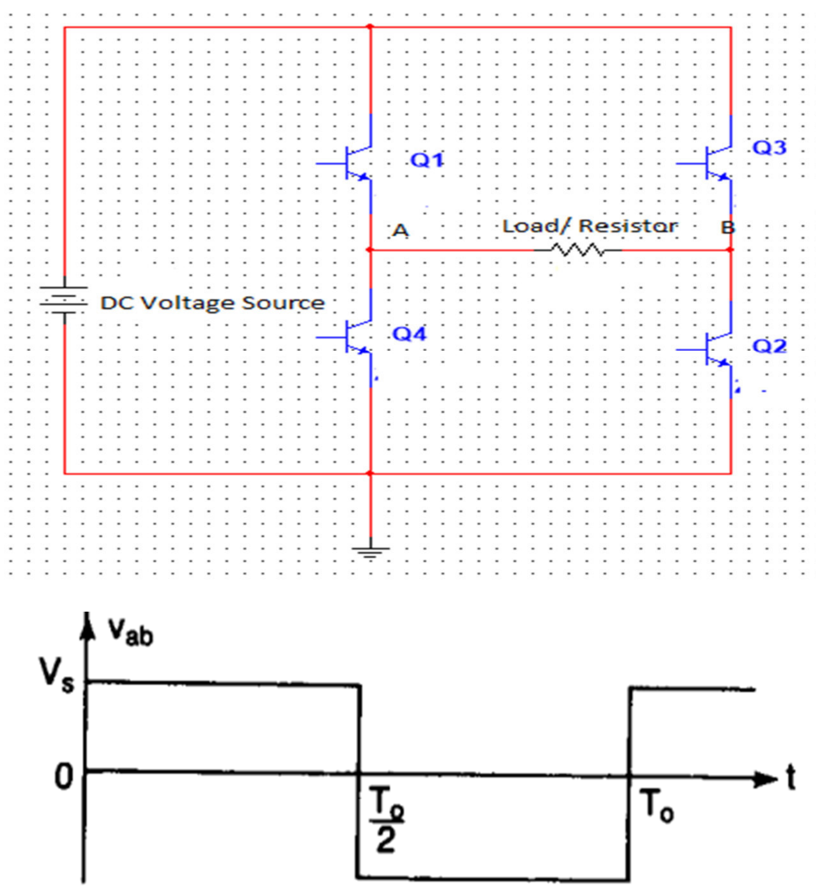

Figure 13.1: Single Phase Full Bridge Inverter

Three phase bridge inverter circuit is shown in Figure 13.2 alongwith the output waveform.

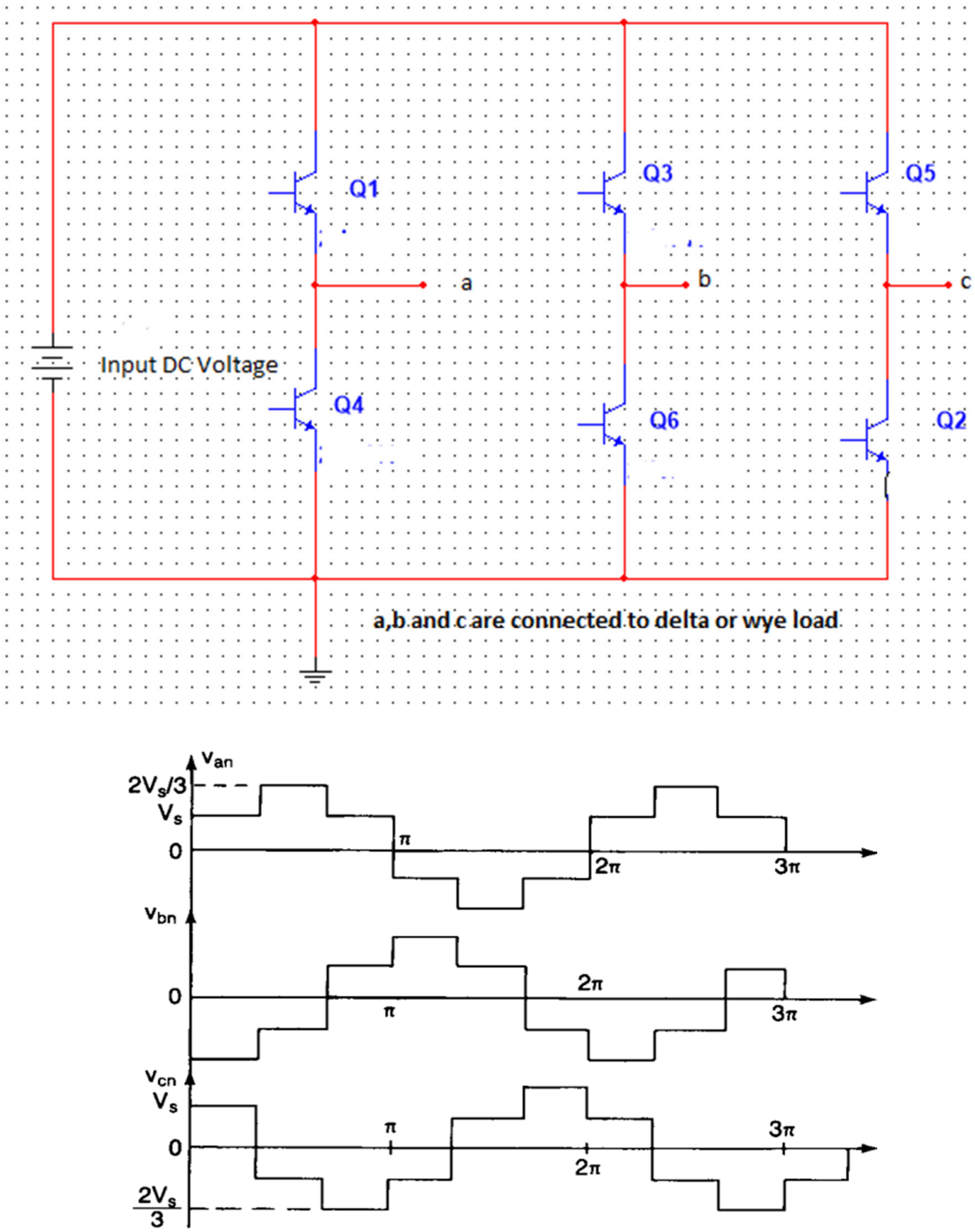

Figure 13.2: Three Phase Bridge Inverter

Switches (BJTs and MOSFET) used in these circuits can be turned on/off at specified instants to acquire the desired output waveform. The switching signals (pulses/ PWM) can be generated via 555 timer IC (for single phase bridge inverter only) or better via programming any controller like Arduino (for both single phase and three phase bridge inverter).

Delieverables:

a) Inverter Circuit on breadboard/ veroboard (preferably 3-phase bridge inverter).
b) Programmed Arduino to generate PWM signals (preferably programed to generate variable frequency switching signal in order to get variable frequency waveform at the ouput of inverter).
c) DC-DC converter attached at the input of inverter to generate variable RMS voltage at the output of inverter (optional task).
d) Proper connections between output pins of Arduino and inverter circuit.
e) Complete report of your lab alongwith proper citation of reference literature, source code of your program, schematic and simulation results of your circuit, snapshots of observed output from multimeter and osciloscope.

F/OBEM 01/05/00

NED University of Engineering & Technology
Department of ____**ELECTRONIC**__ Engineering
Course Code and Title: ____**EL-344 POWER ELECTRONICS**______

Psychomotor Domain Assessment Rubric-Level P3					
Skill Sets	Extent of Achievement				
	0	1	2	3	4
Equipment Identification Sensory skill to ***identify*** equipment and/or its component for a lab work.	Not able to identify the equipment.	--	--	--	Able to identify equipment as well as its components.
Equipment Use Sensory skills to ***demonstrate*** the use of the equipment for the lab work.	Doesn't demonstrate the use of equipment.	Slightly demonstrates the use of equipment.	Somewhat demonstrates the use of equipment.	Moderately demon strates the use of equipment.	Fully demonstrates the use of equipment.
Procedural Skills ***Displays*** skills to act upon sequence of steps in lab work.	Not able to either learn or perform lab work procedure.	Able to slightly understand lab work procedure and perform lab work.	Able to somewhat understand lab work procedure and perform lab work.	Able to moderately understand lab work procedure and perform lab work.	Able to fully understand lab work procedure and perform lab work.
Response Ability to ***imitate*** the lab work on his/her own.	Not able to imitate the lab work.	Able to slightly imitate the lab work.	Able to somewhat imitate the lab work.	Able to moderately imitate the lab work.	Able to fully imitate the lab work.
Observation's Use ***Displays*** skills to use the observations from lab work for experimental verifications and illustrations.	Not able to use the observations from lab work for experimental verifications and illustrations.	Slightly able to use the observations from lab work for experimental verifications and illustrations.	Somewhat able to use the observations from lab work for experimental verifications and illustrations.	Moderately able to use the observations from lab work for experimental verifications and illustrations.	Fully able to use the observations from lab work for experimental verifications and illustrations.
Safety Adherence Adherence to ***safety*** procedures.	Doesn't adhere to safety procedures.	Slightly adheres to safety procedures.	Somewhat adheres to safety procedures.	Moderately adheres to safety procedures.	Fully adheres to safety procedures.
Equipment Handling ***Equipment care*** during the use.	Doesn't handle equipment with required care.	Rarely handles equipment with required care.	Occasionally handles equipment with required care.	Often handles equipment with required care.	Handles equipment with required care.
Group Work ***Contributes*** in a group based lab work.	Doesn't participate and contribute.	Slightly participates and contributes.	Somewhat participates and contributes.	Moderately participates and contributes.	Fully participates and contributes.

Laboratory Session No. ____13_______ Date: ______________________

Weighted CLO (Psychomotor Score)	
Remarks	
Instructor's Signature with Date:	