CONTROL RECTIFIER FOR VARIABLE SPEED SINGLE PHASE DC MOTOR

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To my beloved mother, father, and brothers

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ABSTRACT

An electric power can be converted from one form to another form by using power electronics devices. The function of power electronics circuits by using semiconductor devices as switch is modifying or controlling a voltage. The goal of power electronics circuits are to convert electrical energy from one form to another, from source to load with highest efficiency, high availability and high reliability with the lowest cost, smallest size and weight. The term rectification refers to the power circuit whose function is to alter the ac characteristic of the line electric power to produce a "rectified"ac power at the load side that contain the dc value. In this project task, the rectifier circuit should be possible to produce a variable average voltage by controlling the delay. The single phase 240 V_{rms} AC source is stepped down to 12 V_{rms} by using step-down power transformer. A versatile method of controlling the output of a full-wave rectifier is to substitute controlled switches such as SCRs for the diodes. The output is controlled by adjusting the delay angle of each SCR, resulting in an output voltage or output current which is variable over a limited range with programmed the microcontroller (PIC16F84A).

ABSTRAK

Kuasa eletrik boleh diubah daripada satu bentuk ke bentuk yang lain dengan menggunakan litar peranti kuasa elektronik.Fungsi litar elektronik berkuasa dengan menggunakan peranti semiconductor sebagai suis untuk mengawal dan mengubah arus voltan.Matlamat litar elektronik berkuasa adalah untuk mengubah kuasa elektrik kepada bentuk yang lain, daripada sumber kuasa kepada beban dengan tahap kecekapan yang tertinggi, perihal boleh didapati yang tertinggi ,perihal yang dapat dipercayai tertinggi dengan kos yang paling murah ,saiz dan berat yang paling kecil.Istilah rektifikasi merujuk kepada litar kuasa yang berfungsi untuk mengubah ciri ac dalam “line” kuasa elektrik untuk menghasilkan “rectified” ac pada beban yang mengandungi nilai dc .Dalam tugasan projek ini, litar “rectifier” sepatutnya akan menghasilkan nilai purata arus voltan yang berubah dengan mengawal kelambatan . Sumber kuasa satu fasa 240 Vrms, diturunkan kepada 12 Vrms dengan menggunakan “ step-down power transformer”.Berbagai kaedah mengawal keluaran “full-wave rectifier” dengan menggantikan diod kepada suis yang boleh dikawal iaitu SCR’s.Keluaran dikawal dengan mengubah nilai “delay angle”setiap SCR’s ,yang mana nilai arus voltan atau nilai arus adalah berubah pada lingkungan yang terhad dengan memprogram mikropengawal (PIC16F84A).

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LIST OF ABBREVIATIONS

AC	-	Alternate Current
DC	-	Direct Current
SCR	-	Silicon Control Rectifier
PIC	-	Programmable Intelligent Computer
IC	-	Integrated Circuit
LCD	-	Liquid Crystal Display
RCT	-	Reverse Conducting Thyristor
DIAC	-	Diode for Alternating Current
SIDAC	-	Silicon Diode for Alternating Current
TRIAC	-	Triode for Alternating Current
GTO	-	Gate Turn-Off Thyristor
IGCT	-	Integrated Gate Commutated Thyristor
MCT	-	MOSFET Controlled Thyristor
SITh	-	Static Induction Thyristor
FCTh	-	Field Controlled Thyristor
BJT	-	Bipolar Junction Transistor

LIST OF SYMBOLS

α	-	Delay Angle
μs	-	mikroseconds
kV	-	kilovolt
kHz	-	kilohertz
V	-	Volts
MW	-	Megawatt
kW	-	kilowatt
Vrms	-	Volts Root Mean Square
f	-	Frequency
°	-	Degree
ms	-	miliseconds
mV	-	milivolts
η	-	Efficiency
MHz	-	Megahertz

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CHAPTER 1

INTRODUCTION

1.1 Overview

The modern era of power electronics began in 1958 ,when the General Electric Company introduced a commercial thyristor ,two years after it was invented by Bell Telephone Laboratory. Soon all industrial applications that were based on mercury-arc rectifiers and power magnetic amplifiers were replaced by silicon-controlled rectifiers(SCRs).In less than 20 years after commercial SCRs were introduced significant improvements in semiconductor fabrication technology and physical operation were made ,and many different types of power semiconductor devices appeared.

The growth in power electronics was made possible with the microelectronic revolution of the 1970s and 1980s ,in which the low power IC control chips provided the brain and the intelligence to control the high – power semiconductor devices .Moreover the introduction of microprocessors made it possible to apply modern control theory to power electronics. In the last 20 years ,the growth in power electronics application has been remarkable because of this introduction of very fast and high-power switching devices, coupled with the utilization of state-of –the –art control algorithms.

An electric power can be converted from one form to another form by using power electronics devices. The function of power electronics circuits by using semiconductor devices as switch is modifying or controlling a voltage. The goal of power electronics circuits are to convert electrical energy from one form to another, from source to load with highest efficiency, high availability and high reliability with the lowest cost, smallest size and weight.

There are four conversion circuits that are used in the majority of today's power electronics circuits. Firstly are ac-to-ac ,secondly is ac-to-dc ,thirdly is dc-to-ac and the last is dc-to-dc.In terms of functional description ,modern power electronics system perform one or more of the following conversion functions.

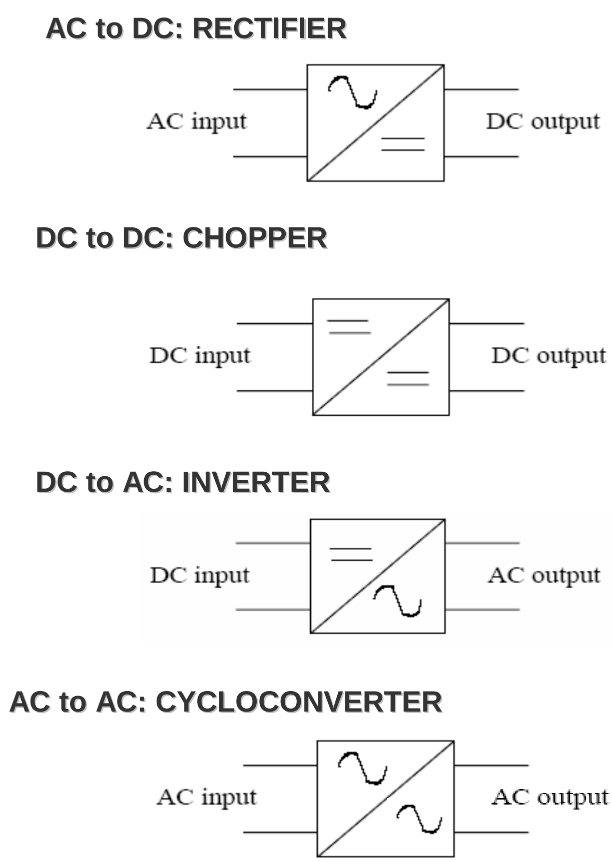

Figure 1.1 Four Types of Conversion

1.2 Background

Power electronic converters can be found wherever there is a need to modify the electrical energy form (i.e modify its voltage, current or frequency). Therefore, their power range from some milliwatts (as in a mobile phone) to hundreds of megawatts (e.g in a HVDC transmission system). With "classical" electronics, electrical currents and voltage are used to carry information, whereas with power electronics, they carry power. Therefore the main metric of power electronics becomes the efficiency.

The first very high power electronic devices were mercury arc valves. In modern systems the conversion is performed with semiconductor switching devices such as diodes, thyristors and transistors. In contrast to electronic systems concerned with transmission and processing of signals and data, in power electronics substantial amounts of electrical energy are processed. An AC/DC converter (rectifier) is the most typical power electronics device found in many consumer electronic devices, e.g., television sets, personal computers, battery chargers, etc. The power range is typically from tens of watts to several hundred watts. In industry the most common application is the variable speed drive (VSD) that is used to control an induction motor. The power range of VSDs start from a few hundred watts and end at tens of megawatts.

Most power electronics systems consist of two major modules as shown in Figure 1.2 which are power electronics processor that handles power transfer from input to output and controller that tells the power processor of what to do by taking the measurement that happens at output and compared to input.

For example, if we have an AC power input, but need DC input for charging the laptop, thus, we need something to convert that input to another form. Power semiconductor devices are characterized by having the two states which "on" and "off" or being either a short circuit or an open circuit. Advance in semiconductor switching capability combined with the desire to improve the efficiency and performance of electrical devices are making power electronics a fast-growing area in electrical engineering [1]. Thereby using switching devices for many applications are desirable because of the relatively small power loss in the device.

Applications of power electronics range from high-power conversion equipment, for examples DC transmission to everyday appliances such as power supplies for notebook computers. Conversion of AC to DC produces a DC output from an AC input is shown in Figure 1.1. This AC-DC converter is also specifically classified as a rectifier. Average power is transferred from an ac source to a dc load [1]. An AC-DC converter enables integrated circuits to operate from a 50/60 Hz AC line voltage by converting the AC signal to a DC signal of the appropriate or suitable voltage. Therefore, this project is assigned as to design and build a single phase controlled AC to DC converter. Most electronic devices are sold in the stories that required fixed AC to DC conversion.

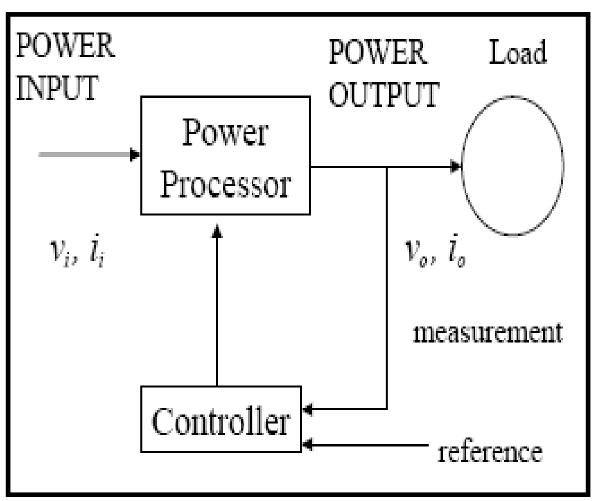

Figure 1.2 Power Processor & Controller

1.3 Objectives

The objective or the purpose of this project is the important part of getting started because it will drive to the outcomes of this project.Basiclly there are two main purpose which are ,firstly to explore and learn the operation of PIC16F84A to control thyristor circuit and secondly to build and test the circuit to control variable speed DC motor. Besides the two main objectives there are also others outcomes that need to be reach at the end of this project such as to produce DC voltage or current with low ripple and to produce the output close to the theoretical value.

1.4 Scopes

This project concentrates on a development of a circuit and hardware to get dc output using SCR and PIC16F84A as main component of the project. Besides the scopes is to program a microcontroller to control delay angle alfa and it produced variable outputs (speed).

To develop the whole project, it consists of three methods which are the concept of switching , the electrical structure, and the software programming.

After designing and building completely the rectifier circuit, the driver circuit should be able to control the delay angle α, that can be adjusted by using microcontroller. It will involve the programming development to control the ON state of the power switch and adjust the phase angle. Here, the trigger angle of SCRs will be programmed in certain time sequence to ensure the input voltage goes from low to full voltage

1.4 Problem Statement

A rectifier is an electronic circuit that converts bidirectional voltage (AC voltage) to unidirectional voltage (DC voltage) by using power diodes or by controlling the firing angle of thyristor/controllable switches. Rectifier usually can be divided into two types that are uncontrolled and phase-controlled. Each type can have either single-phase or three-phase. A diode is the simplest electronics switch which it is uncontrolled that the on and off states can be determined by the power supply in the circuit itself. AC to DC converter is mostly used in industries and also in domestic equipment. But many rectifiers in the market only produce fixed output so the applications of the rectifiers are limited for certain equipment only. So, the DC level of the output and the power transferred to the load are fixed when the source and load parameters are established.

Hence, to overcome this problem there is a way to control the output voltage of the rectifier. Basically, the single phase rectifier is designed using the thyristors or more specifically are called Silicon Control Rectifier (SCR) which connected in full-wave rectifier. A thyristor is four layers (pnpn) semiconductor devices that act as switches, rectifiers or voltage regulators. Thyristors are electronic switches used in power electronics circuits where control of switch turn-on is required [1]. Thus, the output voltage can be variable from the range of zero voltage to full voltage by controlling the delay angle of the SCR.

1.5 Thesis Outline

There are all five chapters being structures in this thesis and every chapter will elaborate in detail about this project. For the first chapter, an overview about this project, single phase controlled rectifier is discussed including the objectives and scopes of the project as a guide to develop the single phase controlled rectifier.

Chapter 2 will explain and discuss on the literature review of the single phase controlled rectifier. It also focuses on general introduction of the AC to DC converter with the complete information about this converter. It gives a brief review about the types of the rectifiers: uncontrolled and controlled single phase and three phase converters used as rectifiers. In this chapter also discuss about the type of thyristor and the characteristic of each type.

Chapter 3 discusses the methodologies of the single phase controlled rectifier that has been applied in completing this project. In this chapter, it consists of block diagram and flow chart which are explained about the process of implementation and how the AC voltage converts to DC voltage then connected to the load such as DC motor. It is also discusses briefly how the output voltage can be varied.

Chapter 4 is discussing and displaying all the results obtained and the limitation of the project. All discussions are concentrated on the result and the overall performance of the single phase controlled rectifier.

Chapter 5 in overall will discuss on the conclusion and summary of the development of the single phase controlled rectifier completed project. In this chapter also discusses on the problems and recommendation for this project development or modification.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review about this project have been made from various sources like journals, books, articles and others. From the literature review ,the input that have been collected is useful for better understanding of this project. It is because for nearly a century, rectifier circuits have been the most common power electronics circuits used to convert AC to DC. The AC-DC converter produces a DC output from an AC input while the average power transferred from an AC source to a DC load. This converter usually also called as a rectifier. The word rectification is used not because these circuits produce DC but rather because the current flows in one direction. Generally, there are two types of AC-DC converters which are uncontrolled and controlled. The input of these converters can be single phase or multi-phase (3 phase).

2.2 Uncontrolled Single Phase Rectifier

This type of rectifier consists of half-wave rectification and full-wave rectification. Uncontrolled rectifiers make use of diodes. Diodes are two-terminal semiconductor devices that allow flow of current in only one direction. The two terminals of a diode are known as the anode and the cathode. The designs are cheap and popular in the industrial applications. In some of these rectifiers, the AC source from the electric utility is directly rectified without using of an expensive and bulky transformer. In some applications, the DC voltage from the rectifier is connected to a DC bus for distribution to several different circuit systems, subsystems and other converters as loads [10]. In other applications, the rectifiers also supply power to inductive-resistive (motors) and capacitive-resistive (power supplies) loads.

2.2.1 Single Phase Half-Wave Rectifiers

The simplest of the rectifier circuit is a single phase half-wave rectifier consists of a single diode as shown in Figure 2.1. A diode is the simplest electronic switch. It is uncontrolled in that the on and off conditions are determined by voltages and currents in the circuit [1]. By using diode, the DC level of the output and the power transferred to the load are fixed when the source and load parameters are established. It produces an output waveform that is half of the incoming AC voltage waveform.

The positive pulse output waveform occurs because of the forward-biased condition of the diode. A diode experiences a forward-biased condition when its anode is at a higher potential than its cathode. Reverse bias occurs when its anode is lower than its cathode. During the positive portion of the input waveform, the diode becomes forward biased, which allows current to pass through the diode from anode to cathode, such that it flows through the load to produce a positive output pulse waveform. Over the negative portion of the input waveform, the diode is reverse-biased ideally so no current flows. Thus, the output waveform is zero or nearly zero during this portion of the input waveform.

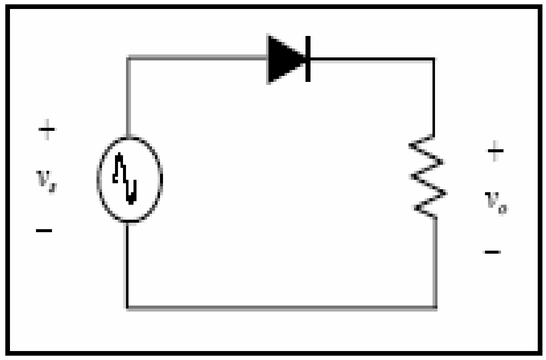

Figure 2.1 Single Phase Half-Wave Rectifier

2.2.2 Single Phase Full-Wave Rectifiers

The purpose of the full-wave rectifier is basically the same as that of the half-wave rectifier but full-wave rectifiers have some fundamental advantages. There are two types of full-wave rectifiers that are the bridge rectifier and the center-tapped rectifier as shown in Figure 2.2 and Figure 2.3.

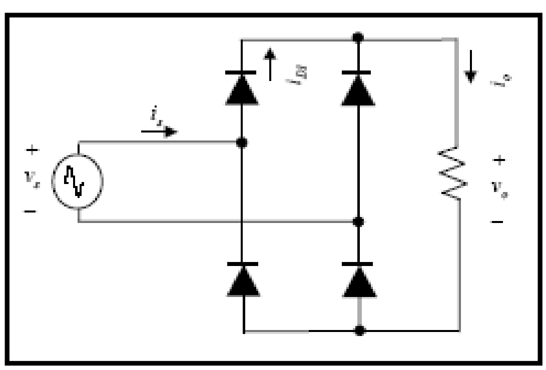

Figure 2.2 The Bridge Rectifier

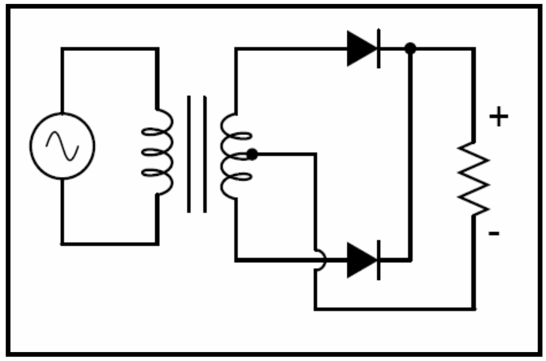

Figure 2.3 The Center-Tapped Transformer Rectifier

The lower peak diode voltage in the bridge rectifier which consists of four diodes arranged makes it more suitable for high-voltage applications. Thus, the center-tapped transformer rectifier in addition to including electrical isolation has only one diode voltage drop between the source and load making it desirable for low-voltage and high current applications.

2.3 Controlled Single Phase Rectifier

The previous rectifiers are classified as uncontrolled rectifiers but once the source and the load parameters are established, the DC level of the output and the power transferred to the load are fixed quantities. As mentioned before that the output voltage of the AC-DC converters using diodes is not controllable because the diodes are not self-controlled switch [10]. Thus, there is a way to control the output by using thyristor instead of a diode. A thyristor is a four-layer (*pnpn*), three-junction device that conducts current only in one direction similar to a diode.

2.3.1 Single Phase Half-Wave Rectifiers

Unlike the diode, the silicon controlled rectifier (SCR) will not to begin to conduct as soon as the source becomes positive [1]. Gate trigger current is the minimum current required to switch silicon controlled rectifiers from the off-state to the on-state at the specified off-state voltage and temperature. Once the SCR is conducting, the gate current can be removed and the SCR remains on until the current goes to zero [1]. Figure 2.4 shows a basic controlled half-wave rectifier.

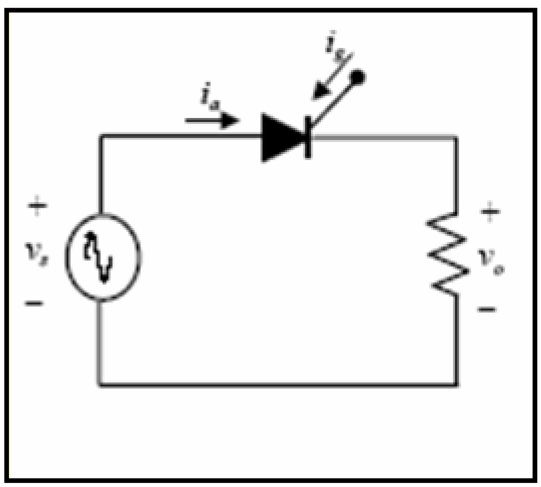

Figure 2.4 A Basic Half-Wave Controlled Rectifier

2.3.2 Single Phase Full-Wave Rectifiers

Popular AC-DC converters use full-bridge topologies [10]. Full-bridge converters are designed for delivering constant but controllable DC current or DC voltage to the load. Similar to the diode bridge rectifier topology, a versatile method of controlling the output of a full-wave rectifier is to substitute controlled switches such as SCRs for the diode. Because of their unique ability to be controlled, the output voltage and hence the power can be controlled to desire levels. The triggering of the thyristor has to be synchronized with the input sinusoidal voltage in an AC to DC rectifier circuit. The delay angle α is the angle interval between the forward biasing of the SCR and the gate signal application [1]. Otherwise, if the delay angle is zero, the rectifiers behave exactly like uncontrolled rectifiers with diodes. Figure 2.5 shows a basic controlled full-wave rectifier.

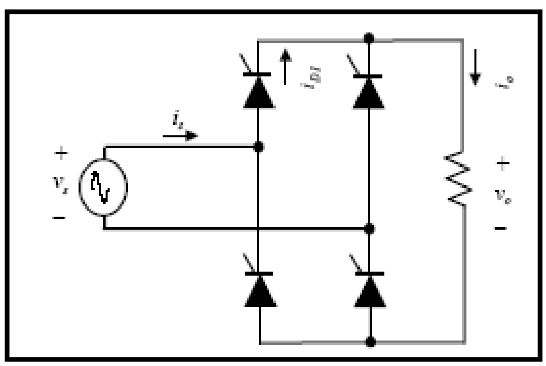

Figure 2.5 A Basic Full-Wave Controlled Bridge Rectifier

2.3.3 Phase Angle Delay Control

Converter operation in steady-state is best described over a period that begins from the phase α to 2π+ α [10]. This operation involves two circuit modes during a single period of the source waveform depending upon the state of the switches as shown in Figure 2.7. Mode 1 starts when the SCRs T1 and T3 are turned on at an angle α by control pulses applied at their gate terminals. During mode 1, SCRs T1 and T3 are in forward-biased mode and SCRs T2 and T4 are in reverse blocking mode. The current Io flows through the path shown in Figure 2.6. After angle π, the input source voltage become negative but the SCRs T1 and T3 still conducting. Note that the current sink is the model of a high value inductor, voltage across it can change instantaneously but current cannot [10]. Hence, the output voltage,Vo become negative and follows the input voltage,V_s waveform. The input source is supplying power to the load during α to π which is referred also as the rectifier operation.

Mode 2 begins when the SCRs T2 and T4 are turned on at an angle α + π by the control pulses applied at their terminals. The current is steered away from the SCRs T1 and T3 to T2 and T4 effecting a natural commutation. Now thyristors T1 and T3 are in reverse blocking mode [10]. This converter operation in this mode is identical to that mode 1 during the angle from π+α to 2π+α.

There several possible output voltages are shown in Figure 2.8 given duty ratio of 50%. The phase delay angle allows control over the DC output just as duty ratio control permits adjustment of the output in DC-DC converter [9]. Since DC output is of interest and because the output current comes along with a DC source, the average voltage Vo needs to be determined. Its value will be:

$$V_o = \frac{1}{\pi}\int_{\alpha}^{\alpha+\pi} V_m \sin(\omega t)\,d\omega t = \frac{2V_m}{\pi}\cos\alpha$$

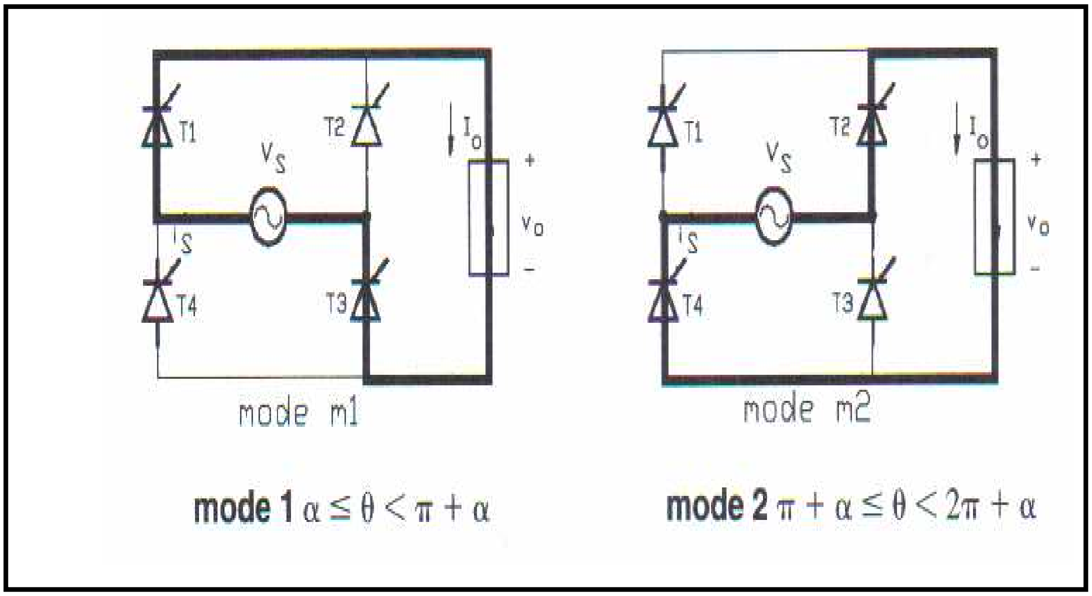

Figure 2.6 Circuit Modes

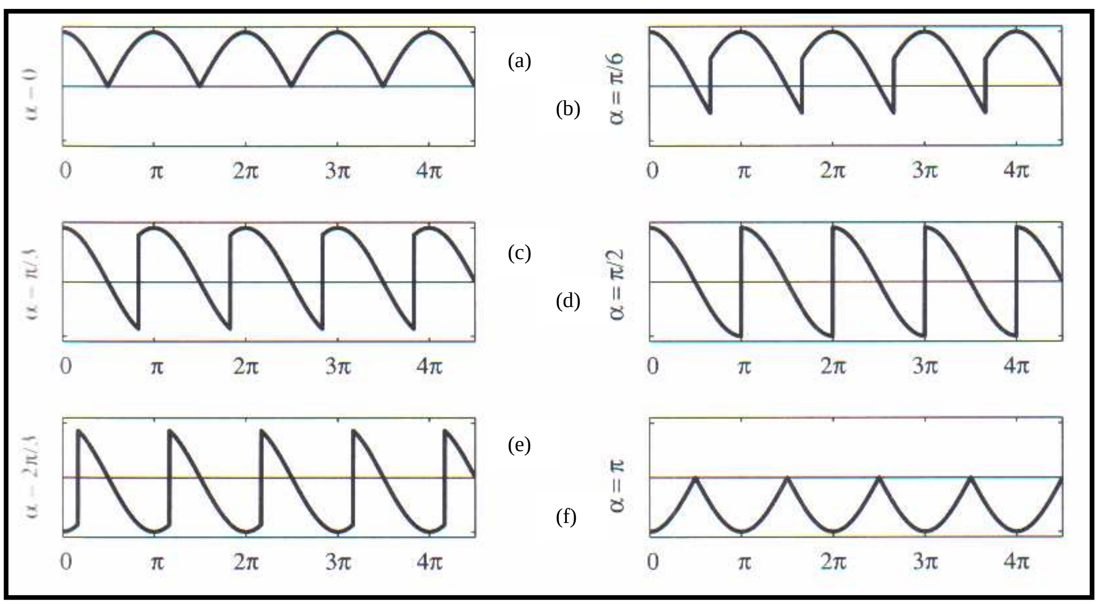

Figure 2.7 Possible Output Voltage waveform For SCR Bridge

2.4 Three Phase Rectifiers

Three phase rectifiers are more commonly used because of the following reasons: [8]

i. Three phase AC power is readily available.
ii. It is economical to provide DC supply to DC motors of capacity 20kW and more from a three phase rectifier rather than single phase.
iii. The ripple frequency of the output current of the three phase rectifiers is higher than that for single phase ones.

2.4.1 Three Phase Uncontrolled Rectifiers

Three phase rectifiers are commonly used in industry to produce a DC voltage and current for large loads [1]. Like single phase rectifiers, three phase rectifiers also have two types that are uncontrolled and controlled. The three phase full-bridge uncontrolled rectifier is shown in Figure 2.8. As mention before in single phase uncontrolled rectifier, this three phase full-bridge rectifier is using diodes as switch. Three phase rectifier divides into two groups which are top group and bottom group. For top group, diode with its anode at the highest potential will conduct at one time. The other two will be reversed. Thus for bottom group, diode with the its cathode at the lowest potential will conduct. The other two will be reversed. Figure 2.10 shows the phase voltage and the resulting combinations of line-to-line voltages from a balanced three phase source.

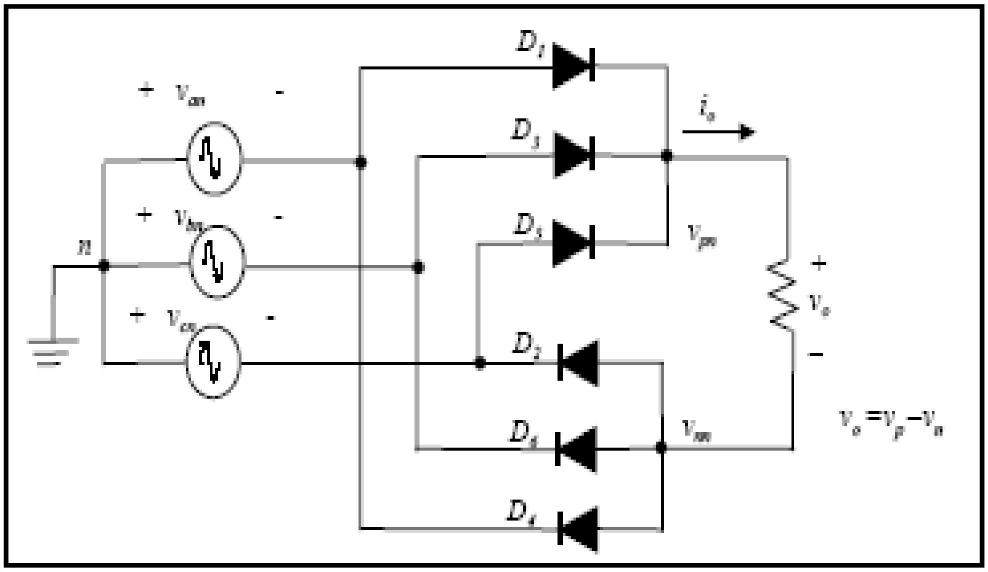

Figure 2.8 The Three Phase Full-Bridge Uncontrolled Rectifier

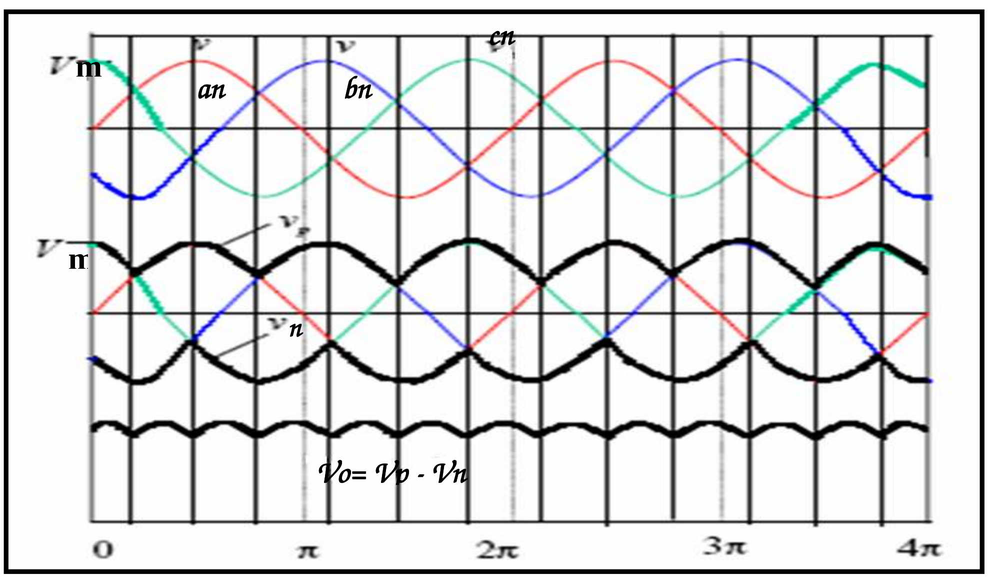

Figure 2.9 Source And Output Voltage

2.4.2 Three phase Controlled Rectifiers

Similar to single phase controlled rectifier, the output of the three phase rectifier can be controlled by substituting SCRs for diodes. Figure 2.10 shows a controlled six-pulse three phase rectifier. As mention before in single phase controlled rectifier, SCRs will conduct until a gate signal is applied while the SCR is forward biased. Thus, the transition of the output voltage to the maximum instantaneous line-to-line source voltage can be delayed [1].

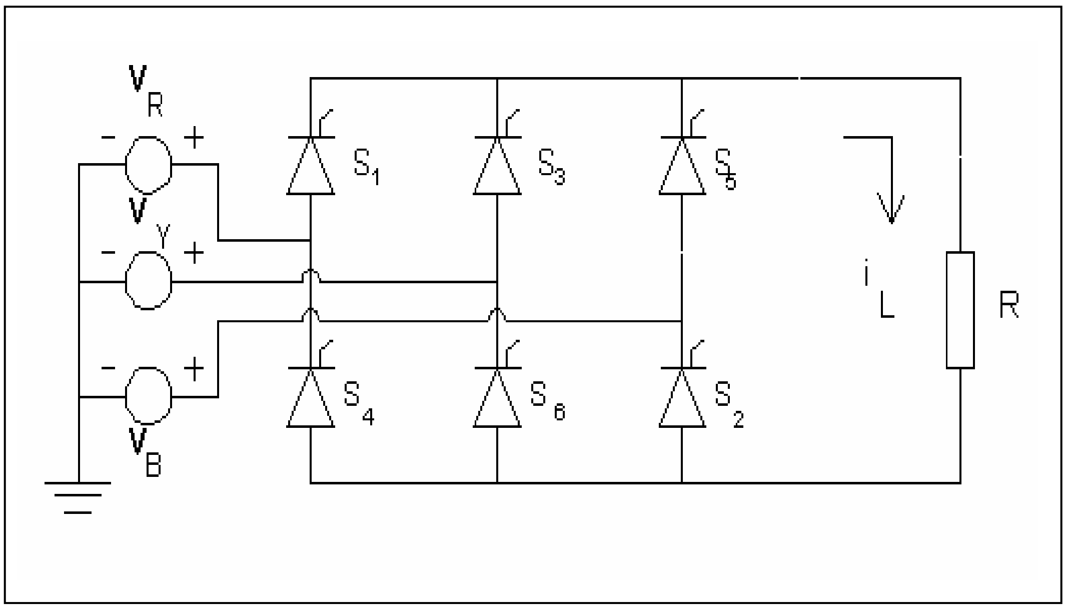

Figure 2.10 The Three Phase Full-Bridge Controlled Rectifier

2.5 Types of Thyristor

2.5.1 Silicon Controlled Rectifier

The thyristor is a solid-state semiconductor device with four layers of alternating N and P-type material. They act as a switch, conducting when their gate receives a current pulse, and continue to conduct for as long as they are forward biased (that is, as long as the voltage across the device has not reversed).

Some sources define silicon controlled rectifiers and thyristors as synonymous; others define SCRs as a subset of thyristors, along with gate turn-off thyristor (GTO), triode ac switch (triac), static induction transistor (SIT), static induction thyristor (SITH) and MOS-controlled thyristor (MCT). Among the latter, the International Electro technical Commission 60747-6 standard stands out.
Non-SCR thyristors include devices with more than four layers, such as triacs and DB-GTOs.

Function

The thyristor is a four-layer semiconducting device, with each layer consisting of alternately N-type or P-type material, for example P-N-P-N. The main terminals, labeled anode and cathode, are across the full four layers, and the control terminal, called the gate, is attached to p-type material near to the cathode. (A variant called an SCS Silicon Controlled Switch brings all four layers out to terminals.) The operation of a thyristor can be understood in terms of a pair of tightly coupled Bipolar Junction Transistors, arranged to cause the self-latching action:

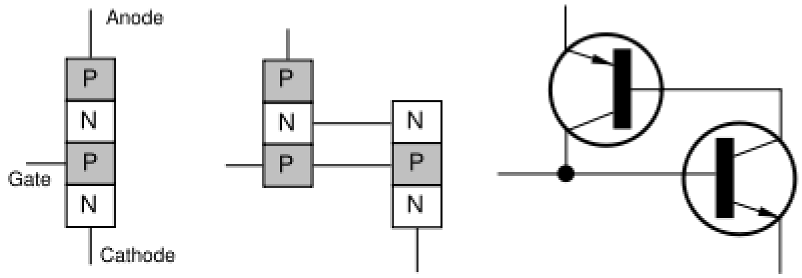

Figure 2.11 Thyristor

Thyristors have three states:

Reverse blocking mode -- Voltage is applied in the direction that would be blocked by a diode

Forward blocking mode -- Voltage is applied in the direction that would cause a diode to conduct, but the thyristor has not yet been triggered into conduction

Forward conducting mode -- The thyristor has been triggered into conduction and will remain conducting until the forward current drops below a threshold value known as the "holding current"

Function of the gate terminal

The thyristor has three p-n junctions (serially named J1, J2, J3 from the anode).

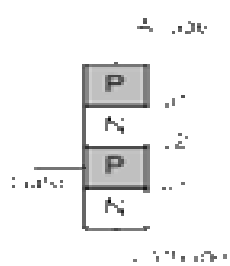

Figure 2.12 Layer Diagram of Thyristor

When the anode is at a positive potential VAK with respect to the cathode with no voltage applied at the gate, junctions J1 and J3 are forward biased, while junction J2 is reverse biased. As J2 is reverse biased, no conduction takes place (Off state). Now if VAK is increased beyond the breakdown voltage VBO of the thyristor, avalanche breakdown of J2 takes place and the thyristor starts conducting (On state).

If a positive potential VG is applied at the gate terminal with respect to the cathode, the breakdown of the junction J2 occurs at a lower value of VAK. By selecting an appropriate value of VG, the thyristor can be switched into the on state immediately.It should be noted that once avalanche breakdown has occurred, the thyristor continues to conduct, irrespective of the gate voltage, until either: (a) the potential VG is removed or (b) the current through the device (anode−cathode) is less than the holding current specified by the manufacturer. Hence VG can be a voltage pulse, such as the voltage output from a UJT relaxation oscillator.

These gate pulses are characterized in terms of gate trigger voltage (VGT) and gate trigger current (IGT). Gate trigger current varies inversely with gate pulse width in such a way that it is evident that there is a minimum gate charge required to trigger the thyristor.

Switching characteristics

In a conventional thyristor, once it has been switched on by the gate terminal, the device remains latched in the on-state (i.e. does not need a continuous supply of gate current to conduct), providing the anode current has exceeded the latching current (IL). As long as the anode remains positively biased, it cannot be switched off until the anode current falls below the holding current (IH).

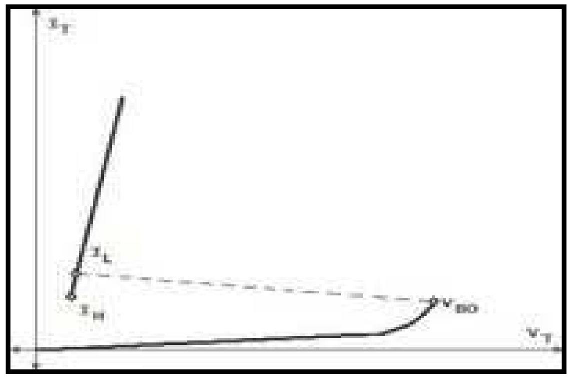

Figure 2.13 V - I Characteristics

A thyristor can be switched off if the external circuit causes the anode to become negatively biased. In some applications this is done by switching a second thyristor to discharge a capacitor into the cathode of the first thyristor. This method is called forced commutation.

After a thyristor has been switched off by forced commutation, a finite time delay must have elapsed before the anode can be positively biased in the off-state. This minimum delay is called the circuit commutated turn off time (tQ). Attempting to positively bias the anode within this time causes the thyristor to be self-triggered by the remaining charge carriers (holes and electrons) that have not yet recombined.

For applications with frequencies higher than the domestic AC mains supply (e.g. 50 Hz or 60 Hz), thyristors with lower values of tQ are required. Such fast thyristors are made by diffusing into the silicon heavy metals ions such as gold or platinum which act as charge combination centers. Alternatively, fast thyristors may be made by neutron irradiation of the silicon.

History

1956 The Silicon Controlled Rectifier (SCR) or Thyristor proposed by William Shockley in 1950 and championed by Moll and others at Bell Labs was developed first by power engineers at General Electric (G.E.) led by Gordon Hall and commercialized by G.E.'s Frank W. "Bill" Gutzwiller.

Application

Figure 2.14 A bank of six, 2000 A Thyristors (white pucks). The clear tubes are for cooling water

Thyristors are mainly used where high currents and voltages are involved, and are often used to control alternating currents, where the change of polarity of the current causes the device to automatically switch off; referred to as Zero Cross operation. The device can be said to operate synchronously as, once the device is open, it conducts current in phase with the voltage applied over its cathode to anode junction with no further gate modulation being required to replicate; the device is biased fully on. This is not to be confused with symmetrical operation, as the output is unidirectional, flowing only from cathode to anode, and so is asymmetrical in nature.Thyristors can be used as the control elements for phase angle triggered controllers, also known as phase fired controllers.

Thyristors can also be found in power supplies for digital circuits, where they can be used as a sort of "circuit breaker" or "crowbar" to prevent a failure in the power supply from damaging downstream components. The thyristor is used in conjunction with a zener diode attached to its gate, and when the output voltage of the supply rises above the zener voltage, the thyristor conducts, shorting the power supply output to ground (and in general blowing an upstream fuse).

The first large scale application of thyristors, with associated triggering diac, in consumer products related to stabilized power supplies within color television receivers in the early 1970s. The stabilized high voltage DC supply for the receiver was obtained by moving the switching point of the thyristor device up and down the falling slope of the positive going half of the AC supply input (if the rising slope was used the output voltage would always rise towards the peak input voltage when the device was triggered and thus defeat the aim of regulation).

The precise switching point was determined by the load on the output d.c. supply as well fluctuations on the input a.c. supply. They proved to be unpopular with the a.c. grid power supplier companies because the simultaneous switching of many television receivers, all at approximately the same time, introduced asymmetry into the supply waveform and, as a consequence injected d.c. back into the grid with a tendency towards saturation of transformer cores and overheating. Thyristors were largely phased out in this kind of application by the end of the decade.

Thyristors have been used for decades as lighting dimmers in television, motion pictures, and theater, where they replaced inferior technologies such as autotransformers and rheostats. They have also been used in photography as a critical part of flashes (strobes).

Snubber circuits

Because thyristors can be triggered on by a high rate of rise of off-state voltage, in many applications this is prevented by connecting a resistor-capacitor (RC) snubber circuit between the anode and cathode terminals in order to limit the dV/dt (i.e., rate of change of voltage versus time).

Comparisons to other devices

The functional drawback of a thyristor is that, like a diode, it only conducts in one direction. A similar self-latching 5-layer device, called a TRIAC, is able to work in both directions. This added capability, though, also can become a shortfall. Because the TRIAC can conduct in both directions, reactive loads can cause it to fail to turn off during the zero-voltage instants of the ac power cycle. Because of this, use of TRIACs with (for example) heavily-inductive motor loads usually requires the use of a "snubber" circuit around the TRIAC to assure that it will turn off with each half-cycle of mains power. Inverse parallel SCRs can also be used in place of the triac; because each SCR in the pair has an entire half-cycle of reverse polarity applied to it, the SCRs, unlike TRIACs, are sure to turn off. The "price" to be paid for this arrangement, however, is the added complexity of two separate but essentially identical gating circuits.

An earlier gas filled tube device called a Thyratron provided a similar electronic switching capability, where a small control voltage could switch a large current. It is from a combination of "thyratron" and "transistor" that the term "thyristor" is derived.
Modern thyristors can switch large amounts of power (up to megawatts). In the realm of very high power applications, they are still the primary choice. However, in low and medium power (from few tens of watts to few tens of kilowatts) they have almost been replaced by other devices with superior switching characteristics like MOSFETs or IGBTs. One major problem associated with SCRs is that they are not fully controllable switches. The GTO (Gate Turn-off Thyristor) and IGCT are two related devices which

address this problem. In high-frequency applications, thyristors are poor candidates due to large switching times arising from bipolar conduction. MOSFETs, on the other hand, have much faster switching capability because of their unipolar conduction (only majority carriers carry the current).

Failure modes

As well as the usual failure modes due to exceeding voltage, current or power ratings, thyristors have their own particular modes of failure, including:
Turn on di/dt — in which the rate of rise of on-state current after triggering is higher than can be supported by the spreading speed of the active conduction area (SCRs & triacs).

Forced commutation — in which the transient peak reverse recovery current causes such a high voltage drop in the sub-cathode region that it exceeds the reverse breakdown voltage of the gate cathode diode junction (SCRs only).

2.5.2 RCT — Reverse Conducting Thyristor

Reverse conducting thyristor (RCT) is high-power switching semiconductor device similar to thyristor with integrated reverse diode. This thyristor is not capable of reverse blocking mode.

These devices are advantageous where reverse or freewheel diode must be used. Because the SCR and diode never conducts at the same time, thus do not need simultaneous colling, they can be placed together and use less space and smaller cooler.
Reverse conducting thyristors are often used in frequency changers and inverters.

2.5.3 DIAC & SIDAC — Both forms of trigger devices

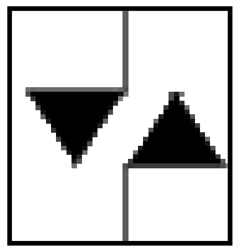

Figure 2.15 Symbol of DIAC

DIAC

The DIAC, or Diode for Alternating Current, is a bidirectional trigger diode that conducts current only after its breakdown voltage has been exceeded momentarily. When this occurs, the resistance of the diode abruptly decreases, leading to a sharp decrease in the voltage drop across the diode and, usually, a sharp increase in current flow through the diode.

The diode remains "in conduction" until the current flow through it drops below a value characteristic for the device, called the holding current. Below this value, the diode switches back to its high-resistance (non-conducting) state. When used in AC applications this automatically happens when the current reverses polarity.

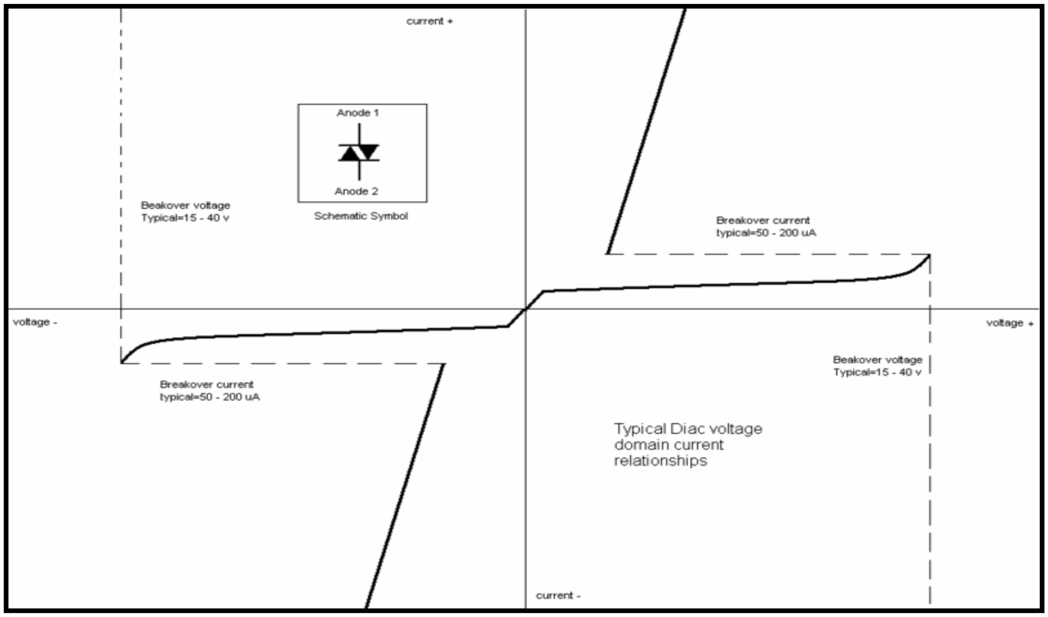

Figure 2.16 Typical Diac voltage and current relationships.

Once the voltage exceeds the turn-on threshold, the device turns on and the voltage rapidly falls while the current increases.

The behavior is typically the same for both directions of current flow. Most DIACs have a breakdown voltage around 30 V. In this way, their behavior is somewhat similar to (but much more precisely controlled and taking place at lower voltages than) a neon lamp.

DIACs are a form of thyristor but without a gate electrode. They are typically used for triggering both thyristors and TRIACs - a bidirectional member of the thyristor family. Because of this common usage, many TRIACs contain a built-in DIAC in series with the TRIAC's "gate" terminal.

DIACs are also called symmetrical trigger diodes due to the symmetry of their characteristic curve. Because DIACs are bidirectional devices, their terminals are not labeled as anode or cathode but as A1 and A2 or MT1 ("Main Terminal") and MT2.
The trisil device has very similar V-A characteristics.

SIDAC

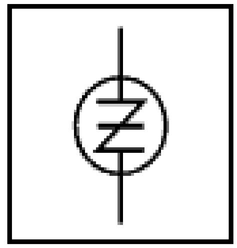

Figure 2.17 Symbol of SIDAC

The SIDAC is a less common electrically equivalent device, the difference in naming being determined by the manufacturer. In general, SIDACs have higher breakover voltages and current handling.

The SIDAC, or Silicon Diode for Alternating Current, is a semiconductor of the thyristor family. Also referred to as a SYDAC (Silicon thyristor for Alternating Current), bi-directional thyristor breakover diode, or more simply a bi-directional thyristor diode, it is technically specified as a bilateral voltage triggered switch. Its operation is similar to that of the DIAC; the distinction in naming between the two devices being subject to the particular manufacturer. In general, SIDACs have higher breakover voltages and current handling capacities than DIACs.

The operation of the SIDAC is quite simple and is functionally similar to that of a spark gap. The SIDAC remains nonconducting until the applied voltage meets or exceeds its rated breakover voltage. Once entering this conductive state, the SIDAC continues to conduct, regardless of voltage, until the applied current falls below its rated holding current. At this point, the SIDAC returns to its initial nonconductive state to begin the cycle once again.

Somewhat uncommon in most electronics, the SIDAC is relegated to the status of a special purpose device. However, where part-counts are to be kept low, simple relaxation oscillators are needed, and when the voltages are too low for practical operation of a spark gap, the SIDAC is an indispensable component.

Versions of the SIDAC that are designed to tolerate large surge currents for the suppression of voltage transients are known as Thyristor Surge Protection Devices (TSPD), SIDACtors, or the now-obsolete Surgector.

2.5.4 TRIAC — Triode for Alternating Current-A bidirectional switching device containing two thyristor structures

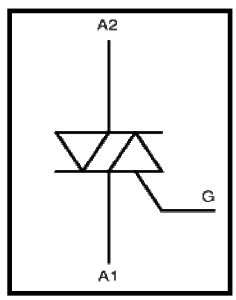

Figure 2.18 Triac Schematic Symbol

A TRIAC, or Triode for Alternating Current is an electronic component approximately equivalent to two silicon-controlled rectifiers (SCRs/thyristors) joined in inverse parallel (paralleled but with the polarity reversed) and with their gates connected together. This results in a bidirectional electronic switch which can conduct current in either direction when it is triggered (turned on).

It can be triggered by either a positive or a negative voltage being applied to its gate electrode. Once triggered, the device continues to conduct until the current through it drops below a certain threshold value, such as at the end of a half-cycle of alternating current (AC) mains power.

This makes the TRIAC a very convenient switch for AC circuits, allowing the control of very large power flows with milliampere-scale control currents. In addition, applying a trigger pulse at a controllable point in an AC cycle allows one to control the percentage of current that flows through the TRIAC to the load (so-called phase control).

Low power TRIACs are used in many applications such as light dimmers, speed controls for electric fans and other electric motors, and in the modern computerized control circuits of many household small and major appliances. However, when used with inductive loads such as electric fans, care must be taken to assure that the TRIAC will turn off correctly at the end of each half-cycle of the ac power.

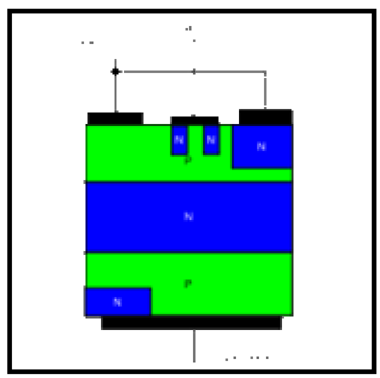

Figure 2.19 Triac semiconductor construction

A snubber circuit is often used to assist this turn off. Snubber circuits are also used to prevent premature triggering. For higher-powered, more-demanding loads, two SCRs in inverse parallel may be used instead of one TRIAC. Because each SCR will have an entire half-cycle of reverse polarity voltage applied to it, turn-off of the SCRs is assured, no matter what the character of the load.

2.5.5 GTO — Gate Turn-Off thyristor

A gate turn-off thyristor (GTO) is a special type of thyristor, a high-power semiconductor device. GTOs, as opposed to normal thyristors, are fully controllable switches which can be turned on and off by their third lead, the GATE lead.

Device description

Normal thyristors (silicon controlled rectifiers) are not fully controllable switches (a "fully controllable switch" can be turned on and off at will). Thyristors can only be turned ON and cannot be turned OFF. Thyristors are switched ON by a gate signal, but even after the gate signal is de-asserted (removed), the thyristor remains in the ON-state until any turn-off condition occurs (which can be the application of a reverse voltage to the terminals, or when the current flowing through (forward current) falls below a certain threshold value known as the holding current). Thus, a thyristor behaves like a normal semiconductor diode after it is turned on or "fired".

The GTO can be turned-on by a gate signal, and can also be turned-off by a gate signal of negative polarity.Turn on is accomplished by a positive current pulse between the gate and cathode terminals. As the gate-cathode behaves like PN junction, there will be some relatively small voltage between the terminals. The turn on phenomenon in GTO is however, not as reliable as an SCR (thyristor) and small positive gate current must be maintained even after turn on to improve reliability.

Turn off is accomplished by a negative voltage pulse between the gate and cathode terminals. Some of the forward current (about one-third to one-fifth) is "stolen" and used to induce a cathode-gate voltage which in turn induces the forward current to fall and the GTO will switch off (transitioning to the 'blocking' state.)

GTO thyristors suffer from long switch off times, whereby after the forward current falls, there is a long tail time where residual current continues to flow until all remaining charge from the device is taken away. This restricts the maximum switching frequency to approx 1 kHz.It may however be noted that the turn off time of a comparable SCR is ten times that of a GTO. Thus switching frequency of GTO is much better than SCR.

Characteristic	Description	Thyristor (1600 V, 350 A)	GTO (1600 V, 350 A)
$V_{T\,ON}$	On state voltage drop	1.5 V	3.4 V
t_{on},Ig_{on}	Turn on time, gate current	2 µs,200 mA	8 µs,2 A
t_{off}	Turn off time	15 µs	150 µs

Figure 2.20 Comparison of an SCR and GTO of same rating.

A distributed buffer gate turn-off thyristor (DB-GTO) is a thyristor with additional PN layers in the drift region to reshape the field profile and increase the voltage blocked in the off state. Compared to a typical PNPN structure of a conventional thyristor, this thyristor would be a PN-PN-PN type structure.

Reverse bias

GTO thyristors are available with or without reverse blocking capability. Reverse blocking capability adds to the forward voltage drop because of the need to have a long, low doped P1 region.

GTO thyristors capable of blocking reverse voltage are known as symmetrical GTO thyristors, abbreviated S-GTO. Usually, the reverse blocking voltage rating and forward blocking voltage rating are the same. The typical application for symmetrical GTO thyristors is in current source inverters.

GTO thyristors incapable of blocking reverse voltage are known as asymmetrical GTO thyristors, abbreviated A-GTO. They typically have a reverse breakdown rating in the tens of volts. A-GTO thyristors are used where either a reverse conducting diode is applied in parallel (for example, in voltage source inverters) or where reverse voltage would never occur (for example, in switching power supplies or DC traction choppers). Asymmetrical GTO thyristors can be fabricated with a reverse conducting diode in the same package. These are known as RCGTO, for reverse conducting GTO.

Safe operating area

Unlike the IGCT or insulated gate bipolar transistor, the GTO thyristor requires external devices to shape the turn on and turn off currents to prevent device destruction. During turn on, the device has a maximum dI/dt rating limiting the rise of current. This is to allow the entire bulk of the device to reach turn on before full current is reached. If this rating is exceeded, the area of the device nearest the gate contacts will overheat and melt from over current. The rate of dI/dt is usually controlled by adding a saturable reactor. Reset of the saturable reactor usually places a minimum off time requirement on GTO based circuits.

During turn off, the forward voltage of the device must be limited until the current tails off. The limit is usually around 20% of the forward blocking voltage rating. If the voltage rises too fast at turn off, not all of the device will turn off and the GTO will fail, often explosively, due to the high voltage and current focused on a small portion of the device. Substantial snubber circuits are added around the device to limit the rise of voltage at turn off. Reseting the snubber circuit usually places a minimum on time requirement on GTO based circuits.

The minimum on and off time is handled in DC motor chopper circuits by using a variable switching frequency at the lowest and highest duty cycle. This is observable in traction applications where the frequency will ramp up as the motor starts, then the frequency stays constant over most of the speed ranges, then the frequency drops back down to zero at full speed.

Applications

The main applications are in variable speed motor drives, high power inverters and traction.

2.5.6 IGCT — Integrated Gate Commutated Thyristor

The Integrated Gate Commutated Thyristor (IGCT) is a new high-power semiconductor device. An IGCT is a sub family of the GTO thyristor and like the GTO thyristor is a fully-controllable power switch.

Device Description

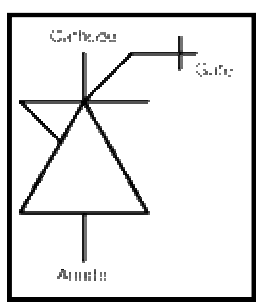

Figure 2.21 Circuit symbol for an IGCT

An IGCT is a special type of thyristor similar to a GTO. They can be turned on and off by a gate signal, have lower conduction loss as compared to GTOs, and withstand higher rates of voltage rise (dv/dt), such that no snubber is required for most applications.

The structure of an IGCT is very similar to a GTO thyristor. In an IGCT, the gate turn off current is greater than the anode current. This results in a complete elimination of minority carrier injection from the lower PN junction and faster turn off times. The main difference is a reduction in cell size, plus a much more substantial gate connection with much lower inductance in the gate drive circuit and drive circuit connection. The very high gate currents plus fast dI/dt rise of the gate current means that regular wires can not be used to connect the gate drive to the IGCT.

The drive circuit PCB is integrated into the package of the device. The drive circuit surrounds the device and a large circular conductor attaching to the edge of the IGCT die is used. The large contact area and short distance reduces both the inductance and resistance of the connection.

The IGCT's much faster turn-off times compared to GTO's allows them to operate at higher frequencies--up to several of kHz for very short periods of time. However, because of high switching losses, typical operating frequency up to 500 Hz.

Reverse Bias

IGCT are available with or without reverse blocking capability. Reverse blocking capability adds to the forward voltage drop because of the need to have a long, low doped P1 region.

IGCT capable of blocking reverse voltage are known as symmetrical IGCT, abbreviated S-IGCT. Usually, the reverse blocking voltage rating and forward blocking voltage rating are the same. The typical application for symmetrical IGCT is in current source inverters.

IGCT incapable of blocking reverse voltage are known as asymmetrical IGCT, abbreviated A-IGCT. They typically have a reverse breakdown rating in the 10's of volts. A-IGCT are used where either a reverse conducting diode is applied in parallel (for example, in voltage source inverters) or where reverse voltage would never occur (for example, in switching power supplies or DC traction choppers).

Asymmetrical IGCT can be fabricated with a reverse conducting diode in the same package. These are known as RC-ICT, for reverse conducting IGCT.

2.5.7 MCT -MOSFET Controlled Thyristor — It contains two additional FET structures for on/off control.

MOS Controlled Thyristor (or MCT) is voltage controlled fully controllable thyristor. The MCT is similar in operation with GTO thyristor, but it has voltage controlled insulated gate. It has two MOSFETs in its equivalent circuit. One is responsible for turn-on and the another is responsible for turn-off. Thyristor with only one MOSFET in its equivalent circuit, which can be only turned-on, (like usual SCRs) is called MOS Gated Thyristor.

Positive voltage on gate terminal with respect to cathode turns the thyristor into on state. Negative voltage on gate terminal with respect to anode (which is close to cathode voltage in on state) turns the thyristor into off state.

2.5.8 SITh — Static Induction Thyristor, or FCTh — Field Controlled Thyristor containing a gate structure that can shut down anode current flow.

The static induction thyristor (SI-thyristor, SITh) is a thyristor with a buried gate structure in which the gate electrodes are placed in n-base region. Since they are normally on-state, gate electrodes must be negatively biased to hold off-state.

A SIT(Static Induction Transistor) is high power, high frequency device. It is a vertical structure device with short multichannels. A SIT has short channel length, low GATE series resistance, low GATE-SOURCE capacitance and small thermal resistance. It has low noise, low distortion and high audio frequency power capability. Turn-on and Turn-off time are very small typically in 0.25μs.

2.6 Switches comparisons (2000)

Table 2.1 Switches Comparison

Device Type	Year made	Rated Voltage	Rated Current	Switching Frequency	Rated Power	Drive Circuit	Comments
SCR	1957	6kV	3.5kA	500Hz	100s MW	Simple	Cannot turn-off using gate signal
GTO	1962	4.5kV	3kA	2kHz	10s MW	Very Difficult	King in very high power
BJT	1960s	1.2kV	400A	5kHz	1 MW	Difficult	Phasing out in new product
MOSFET	1976	500V	200A	1MHz	100 kW	Very Simple	Good performance in high frequency
IGBT	1983	3.3kV	1.2kA	100kHz	100s kW	Very Simple	Best overall performance

After literature review about types of thyristor , SCR is used in this project as power semiconductor devices.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will discuss on the methods that will be used to ensure the project could achieve the objective and scope of the project. Thus, all the methods need to be done as in schedule so that this project could be completed within the time. There are several steps to be applied in designing a single phase controlled rectifier. Most electronic devices are sold in the stores that require fixed AC to DC conversion. This design will be able to rectify the AC voltage to a DC voltage with variable output voltages. The relevant information is gathered through literature review. First of all, data and analysis from controlled rectifier project has been collected. Secondly, the theoretical design which includes the main circuit (bridge rectifier) and the control unit concept. Thirdly, simulate the design circuit by using OrCad PsPice software and make a comparison between the results and theory. Lastly, to develop the hardware according to the design. Figure 3.1 shows the block diagram of the methodology that has been applied. Figure 3.2 shows the block diagram for the hardware part.

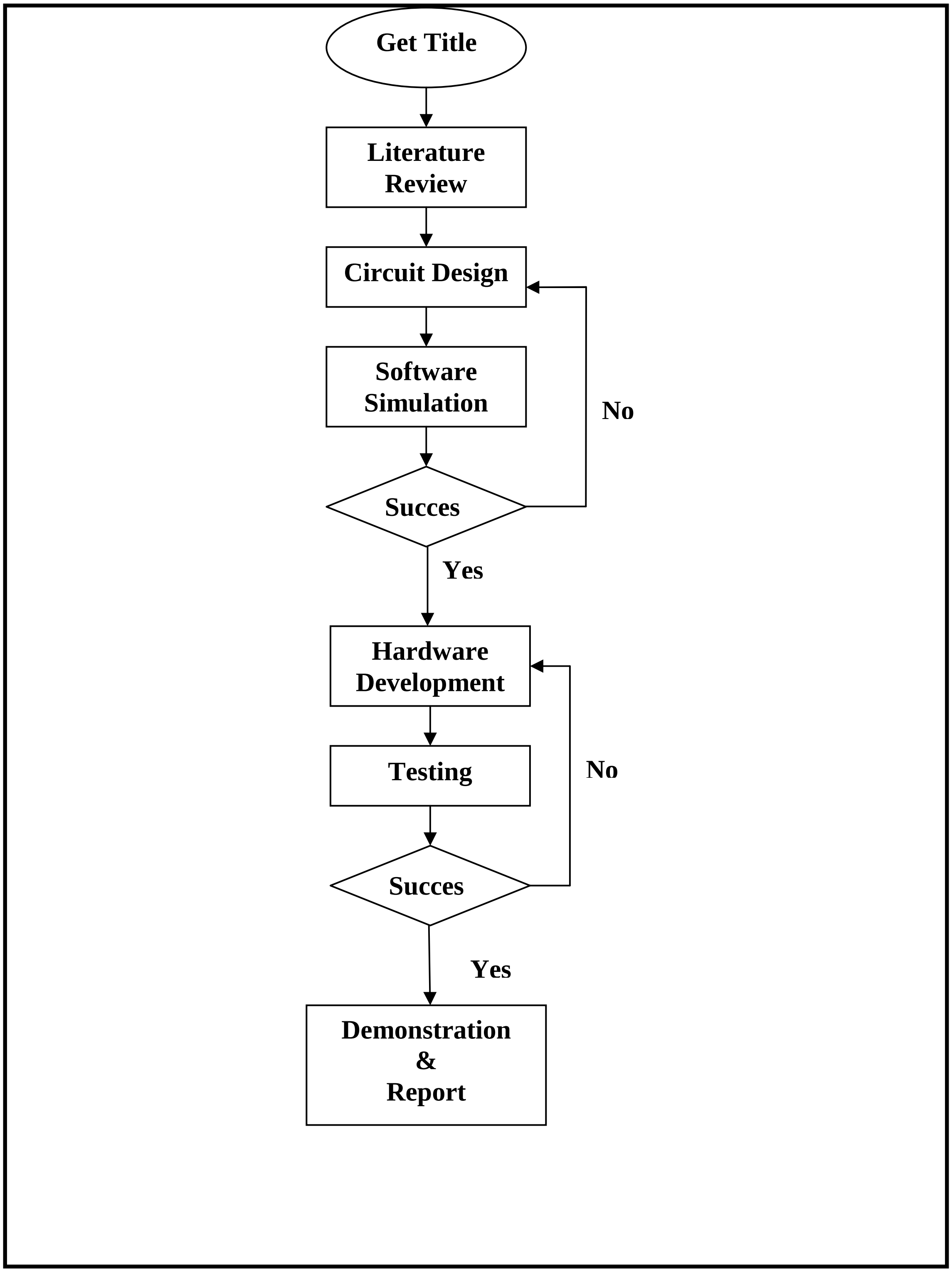

Figure 3.1 Flow Chart of Project Development

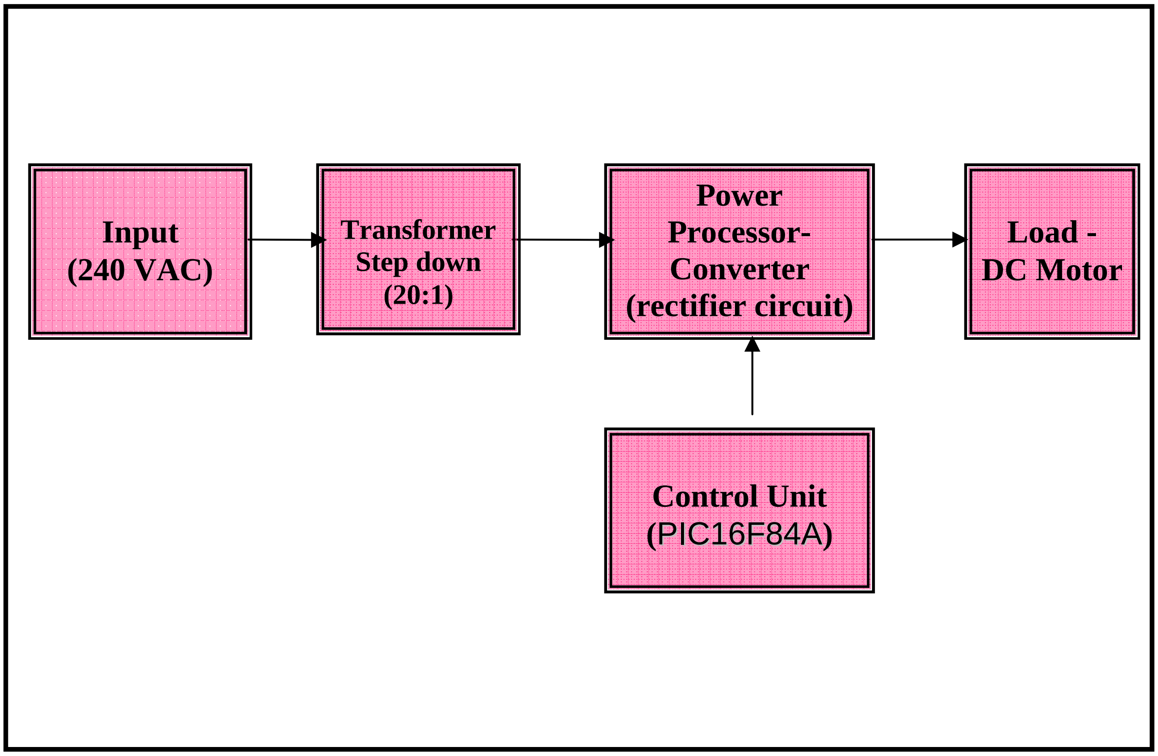

Figure 3.2 A Single Phase Controlled Rectifier Block Diagram

3.2 Literature Review and Background Studies

In this project, basic knowledge about a single phase controlled AC to DC converter is obtained from the literature review. From the studies, the related information is discussed with the project supervisor to ensure that the project progress can be continued to the next level. All the information about the types of rectifier are collected. This includes the circuit that needs to be designed for all the methods that are used. There are two types of rectifier which are uncontrolled and controlled.

3.3 Theoretical Design

Theoretical design is where a designing project is started. It is the most important parts that move from general to specific, first introducing underlying ideas and then discussing implementation details specific to the research.

3.3.1 Input

To begin the design of an AC to DC converter, there is an obvious need to convert the standard utility 240 AC voltage with frequency 50Hz to a useful DC voltage which would power the components within the rectifier. To use any other voltage source other than the AC voltage for this project would defeat its purpose. The 240 AC voltage power supply will step down by a power transformer then the output of the transformer will supply power to the rectifier circuit and controller circuit. Figure 3.3 below shows the 240 AC voltage step down by using transformer.

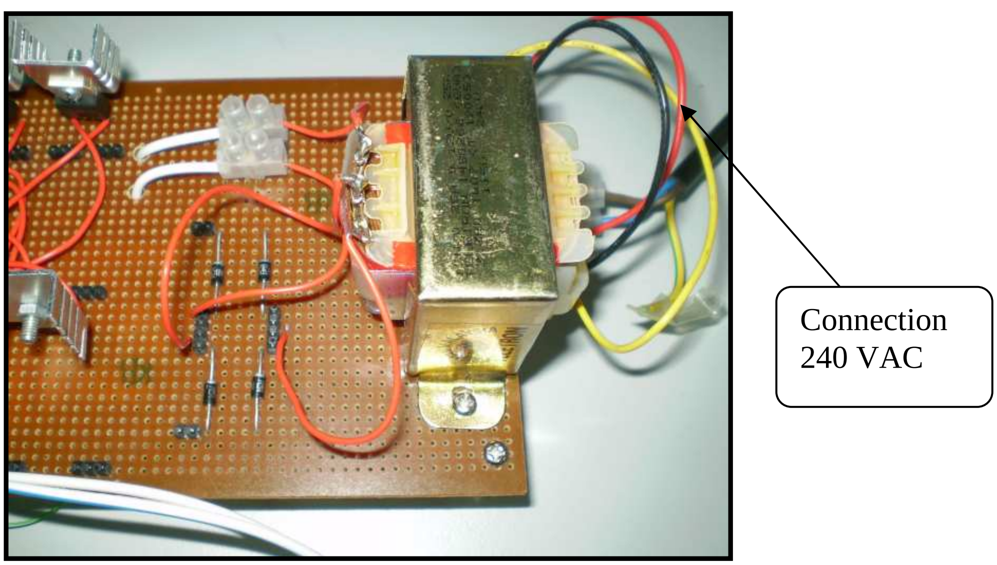

Figure 3.3 Connection 240 VAC to Power Transformer

3.3.2 Power Transformer

The transformer of the power converter circuit required an AC input. A basic three pin AC plug connector was connected to the transformer allowing it to be plugged into any standard wall plug. The transformer used in this project was a step down controlled transformer. The specification of the power transformer is using 240V or 115V input voltage then will produces 12V output voltage and 0.25A output current. The transformer will produces output power about 6.0VA. Then, the output of the transformer will connect to the rectifier circuit and the diode rectifier for controller circuit.

The transformer is designed to connect in series for a single phase controlled rectifier. It is needed for input at 240 VAC and output at 12 VAC. It is about a 20:1 step down rate. Isolation is not only providing electrical isolation between the power line circuit and the electronic circuits, but also it biased the rectifier circuit. This isolation can totally reduce the risk of electrical shock or overshoot.

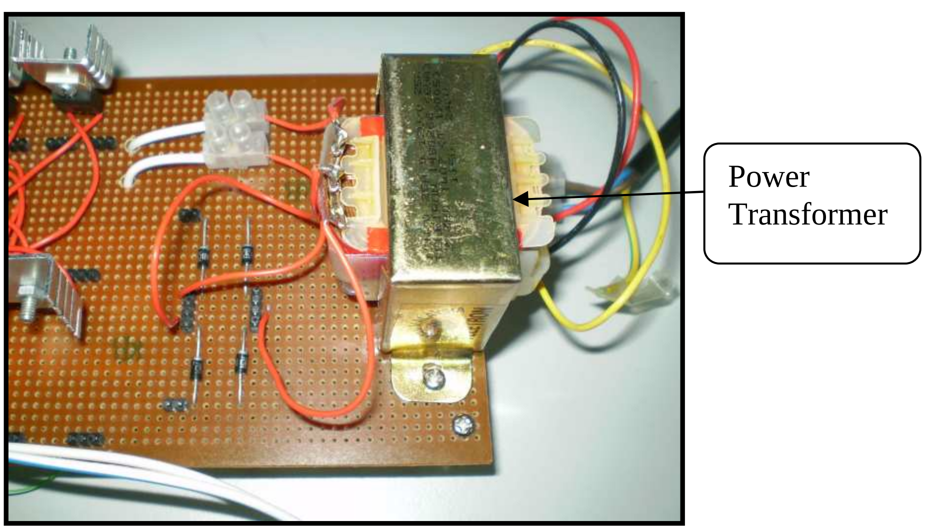

Figure 3.4 Power Transformer

3.3.3 Silicon Controlled Rectifier (SCR)

In this project, the Silicon Controlled Rectifier (SCR) has been chosen as a power switch. The SCR is a solid state rectifier with the ability to rapidly switch heavy current. It will trigger when voltage is applied to its gate and will turn off when current flow is stopped.

If an SCR's gate is left floating (disconnected), it behaves just exactly as a Shockley diode. It may be latched by breakover voltage (VBO) or by exceeding the critical rate of voltage rise between anode and cathode just as with the Shockley diode. Dropout is accomplished by reducing current until one or both internal transistors fall into cutoff mode also like the Shockley diode. However, because the gate terminal connects directly to the base of the lower transistor it may be used as an alternative means to latch the SCR.

By applying a small voltage between gate and cathode, the lower transistor will be forced on by the resulting base current which will cause the upper transistor to conduct which then supplies the lower transistor's base with current so that it no longer needs to be activated by a gate voltage. The necessary gate current to initiate latch-up, of course, will be much lower than the current through the SCR from cathode to anode, so the SCR does achieve a measure of amplification.

This method of securing SCR conduction is called triggering and it is by far the most common way that SCRs are latched in actual practice. In fact, SCRs are usually chosen so that their breakover voltage is far beyond the greatest voltage expected to be experienced from the power source so that it can be turned on only by an intentional voltage pulse applied to the gate.

It should be mentioned that SCRs may sometimes be turned off by directly shorting their gate and cathode terminals together or by "reverse-triggering" the gate with a negative voltage (in reference to the cathode), so that the lower transistor is forced into cutoff. The advantages of the SCR that have been the reasons to be chosen include:

i. Robust
ii. Simple
iii. Economical
iv. Small in size, are rugged and has no contacts
v. Unlimited life can be expected.

3.3.4 Power Processor Converter

This project describes the operation of a single-phase fully- controlled bridge rectifier circuit with a resistive load. The operation of this circuit can be understood more easily when the load is purely resistive. The analysis in this page is based on the assumption that the SCRs are ideal controlled switches. It means that when the SCRs are ON, the ON-state voltage drops are zero. In the OFF- state, the leakage current is assumed to be zero.

The main purpose of a fully-controlled bridge rectifier circuit is to provide a variable DC voltage from an AC source. In this project, SCR TYN812 shown in Figure 3.5 is used as a switch because it is suitable to fit all modes of control found in applications such as overvoltage crowbar protection, motor control circuits in power tools and kitchen aids, in-rush current limiting circuits, capacitive discharge ignition, voltage regulation circuits. This type also available in though-hole or surface-mount packages, they provide an optimized performance in a limited space area.

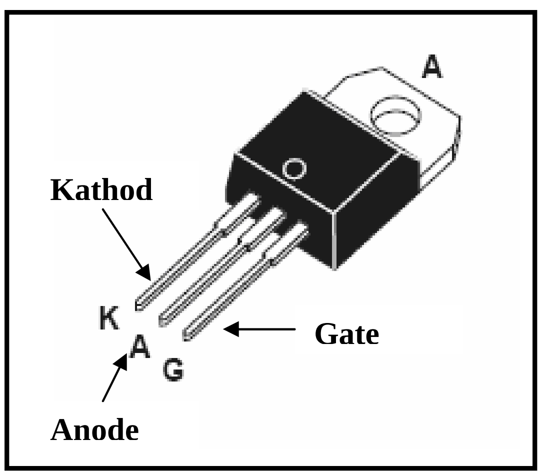

Figure 3.5 SCR TYN812

The circuit of a single-phase fully-controlled bridge rectifier circuit is shown in the Figure 3.6. The circuit has four SCRs. It is preferable to state that the circuit has two pairs of SCRs, with SCR_2 and SCR_4 forming one pair while SCR_1 and SCR_3 the other pair. For this circuit, the source is marked as Vs and it is a sinusoidal voltage source. When Vs is positive, SCR_2 and SCR_4 can be triggered and then current flows from Vs through SCR_4, load resistor R, SCR_2 and back into the source. In the next half-cycle, the other pair of SCRs conducts. Even though the direction of current through the source alternates from one half-cycle to the other half-cycle, the current through the load remains unidirectional.

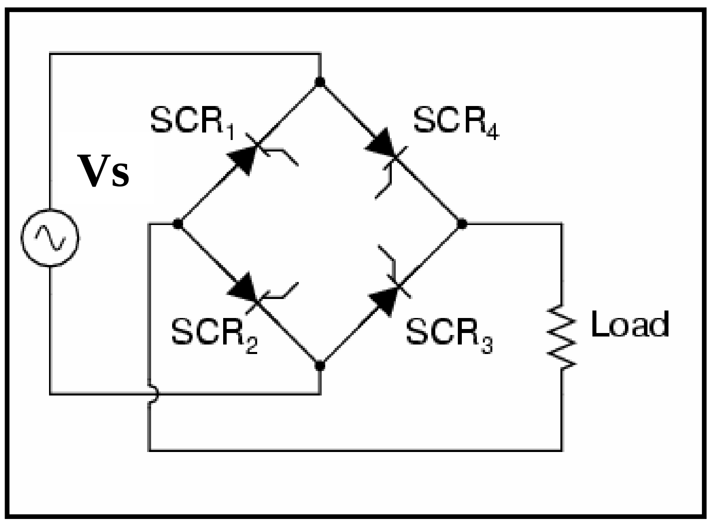

Figure 3.6 A Single Phase Controlled Bridge Rectifier

The main purpose of this circuit is to provide a variable DC output voltage, which is brought about by varying the firing angle. Let Vs = E x Sin wt, with $0 < wt < 360^o$. If $wt = 30^o$ when SCR_2 and SCR_4 are triggered, then the firing angle is said to be 30^o. In this instance, the other pair is triggered when $wt = 210^o$. When Vs changes from a positive to a negative value, the current through the load becomes zero at the instant $wt = \pi$ radians, since the load is purely resistive and the SCRs cease to conduct. After that there is no current flow till the other pair is triggered. Hence the conduction or current flow through the load is discontined.

In any bridge rectifier circuit, the rectifying diodes (or in this case, the rectifying SCRs) must conduct in opposite pairs. SCR_1 and SCR_3 must be fired simultaneously, and likewise SCR_2 and SCR_4 must be fired together as a pair as shown in Figure 3.7. Though, these pairs of SCRs do not share the same cathode connections, meaning that it would not work to simply parallel their respective gate connections and connect a single voltage source to trigger both.

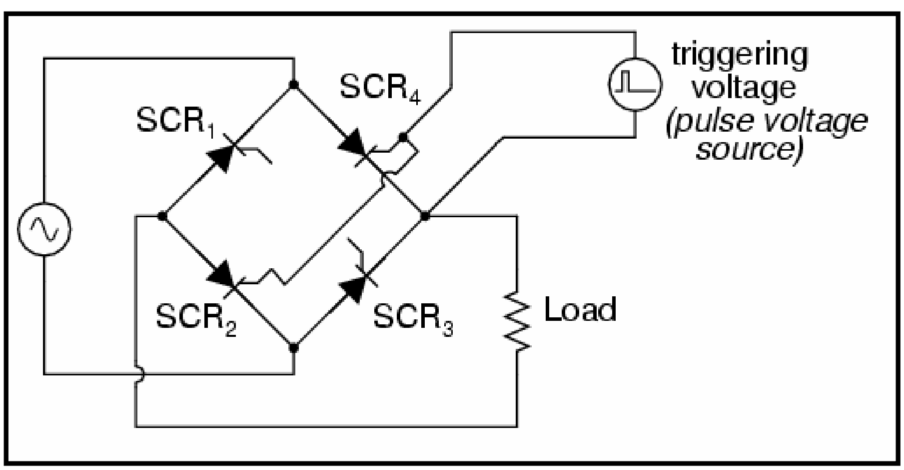

Figure 3.7 Triggering SCR_2 and SCR_4 as a pair

Although the triggering voltage source will trigger SCR_4, it will not trigger SCR_2 properly because the two thyristors do not share a common cathode connection to reference that triggering voltage. Pulse transformers connecting the two thyristor gates to a common triggering voltage source will work.

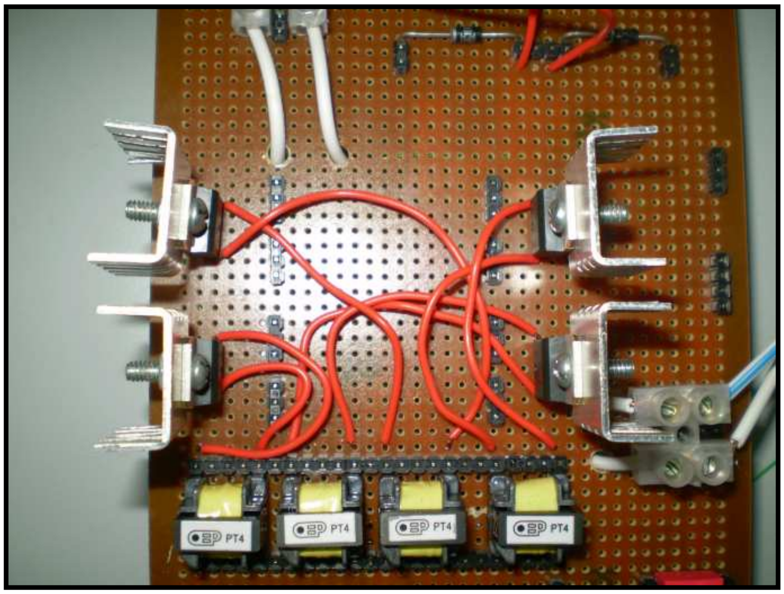

Figure 3.8 Controlled Bridge Rectifier

3.3.5 Pulse Transformer as an Driver Circuit

Driver circuit is used to interface between control (low power electronics) and (high power) switch. The functions of the driver circuit are used to:

i. amplify control signal to a level required to drive power switch
ii. provide electrical isolation between power switch and logic level

In this project, pulse transformer shown in Figure 3.8 is used for isolation. Isolation is required to prevent damages on the high power switch to propagate back to low power electronics. Pulse transformers usually (not always) operate at high frequency necessitating use of low loss cores (usually ferrites). Modern day electronic circuits utilize many gated semiconductor devices such as ordinary transistors, field effect transistors, SCRs and others. These transformers are used in some of these circuits. A signal must be supplied to (or removed from) the device’s gate node to activate (or deactivate) the device. When used, pulse transformers are located within the circuitry driving the gate. Pulse transformers are used to modify the voltage level to the gate, provide impedance matching, and to provide voltage isolation. Pulse transformer may be used to deliver voltage to the grids or plates of a vacuum tube or flash tube.

Some pulse transformers simply deliver a voltage pulse or a series of voltage pulses to a semiconductor gate. A pulse transformer functioning in this manner could also be called a pulse transformer. Most circuit designers would consider these gate drive transformers to be a type of pulse transformer. If the pulse transformer’s pulse initiates some action or event, the pulse transformer could be called a trigger transformer. Some applications require a close reproduction of the pulse. The pulse transformer designer will seek to minimize winding capacitance and leakage inductance because these parasitic components distort the signal.

Some amplifying circuits use a pulse transformer to deliver a signal to a semiconductor gate. Here the objective is to reproduce the signal, but with increased power and increased voltage or current. In most amplifying circuits the signal is injected into a direct current biased transistor circuit, hence the pulse transformer may have to tolerate a DC current bias. Even though these pulse transformers drive a gate, circuit designers will usually refer to them as signal transformers.

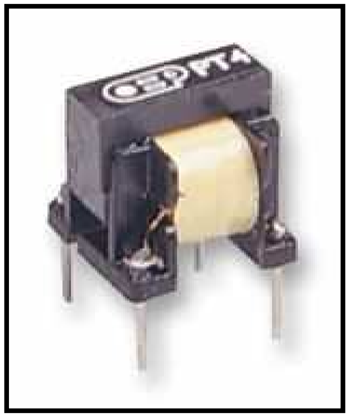

Figure 3.9 Pulse Transformer

Sometimes, pulse transformers are used to couple a triggering circuit to the gate and cathode of an SCR to provide electrical isolation between the triggering and power circuits as shown in Figure 3.10.

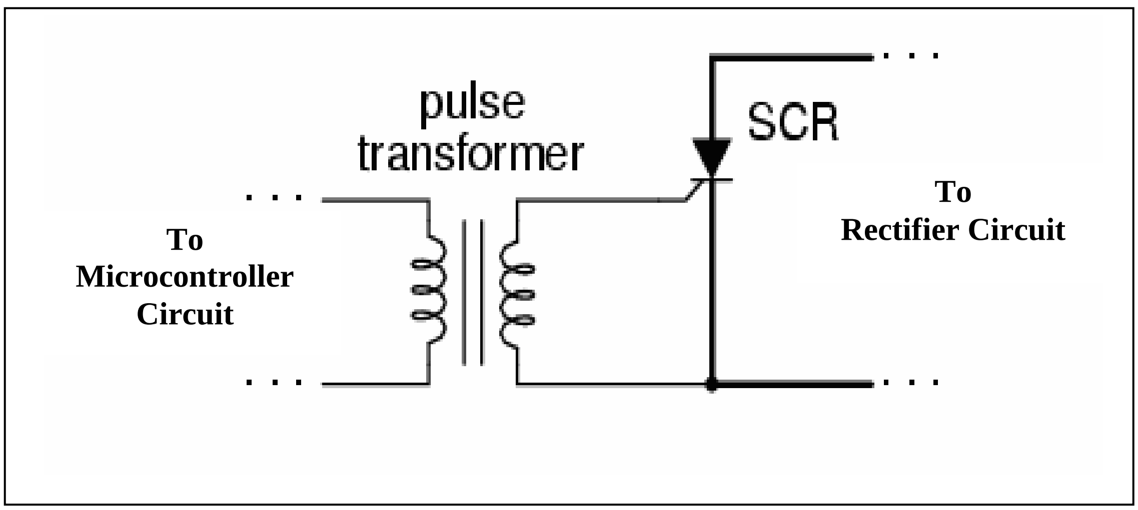

Figure 3.10 Pulse Transformers as a Coupler for a Triggering Circuit to the Gate and Cathode of an SCR

Besides for isolation, pulse transformer is used to separate the common cathode. When multiple SCRs are used to control power, their cathodes are often not electrically common, making it difficult to connect a single triggering circuit to all SCRs equally. The circuit in Figure 3.11 only shows the gate connections for two out of the four SCRs. Pulse transformers and triggering sources for SCR_1 and SCR_3, as well as the details of the pulse sources themselves, have been omitted for the sake of simplicity.

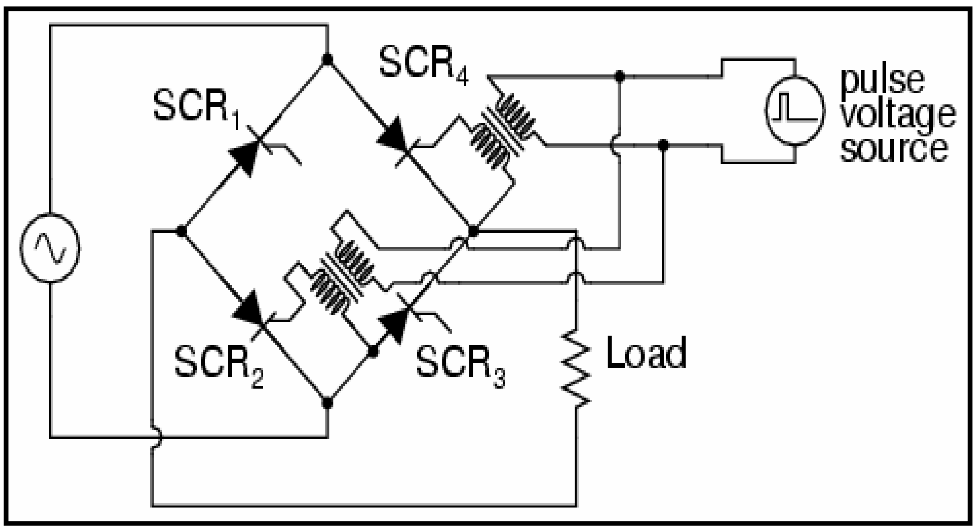

Figure 3.11 The Gate Connections for Two SCRs

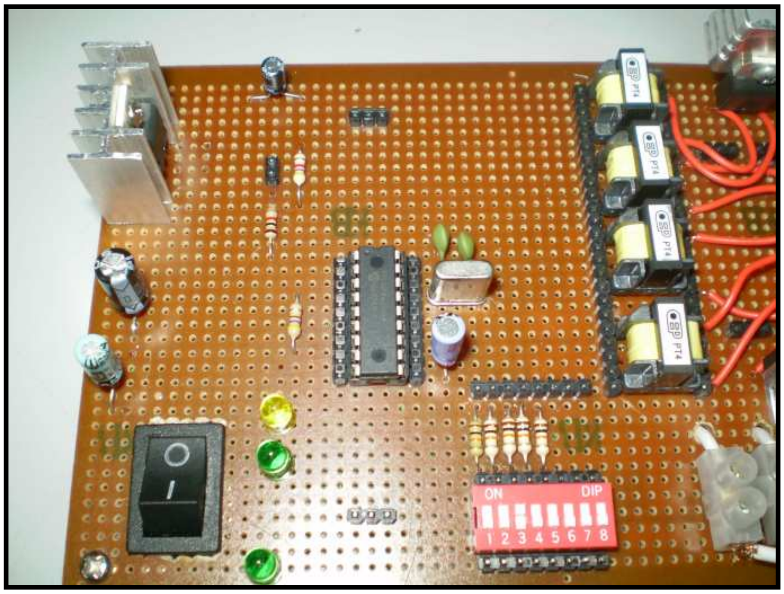

Figure 3.12 Pulse Transformers as Interface Circuit

3.3.6 PIC as the Controller Unit

After constructed the power circuit, the control circuit now is ready to be built. As stated in the scope of this project, the controlled bridge rectifier will be controlled by using the microcontroller means that, the microcontroller will control the speed of the motor with variable speeds. The core of the control circuit is the IC chip of PIC16F84A, which functions to control the main circuit of the single phase controlled rectifier.

The PIC series of processors uses a non-unified addressing scheme, the instruction addressing is 1 per instruction word, and each instruction uses a word of memory varying from 12 to 16 bits in length. The processor data is addressed as 1 per byte of data. To properly address the program/data spaces you, the programmer, must separate your program and data into separate code and data areas. The data area is addressed as 1 per byte and the code area is addressed as 1 per instruction.

The assembler/linker processes the instruction code so that the linker will output 2 bytes for each instruction word. The instruction word address will be the file-encoded address divided by 2.

In this project, the microcontroller is clocked at 4 MHz. The PIC microcontroller also can use the oscillator of frequencies other than 4 MHz. The schematic below shows in Figure 3.13 gives an idea of the few things that need to be connected to the PIC microcontroller to make it work. As stated before, this PIC is used to control the delay angle, α of the SCR to make alternative output voltages.

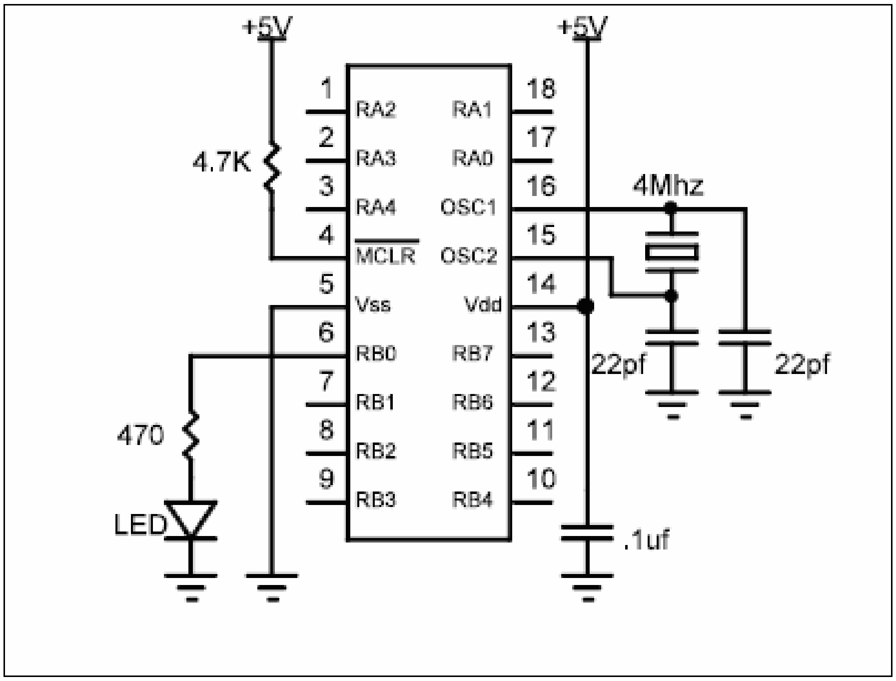

Figure 3.13 Schematic of PIC16F84A Connection

The PIC is connected to DIP switch as an input. The switch is using active high (1) connection. The program in the PIC will not execute until the switch is pressed to give input 0 (low) to the microcontroller. The switch connection is shown in Figure 3.14. This project only used three switches that are connected to Port B pin 4, 5 and 6 of the microcontroller. When switch 1 is pressed, the program in the PIC will execute for delay angle 60˚ and when switch 2 is pressed, it will execute the program for delay angle 90˚. This is also done for switch 3 when it is pressed, the program for delay angle 120˚ will executes. Then, the output of the PIC16F84A which is using Port A, pin 0 and 1 as the output port are connected to the pin gate of SCRs.

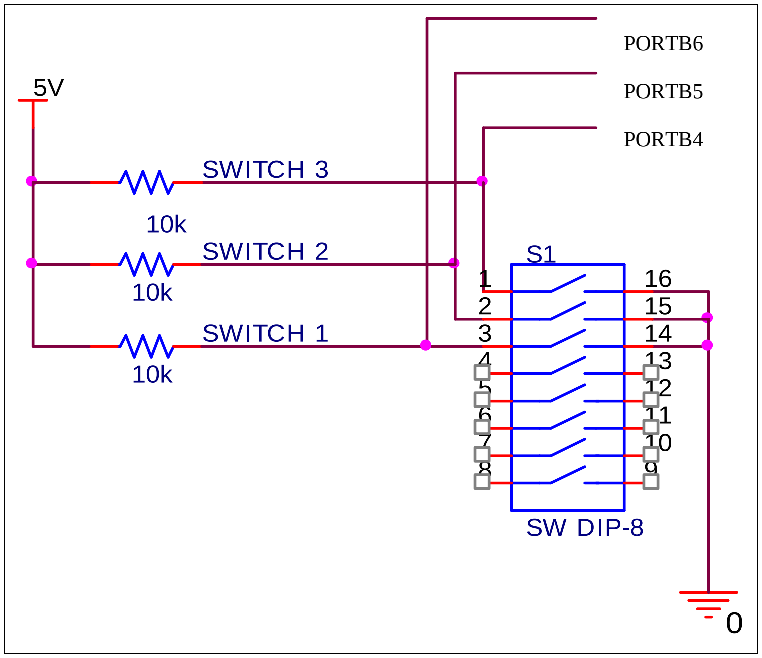

Figure 3.14 DIP Switch Connection

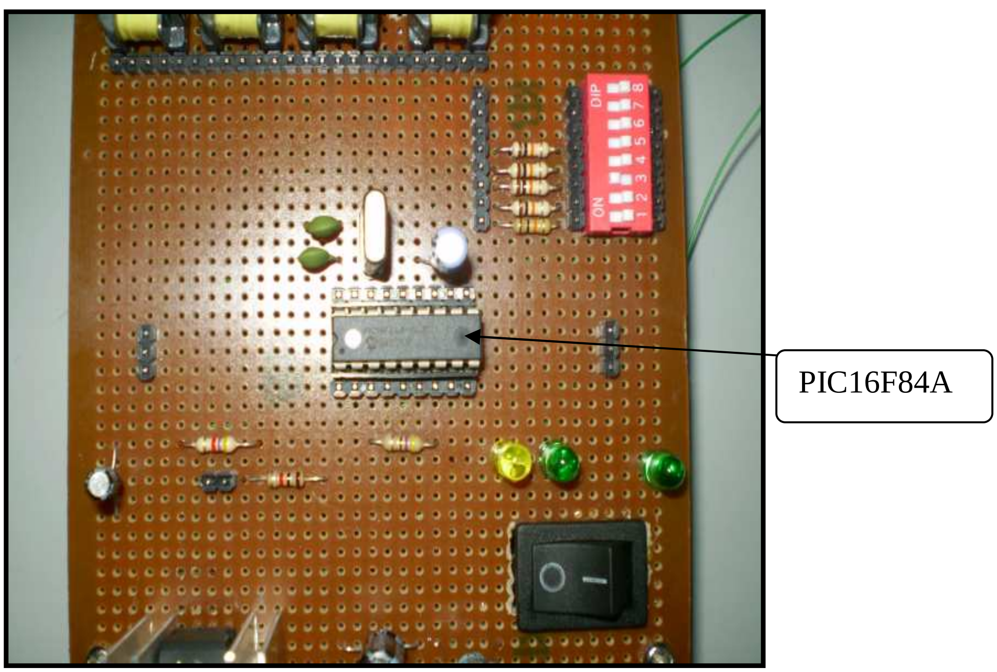

Figure 3.15 Control Unit Circuit

3.3.7 DC Motor as a Load

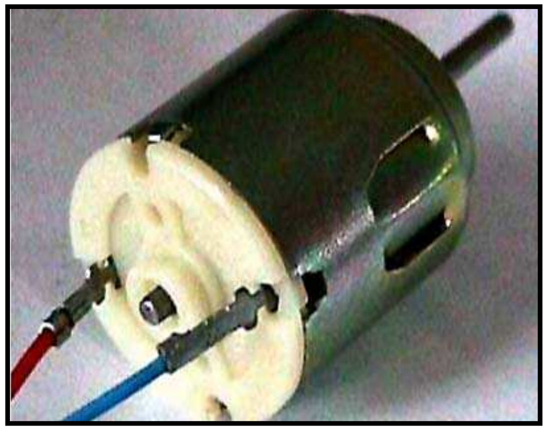

Figure 3.16 DC Motor

An electric motor is a device that transforms electrical energy into mechanical energy by using the motor effect.

DC motor principles

DC motors consist of rotor-mounted windings (armature) and stationary windings (field poles). In all DC motors, except permanent magnet motors, current must be conducted to the armature windings by passing current through carbon brushes that slide over a set of copper surfaces called a commutator, which is mounted on the rotor.

The commutator bars are soldered to armature coils. The brush/commutator combination makes a sliding switch that energizes particular portions of the armature, based on the position of the rotor. This process creates north and south magnetic poles on the rotor that are attracted to or repelled by north and south poles on the stator, which are formed by passing direct current through the field windings. It's this magnetic attraction and repulsion that causes the rotor to rotate.

The Advantages

The greatest advantage of DC motors may be speed control. Since speed is directly proportional to armature voltage and inversely proportional to the magnetic flux produced by the poles, adjusting the armature voltage and/or the field current will change the rotor speed.

Today, adjustable frequency drives can provide precise speed control for AC motors, but they do so at the expense of power quality, as the solid-state switching devices in the drives produce a rich harmonic spectrum. The DC motor has no adverse effects on power quality

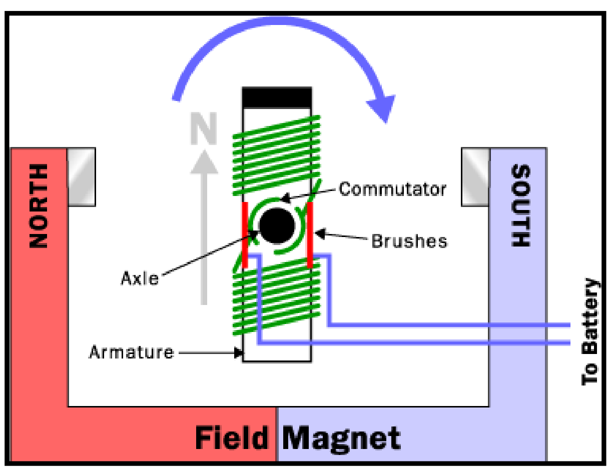

Figure 3.17 Parts of an electric motor

3.4 Software Development

In this part, a program is needed to develop to control the amplitude which is the applied voltage to the motor. After completing the hardware designed, the progress of this project could be proceeding to the final stage in designing a controlled rectifier circuit. Besides that, the design circuit would be simulated by using OrCad PsPice software then the results were compared with the practical design.

For programming code, Microcode Studio software is used to create program to control the delay angle of SCR. MicroCode Studio software is a powerful, visual Integrated Development Environment (IDE) with In Circuit Debugging (ICD) capability designed specifically for microEngineering Labs PICBASIC™ and PICBASIC PRO™ compiler. Then, the programming code will compile by using compiler to convert into HEX file. Lastly, a PIC programmer is used to write and load the program into the PIC microcontroller.

3.5 Hardware Development and Software Tested

In this project, every parts and stages that had been executed are needed to be tested in sequence to fulfill the objectives and scope. Now the hardware can be experimented and so with the software that has been programmed. Same method is being used in this part where each phase needs to be tested individually by connecting the circuit to an adjustable single phase AC input. Then, 12 V DC motor is used as the load.

CHAPTER 4

RESULT AND ANALYSIS

4.1 Introduction

This chapter will briefly discuss on the results and discussions of the hardware and software development.

4.2 Design Philosophy

A versatile method of controlling the output of a full-wave rectifier is to substitute controlled switches such as SCRs for the diodes. The output is controlled by adjusting the delay angle of each SCR, resulting in an output voltage or output current which is variable over a limited range.

In this project task, the rectifier circuit should be possible to produce a variable average voltage by controlling the delay. The single phase 240 V_{rms} AC source is stepped down to 12 V_{rms} by using step-down power transformer.

4.3 Hand Calculation For Controlled Full-Wave Rectifier

Given f = 50Hz, V_{rms} =12V Vm= 17V

4.3.1 Calculation for Delay Angle of 0˚

Let α = 0˚,

Thus,

The average load voltage is given by,

$$V_o = \frac{Vm}{\pi}[1+\cos\alpha]$$

$$= 17/\pi\ [1+\cos 0^\circ]$$

$$= 10.823\ \text{V}$$

Delay angle in time domain,

$$TD = (0^\circ/180^\circ)\ (10\text{ms}) = 0\text{ms}.$$

4.3.2 Calculation for Delay Angle of 30˚

Let α = 30˚,

Thus,

The average load voltage is given by,

$$V_o = \frac{Vm}{\pi}[1+\cos\alpha]$$

$$= 17/\pi\ [1+\cos 30^\circ]$$

$$= 10.098\ \text{V}$$

Delay angle in time domain,

TD = (30˚/180˚) (10ms) = 1.67ms.

4.3.3 Calculation for Delay Angle of 60˚

Let α = 60˚,

Thus,

The average load voltage is given by,

$$V_o = \frac{Vm}{\pi}[1+\cos\alpha]$$

$$= 17/\pi\ [1+\cos 60^\circ]$$

$$= 8.117\ \text{V}$$

Delay angle in time domain,

TD = (60˚/180˚) (10ms) = 3.33ms.

4.3.4 Calculation for Delay Angle of 90˚

Let α = 90˚,

Thus,

The average load voltage is given by,

$$V_o = \frac{Vm}{\pi}[1+\cos\alpha]$$

$$= 17/\pi\ [1+\cos 90^\circ]$$

$$= 5.411\ \text{V}$$

Delay angle in time domain,

$$TD = (90^\circ/180^\circ)\ (10ms) = 5.00ms.$$

4.3.5 Calculation for Delay Angle of 120˚

Let α = 120˚,

Thus,

The average load voltage is given by,

$$V_o = \frac{Vm}{\pi}[1+\cos\alpha]$$

$$= 17/\pi\ [1+\cos 120^\circ]$$

$$= 2.705\text{V}$$

Delay angle in time domain,

$$TD = (120^\circ/180^\circ)\ (10ms) = 6.67ms$$

4.3.6 Calculation for Delay Angle of 150˚

Let α = 150˚,

Thus,

The average load voltage is given by,

$$V_o = \frac{Vm}{\pi}[1 + \cos\alpha]$$

$$= 17/\pi\ [1+\cos 150^\circ]$$

$$= 0.725V$$

Delay angle in time domain,

TD = (150˚/180˚) (10ms) = 8.33ms

4.3.7 Calculation for Delay Angle of 180˚

Let α = 180˚,

Thus,

The average load voltage is given by,

$$V_o = \frac{Vm}{\pi}[1 + \cos\alpha]$$

$$= 17/\pi\ [1+\cos 180^\circ]$$

$$= 0.000V$$

Delay angle in time domain,

TD = (180˚/180˚) (10ms) = 10ms

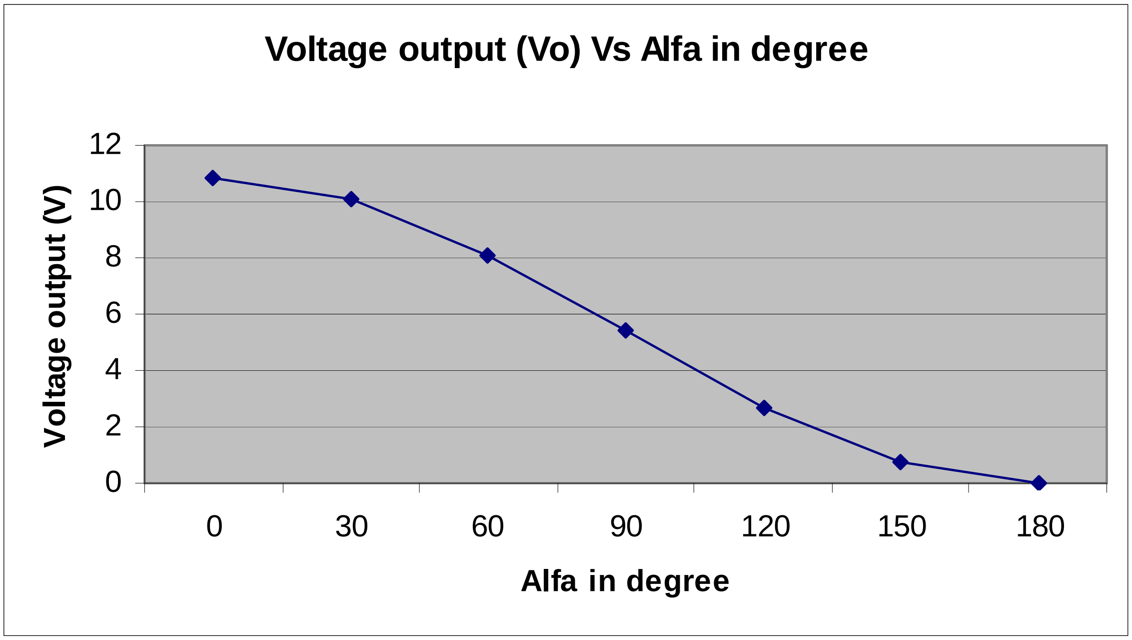

Figure 4.1 Alfa Vs Voltage output

From the graph above ,the voltage output (V) is plot versus alpha(α) in degree(˚) which is the range of voltage output is from 0 to 11 V. For the alpha(α)the value is taken from 0˚ to 180˚ in range. Figure above shown that the curve is decreased from the maximum value to the minimum value of voltage output if the Alfa (α) is increased.

4.4 OrCAD PSpice Simulation

The simulation of the full-wave rectifier of the single phase controlled rectifier had been done by using the OrCAD PSpice software. This simulation is to view in theory concept of the waveform results for the single phase full-wave controlled rectifier.

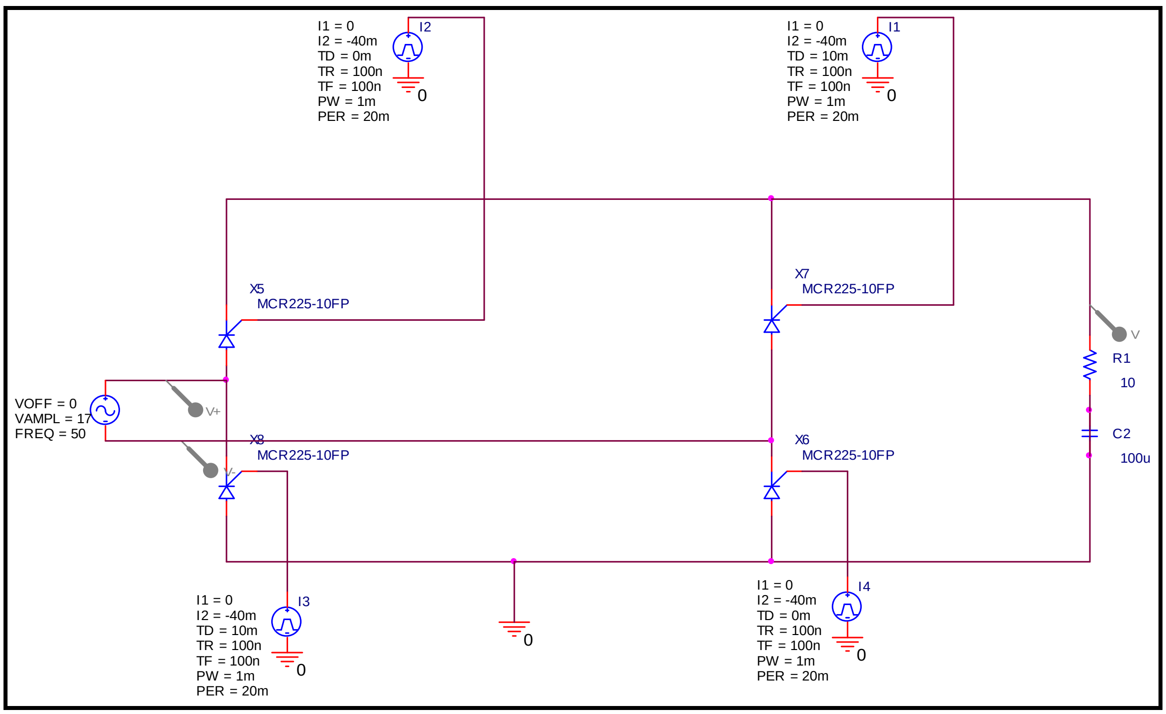

Figure 4.2 Simulation with Delay Angle of 0˚

Figure 4.2 shows the example of design circuit of controlled rectifier with the delay angle of 0˚. For this circuit, the design requirement is to produce an average voltage of 10.8233V. The fundamental concept of controlled rectifier in producing variable average voltage is by controlling the delay angle of the SCR.

In such that to meet this design requirement, some calculation has been made to determine the delay angle of the SCR.

As shown in the Figure 4.2, the time delay has been set to the 0ms. This is because from the calculation that have made, it shows that in order to produce average voltage of 10.823V the time delay of the rectifier is to be set at 0ms.But from the simulation made the output is have a slight difference which is 10.753V.

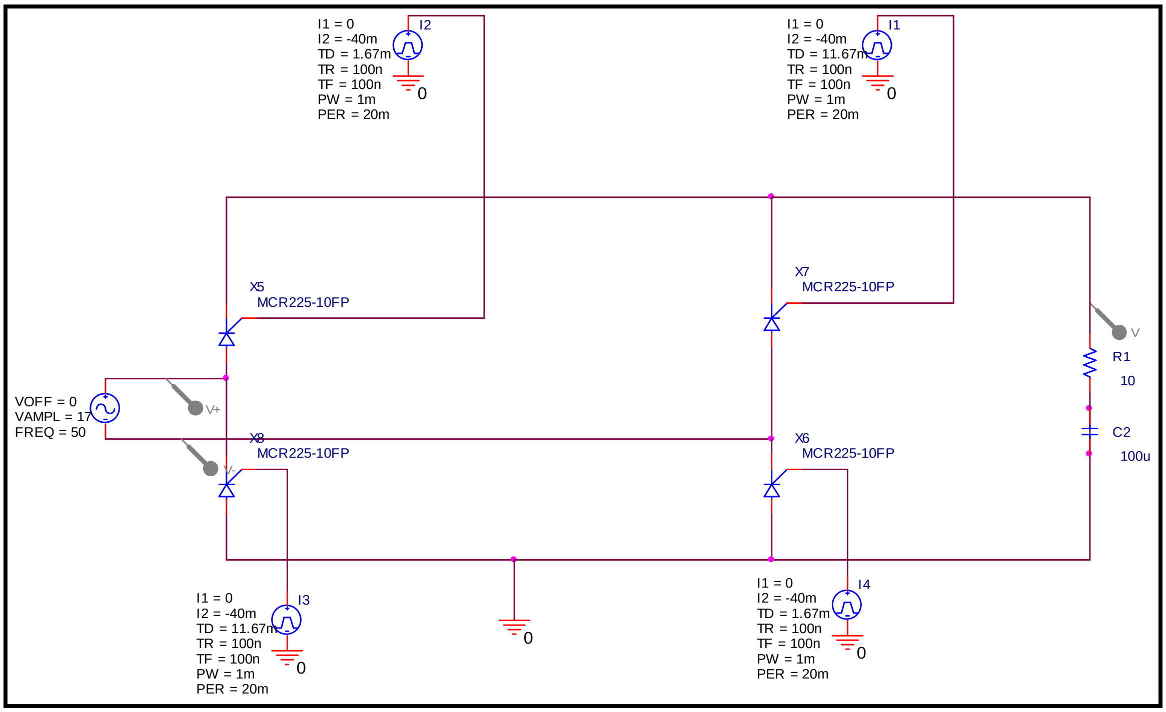

Figure 4.3 Simulation with Delay Angle of 30˚

As shown in the Figure 4.3, the time delay has been set to the 1.67ms. This is because of the calculation that have made before shows that, in order to produce average voltage of 10.098V the time delay of the rectifier is to be set at 1.67ms.For the simulation result the voltage output is 9.3919V.

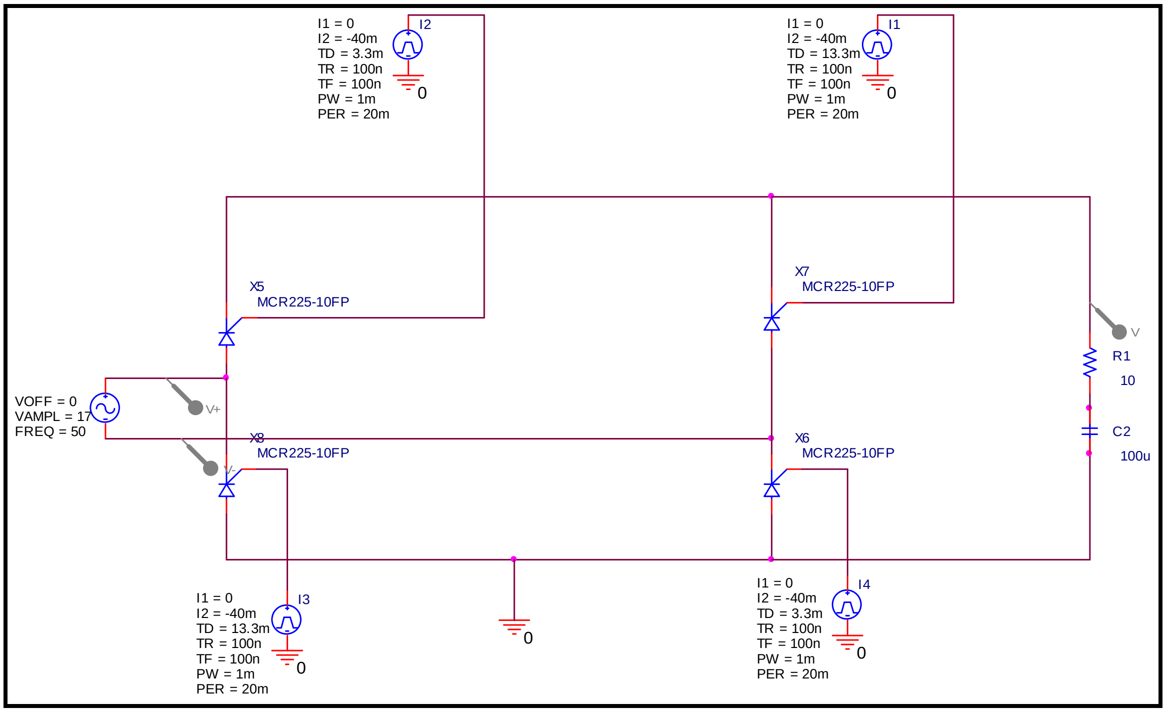

Figure 4.4 Simulation with Delay Angle of 60˚

Figure 4.4 shows the example of design circuit of controlled rectifier with the delay angle of 60˚. For this circuit, the design requirement is to produce an average voltage of 8.117V. In order to produce average voltage of 8.117V the time delay of the rectifier is to be set at 3.33ms.The simulation result is 8.0409V.

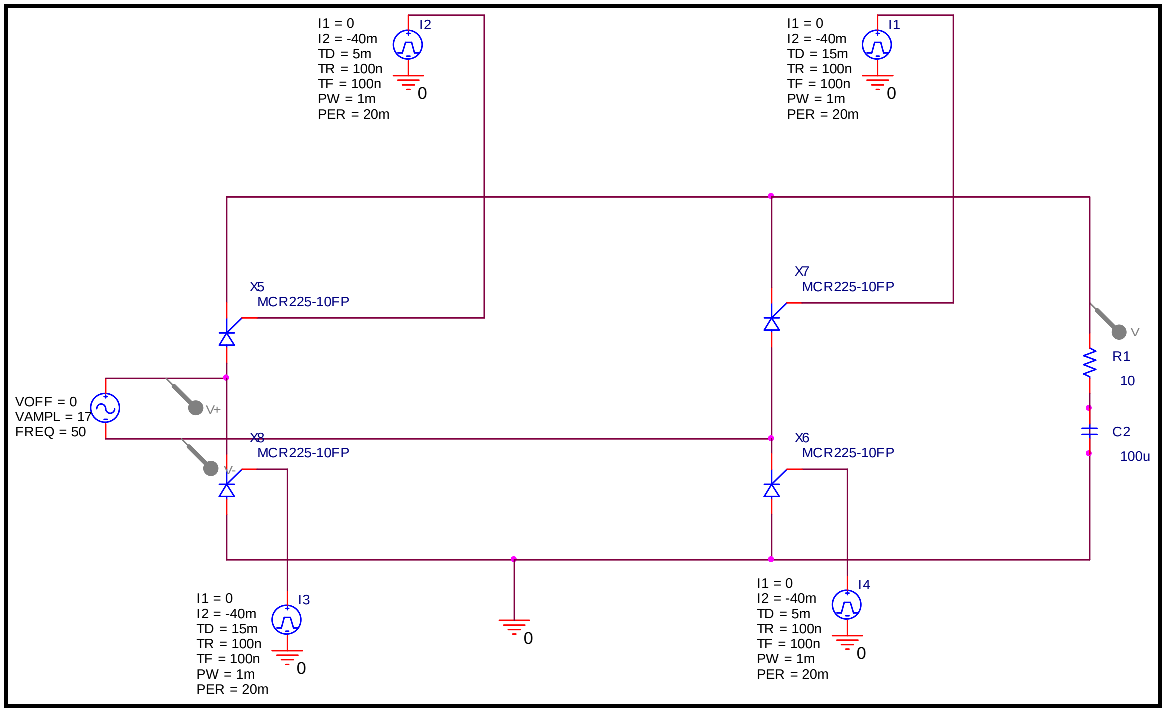

Figure 4.5 Simulation with Delay Angle of 90˚

Figure 4.5 shows the example of design circuit of controlled rectifier with the delay angle of 90˚. For this circuit, the design requirement is to produce an average voltage of 5.411V. In order to produce average voltage of 5.411V the time delay of the rectifier is to be set at 5.00ms.The simulation result is 5.1104V

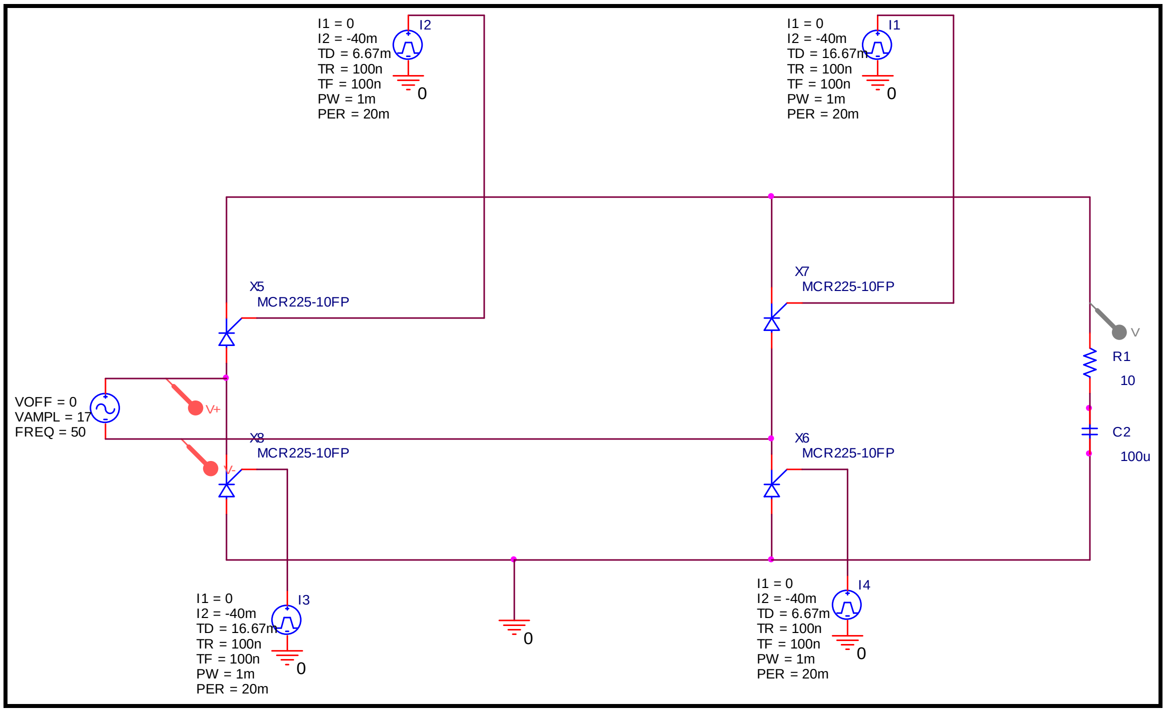

Figure 4.6 Simulation with Delay Angle of 120˚

Figure 4.6 shows the example of design circuit of controlled rectifier with the delay angle of 120˚. For this circuit, the design requirement is to produce an average voltage of 2.705V. In order to produce average voltage of 2.705V the time delay of the rectifier is to be set at 6.67ms.For the simulation , voltage output is 2.3975V

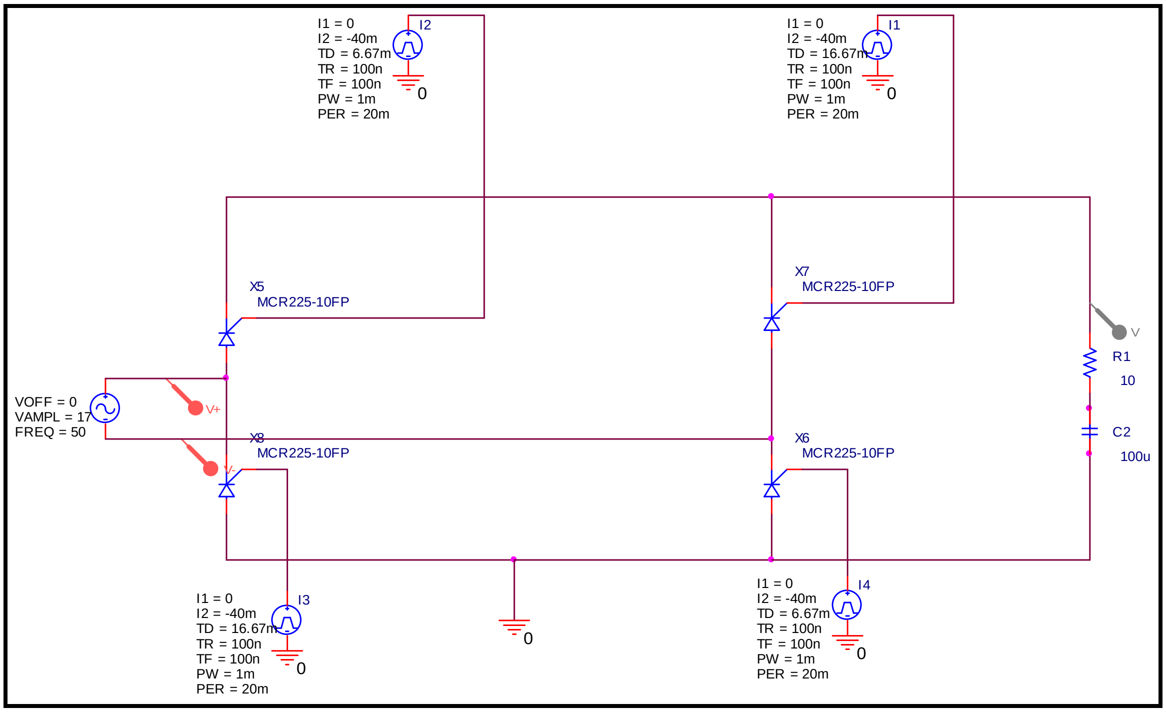

Figure 4.7 Simulation with Delay Angle of 150˚

Figure 4.7 shows the example of design circuit of controlled rectifier with the delay angle of 150˚. For this circuit, the design requirement is to produce an average voltage of 0.725V. In order to produce average voltage of 0.725V the time delay of the rectifier is to be set at 8.33ms.But for simulation result the output is 0.5554V

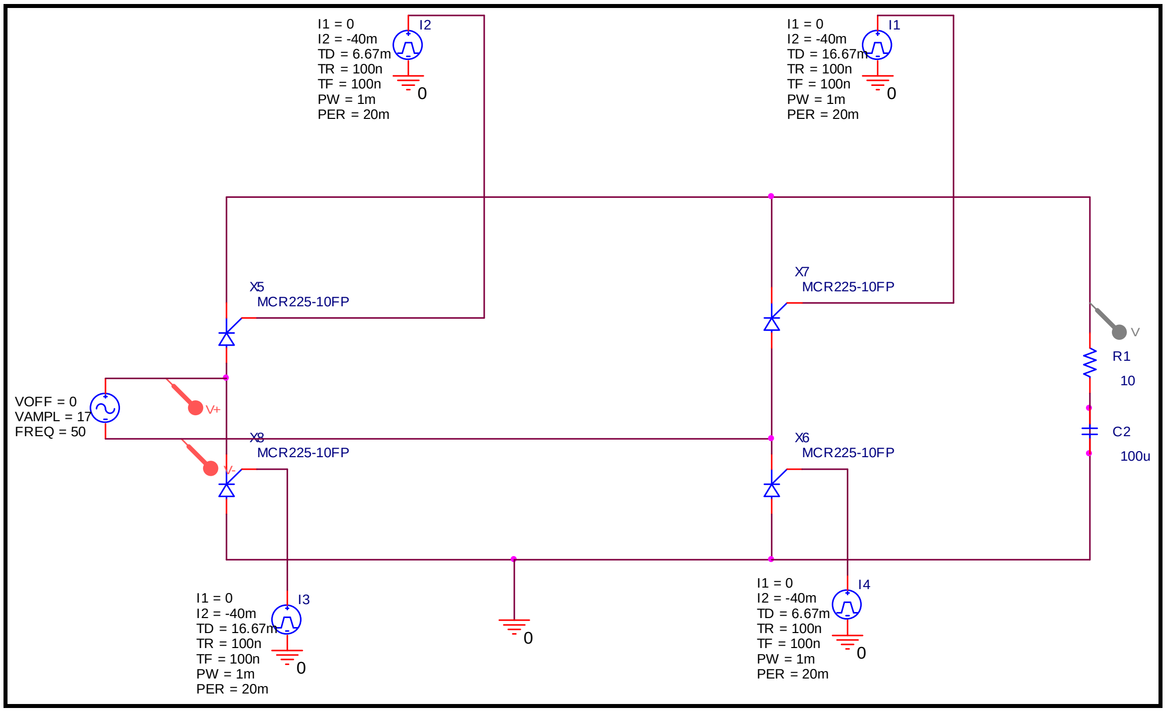

Figure 4.8 Simulation with Delay Angle of 180˚

Figure 4.8 shows the example of design circuit of controlled rectifier with the delay angle of 180˚. For this circuit, the design requirement is to produce an average voltage of 0.000V. In order to produce average voltage of 0.000V the time delay of the rectifier is to be set at 10ms.But for the simulation the voltage output is 79.128mV

4.5 Output Waveform

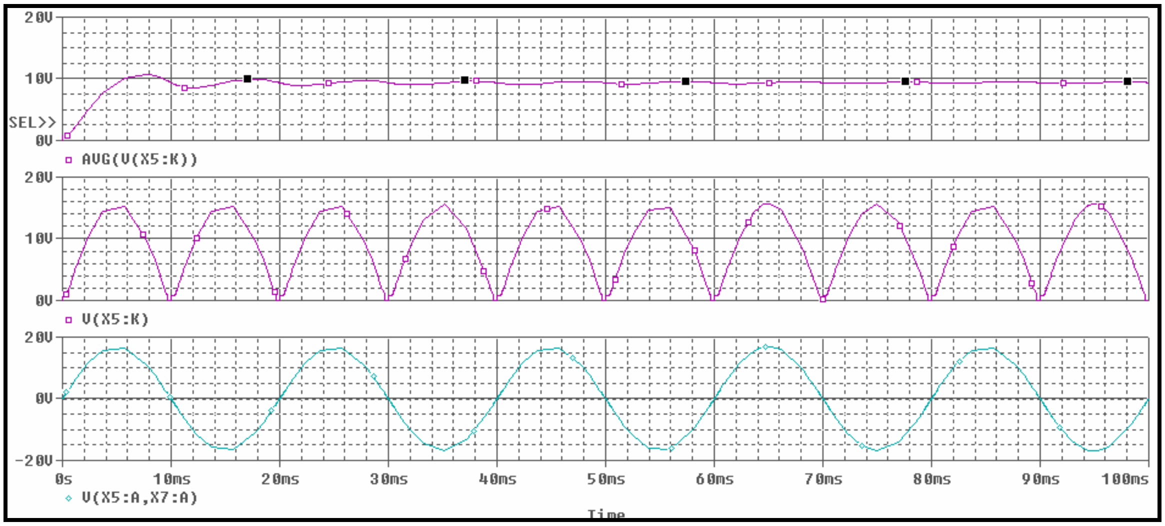

Figure 4.9 Controlled Rectifier Waveform with Delay Angle of 0˚

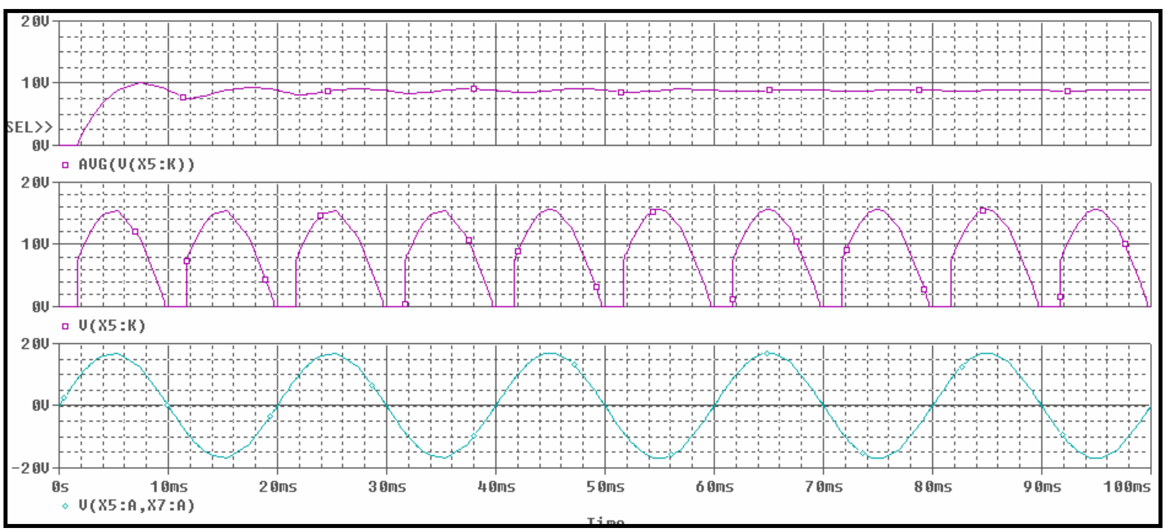

Figure 4.10 Controlled Rectifier Waveform with Delay Angle of 30˚

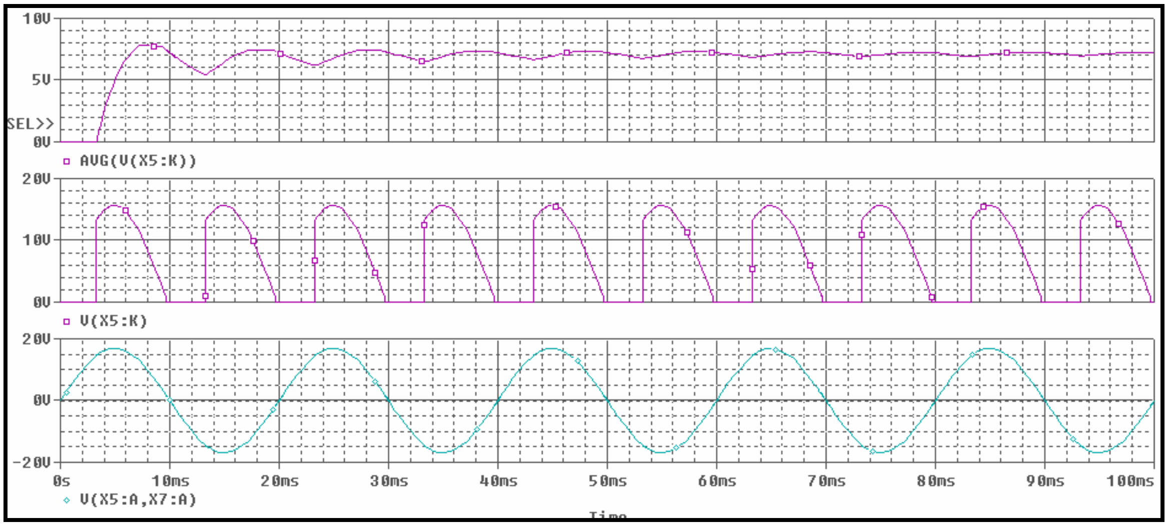

Figure 4.11 Controlled Rectifier Waveform with Delay Angle of 60˚

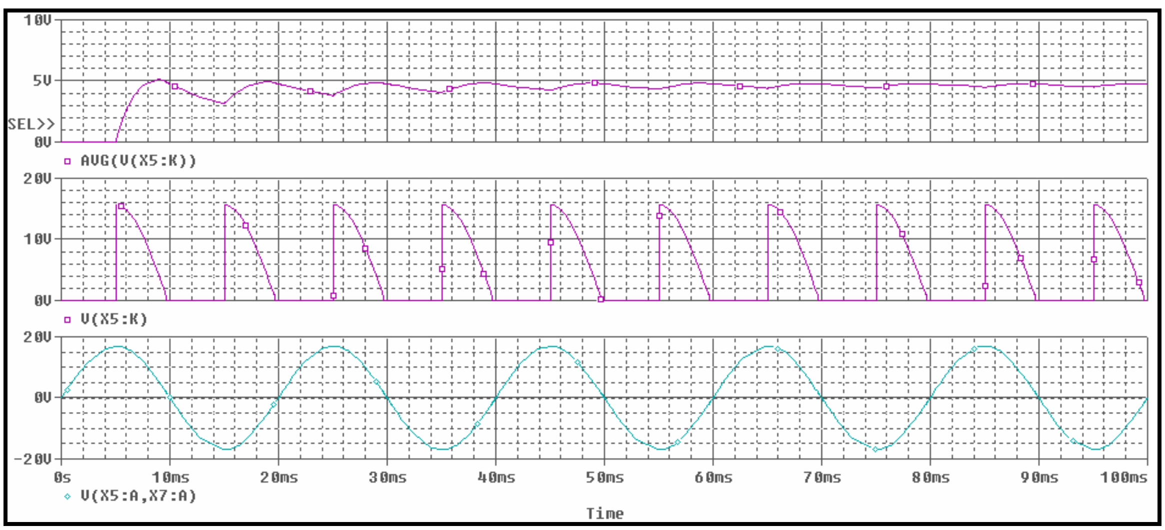

Figure 4.12 Controlled Rectifier Waveform with Delay Angle of 90˚

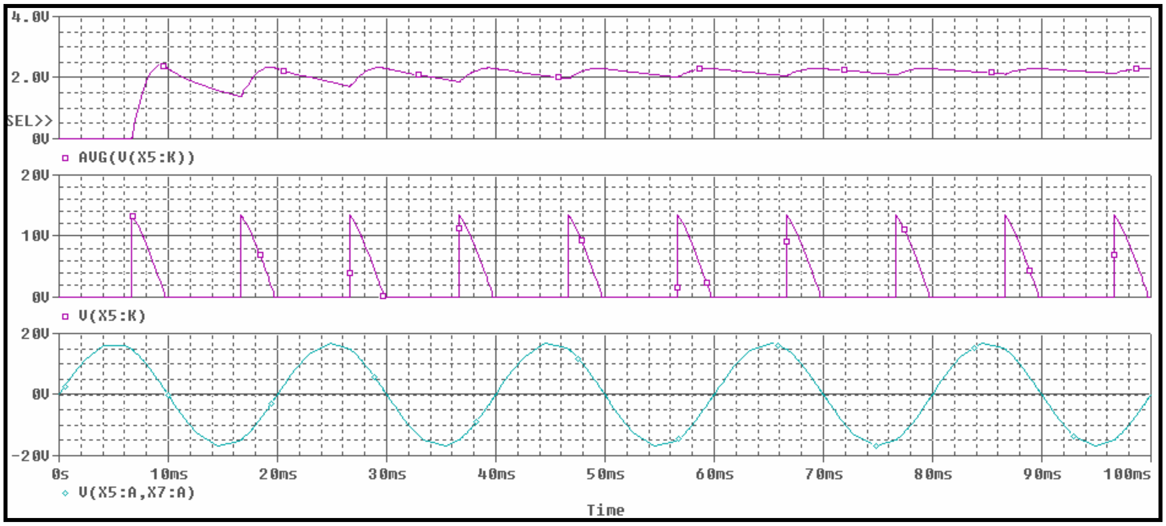

Figure 4.13 Controlled Rectifier Waveform with Delay Angle of 120˚

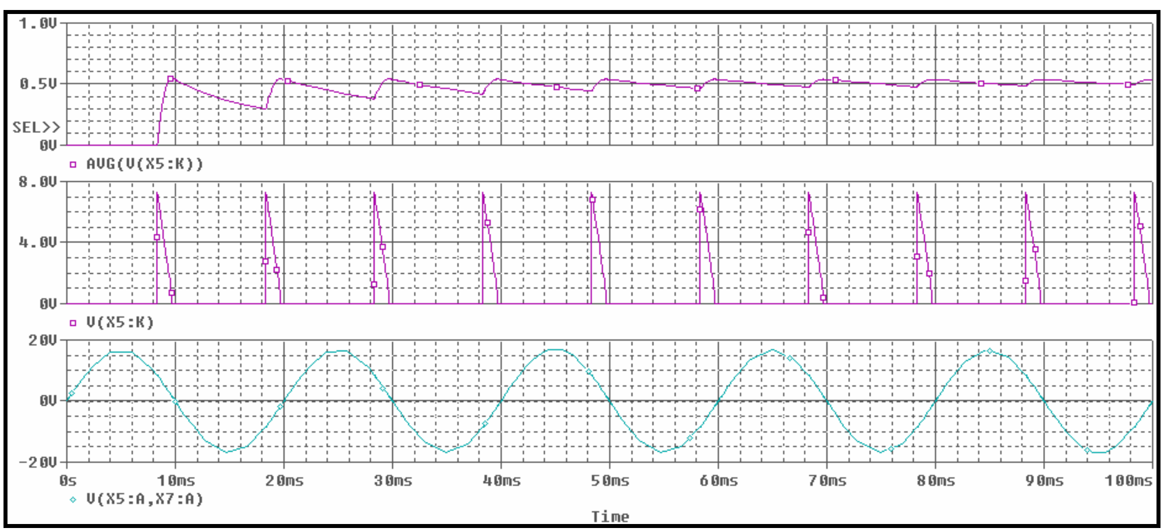

Figure 4.14 Controlled Rectifier Waveform with Delay Angle of 150˚

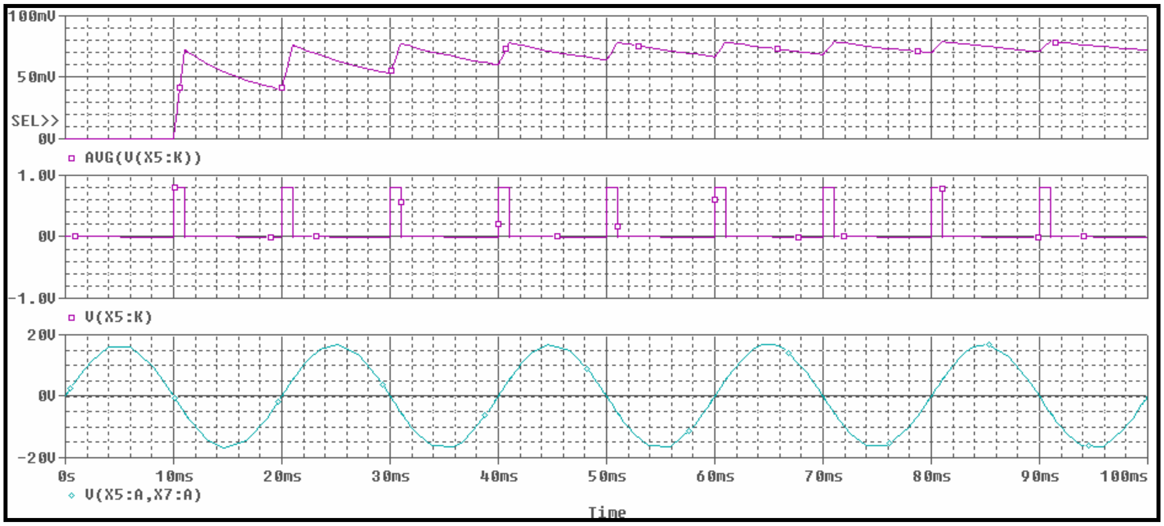

Figure 4.15 Controlled Rectifier Waveform with Delay Angle of 180˚

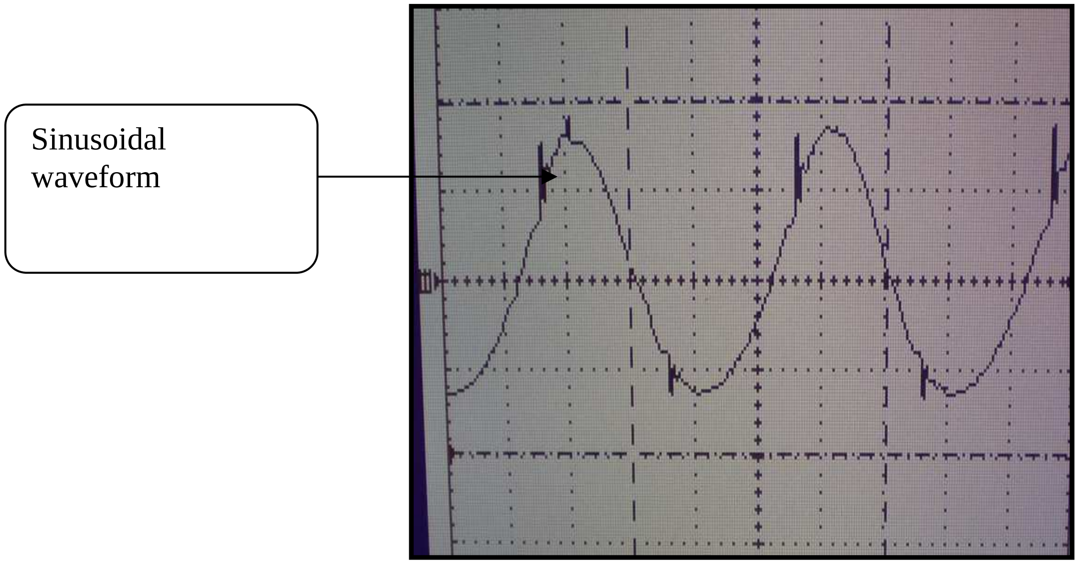

Figure 4.16 Waveform after stepdown by transformer (12 Vrms)

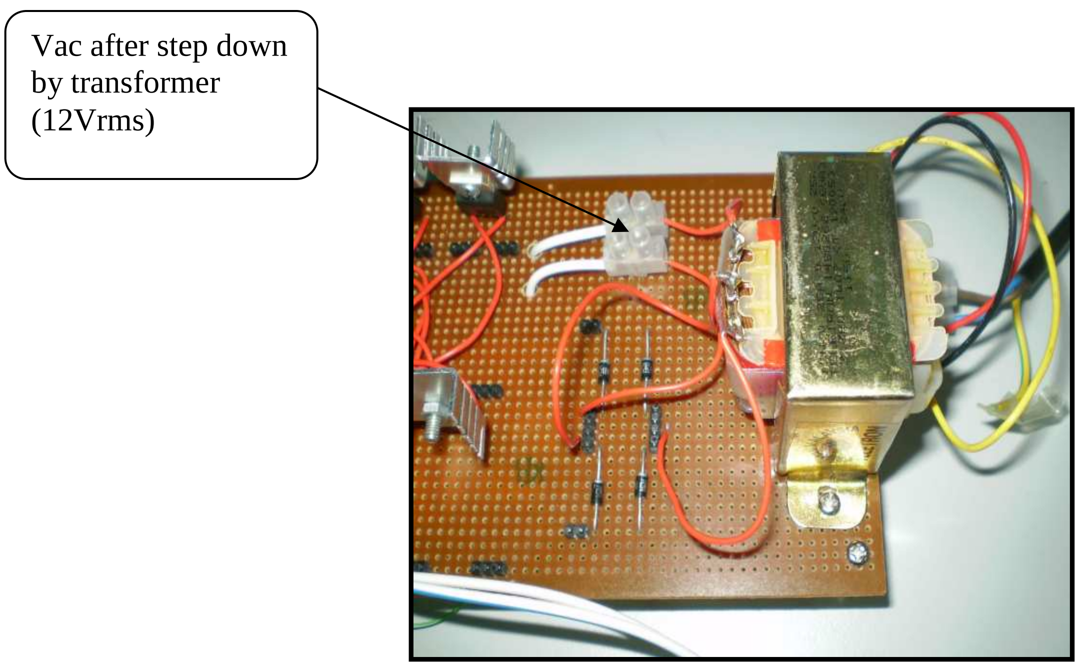

Figure 4.17 Vac after step down by transformer (12Vrms)

Vdc at alfa = 60 degree

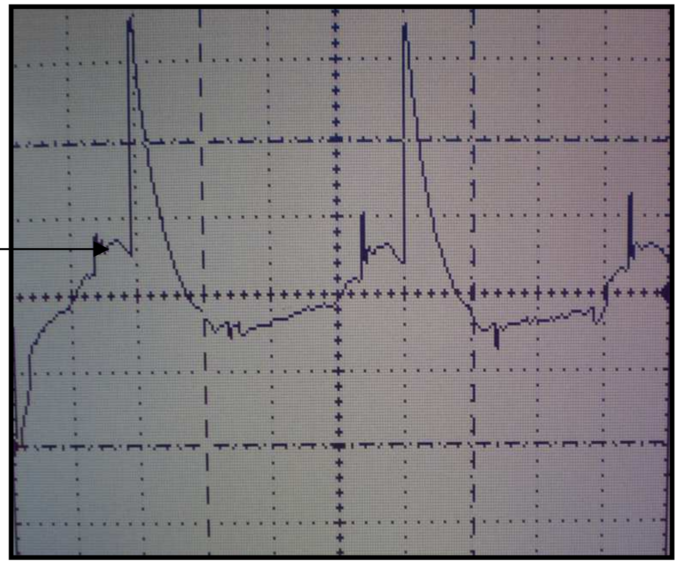

Figure 4.18 Waveform at alfa 60 degree

Programming the delay alfa using PIC

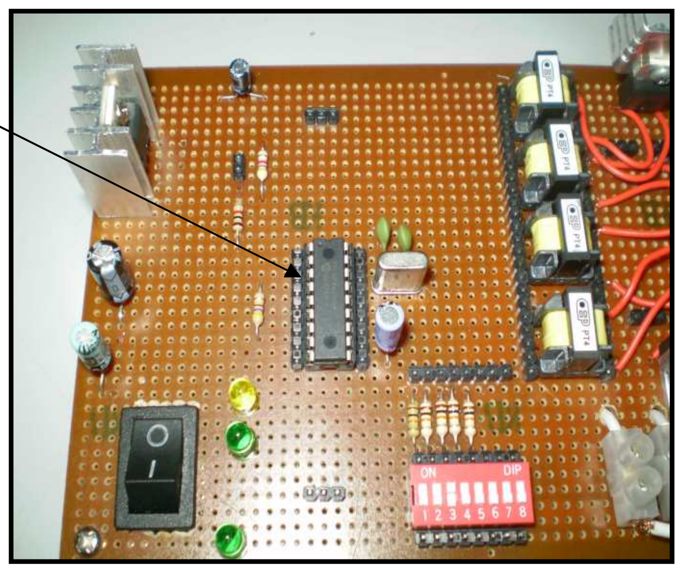

Figure 4.19 Hardware of PIC to program Delay angle

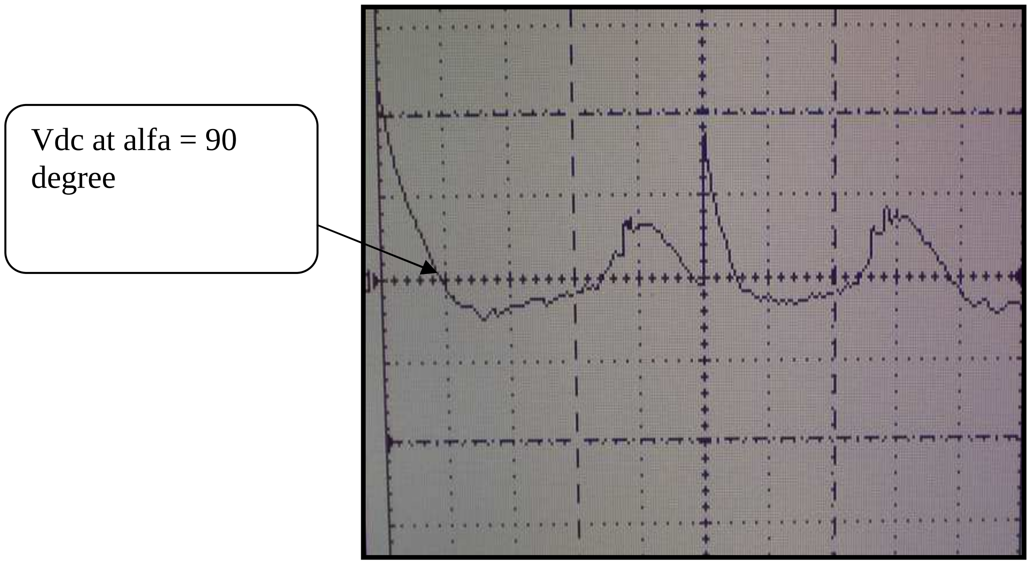

Figure 4.20 Waveform at alfa 90 degree

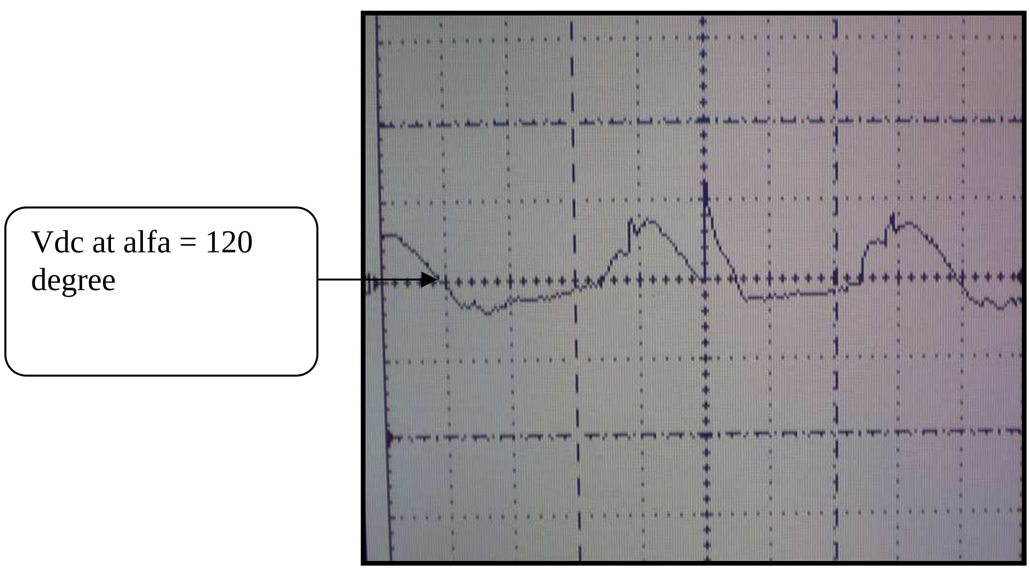

Figure 4.21 Waveform at alfa 120 degree

4.6 Comparison Result

In this project the comparison is about hand calculation, simulation result and practical measurement have been made to show the difference values of average voltages. Here, the data will be analyzed as shown in Table 4.1

Table 4.1 Comparison Results

Delay Angle	Delay Time	Hand Calculation	OrCAD Simulation
0˚	0.00ms	10.823 V	10.753 V
30˚	1.67ms	10.098 V	9.3919 V
60˚	3.33ms	8.117 V	8.0409 V
90˚	5.00ms	5.411 V	5.1104 V
120˚	6.67ms	2.705 V	2.3975 V
150˚	8.33ms	0.725 V	0.5554 V
180˚	10.00ms	0.000 V	79.128 mV

From table 4.1 above, note that, for different values of calculation, simulation and measurement, there are the difference in the delay angle. From an early observation, as expected that, in practical and design simulation, for a different setting of delay angle regardless of the input voltage, whether it is the same or not, the average voltage to be produced is rely on the delay time that has been set to the SCRs. From the table above, the practical values are quite big different with calculation and simulation. The measurements were taken by using a digital multimeter. This is because there is a problem in programming to set the delay time into the microcontroller.

4.6.1 Comparison for 3 Delay Angle

Table 4.2 Comparison Results For 3 Delay Angle

Delay Angle	**Delay Time**	**Hand Calculation**	**OrCAD Simulation**	**Hardware**
60˚	3.33ms	8.117 V	8.0409 V	6.17V
90˚	5.00ms	5.411 V	5.1104 V	5.09V
120˚	6.67ms	2.705 V	2.3975 V	1.89V

From the table 4.2 above , note that the value are compared for only three delay angle for this project. It is meet the minimum requirements to achieve the scope of the project which is to produce variable DC outputs. From the table 4.1 there are different for value of output using calculation, simulation and hardware. This is because due to the certain factors.

4.6.2 Graph For 3 Delay Angle

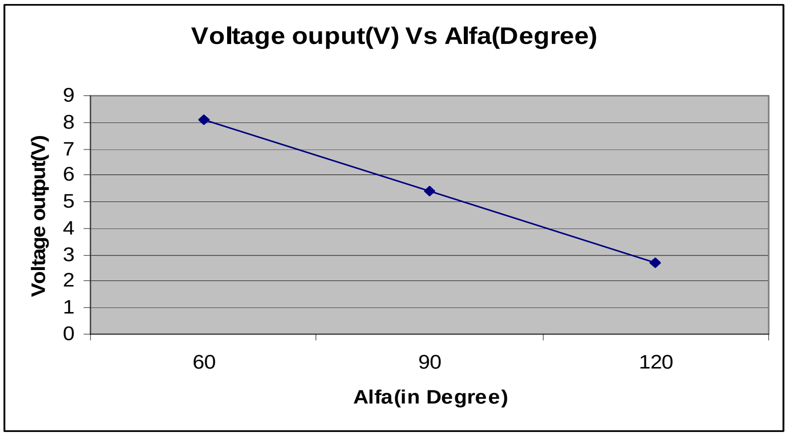

Figure 4.22 Graph for Theoretical

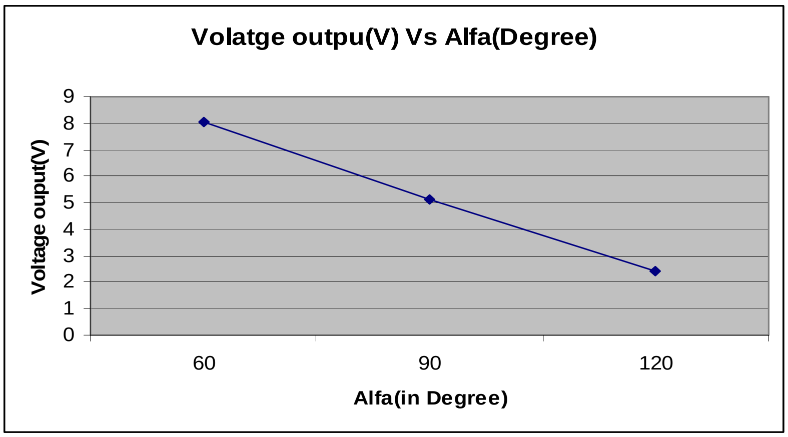

Figure 4.23 Graph for Simulation

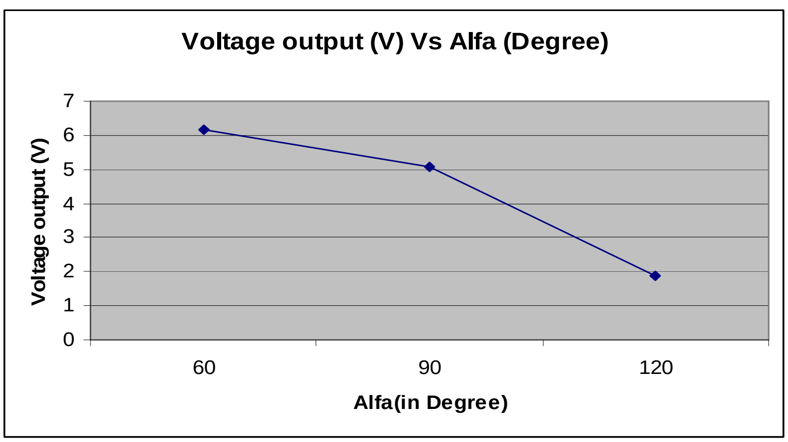

Figure 4.24 Graph for Hardware

From the figure 4.22 ,figure 4.23 and figure 4.24 , the gradient of curve of the graph is negative for all the graph .But there are 2 different gradient for hardware output , this is because due the problem occurred during the project is done. The problem can be categorized into 2 main factor:

The design of circuit

For this project the circuit design that used have a few problem , firstly the voltage drop in the circuit is big and cannot be avoid due to the use of solder .Secondly the filter circuit at the output is not design for this project resulting a flicker in output waveform.

Solution

Voltage drop can be reduce if using printed PCB board and study of software related is compulsory . The design of filter circuit is need to smooth the dc output with more analysis from literature review .

Concept of switching

The lack of knowledge about the concept of switching and firing angle is also the main problem for this project. The alfa is not firing as expected in this project resulting the output as shown in Table 4.2 .

Solution

To overcome this problem the project and firing gate must be test before implement it to the board because to make sure the firing gate is correctly .

4.7 Efficiency of the Project

Simulation Result

$$\text{Efficiency for alfa} = \frac{\text{Vcalculation- Vactual}}{\text{Vcalculation}} \times 100\%$$

For Alfa= 60 degree

$$\eta = \frac{8.117\text{ V} - 8.0409\text{V}}{8.117\text{ V}} \times 100\%$$

$$= 0.94\ \%$$

For Alfa= 90 degree

$$\eta = \frac{5.411\text{ V} - 5.1104\text{V}}{5.411\text{V}} \times 100\%$$

$$= 0.06\%$$

For Alfa= 120 degree

$$\eta = \frac{2.705\text{ V} - 2.3975\text{ V}}{2.705\text{V}} \times 100\%$$

$$= 0.11\ \%$$

Hardware Result

$$\text{Efficiency for Alfa} = \frac{\text{Vcalculation- Vactual}}{\text{Vcalculation}} \times 100\%$$

For alfa= 60 degree

$$\eta = \frac{8.117\text{ V} - 6.17\text{ V}}{8.117\text{ V}} \times 100\%$$

$$= 23.9\ \%$$

For alfa= 90 degree

$$\eta = \frac{5.411\text{ V} - 5.09\text{ V}}{5.411\text{V}} \times 100\%$$

$$= 0.06\ \%$$

For alfa= 120 degree

$$\eta = \frac{2.705\text{ V} - 1.89\text{ V}}{2.705\text{V}} \times 100\%$$

$$= 0.30\%$$

4.8 Software Development

Software development that involves the programming of microcontroller is the heart of this project where the variable output voltages can only be produced by controlling the delay angle of the SCR using the control circuit. As being discussed in previous chapter, the program had been implemented in this project to set the delay time of the SCR to produce variable speed of the DC motor. The program below shows that it used to adjust the delay angle of each SCR.

```
***************** INITIALIZE OSCILLATOR ***********************

DEFINE OSC 4
INCLUDE "bs1defs.bas"

***************** SCANNING SWITCHES *************************

switch3:    IF PORTB.4=0 THEN
            GOTO speed1
            ELSE
            GOTO switch2
            ENDIF

switch2:    IF PORTB.5=0 THEN
            GOTO speed2
            ELSE
            GOTO switch1
            ENDIF
```

```
switch1:    IF PORTB.6=0 THEN
            GOTO speed3
            ELSE
            GOTO switch3
            ENDIF

***************** SPEED PROGRAMMING *************************

    speed1:     LOW 8
                PULSOUT 8,1             ;time delay for 60 degree
                PAUSE 1
                LOW 9
                PULSOUT 9,1
                PAUSE 1


    speed2:     LOW 8
                PULSOUT 8,1             ;time delay for 90 degree
                PAUSE 8
                LOW 9
                PULSOUT 9,1
                PAUSE 8


    speed3:     LOW 8
                PULSOUT 8,20            ;time delay for 120 degree
                PAUSE 12
                LOW 9
                PULSOUT 9,20
                PAUSE 12
```

For the software development the explanations as below.

INITIALIZE OSCILLATOR

DEFINE OSC 4

By default, the PicBasic Pro Compiler generates programs intended to be run on a PICmicro MCU with a 4MHz crystal or ceramic resonator. Besides that , to make it compatible and initialize with the hardware so 4MHz clock is used in this project.

INCLUDE "bs1defs.bas"

There are no predefined user variables in PicBasic Pro. For compatibility sake, two files have been provided that create the standard variables used with the BASIC Stamps:

BS1DEFS.BAS and

BS2DEFS.BAS.

To use one of these files, add the line:

Include “bs1defs.bas”

or

Include “bs2defs.bas”

Near the top of the PicBasic Pro program. These files contain numerous VAR statements that create all of the BASIC Stamp variables and pin definitions. However, instead of using these “canned” files, we can create our own variables using names that are meaningful to us. The number of variables available depends on the amount of RAM on a particular device and the size of the variables and arrays. PBP reserves approximately 24 RAM locations for its own use. It may also create additional temporary variables for use in sorting out complex equations

SCANNING SWITCHES PROGRAM

Switch 3

If port 4 is zero or low ,next step the program will executed and run at speed 1 which is at 60 degree else scan for speed 2.

Switch 2

If port 5 is zero or low ,next step the program will executed and run at speed 2 which is at 90 degree else scan for speed 1.

Switch 1

If port 6 is zero or low ,next step the program will executed and run at speed 3 which is at 120 degree else scan for speed 3.

SPEED PROGRAMMING

PULSOUT Pin, Period

Generates a pulse on Pin of specified Period. The pulse is generated by toggling the pin twice, thus the initial state of the pin determines the polarity of the pulse. Pin is automatically made an output. Pin may be a constant, 0 - 15, or a variable that contains a number 0 - 15 (e.g. B0) or a pin name (e.g. PORTA.0).The resolution of PULSOUT is dependent upon the oscillator frequency. If a 4MHz oscillator is used, the Period of the generated pulse will be in 10us increments. If a 20MHz oscillator is used, Period will have a 2us resolution. Defining an OSC value has no effect on PULSOUT. The resolution always changes with the actual oscillator speed.

Send a pulse 1mSec long (at 4MHz) to Pin5

PULSOUT PORTB.5,100

Others explanation about pulsout

Pulsout

PULSOUT pin, time

Output a pulse.

Pin is a variable or constant that specifies the I/O pin to use.

This pin will be placed into output mode immediately before the pulse and left in that state after the instruction finishes.

Time is a variable or constant (0-65535) that specifies the duration of the pulse in µs.

Explanation

PULSOUT will generate a pulse on the specified pin for the given period.The pulse is generated by toggling the pin state twice. The initial state of the pin will determine the polarity of the pulse. The pin specified to generate the pulse is automatically made an output.

PULSOUT will generate a pulse with a period in 1 µs increments. The minimum pulse width is 4 µs. You can not go below this value.

Example

```
PULSOUT B0,1000          ;Generate a pulse for 1 millisecond long to B0
```

The small program below illustrates one use of the PULSOUT command:

```
Low B4              ;Preset Pin to LOW
main                ;this program will loop forever
pulsout B4,25000    ;Pulse pin High for 25 of a millisecond
pause 1000          ;Wait 1 second until repeating
goto main
end
```

This program will simply generate a infinite pulse on pin B4.So from this info about pulsout the speed programming can be understand easily.

4.9 Hardware Design

As being mentioned before in chapter 3.3, there are three types of circuit that has being constructed which are control circuit, power circuit and the interface circuit between the control and power circuit.

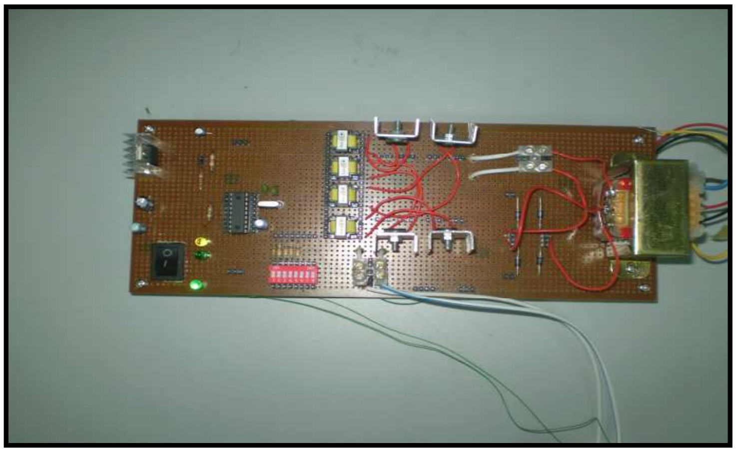

Figure 4.25 Controlled Rectifier For Variable Speed Single Phase DC Motor

The whole circuit that had been constructed in this project is shown in Figure 4.7 which includes the combination of the power processor converter and control circuit together with the pulse transformers circuit as interfacing. A single phase supply voltage is stepped down power transformer before connected to the power circuit and 12 VDC is supplied to the microcontroller circuit and will be regulated to be 5 VDC.

This project consists of three switches to make a control in a different speed. The DC motor will run after the SCRs are triggered on when the switch is pressed. At this point, the motor will start run in variable speeds depends on what switches are pushed. Full schematic circuit for a Single Phase Controlled Rectifier is in Appendix A.

4.10 Costing

Table 4.3 Cost of Components

NO.	Component	Specification	Price / unit	Quantity	Price
1	THYRISTOR (SCR)	TYN812	10.965	4	43.86
2	HEAT SINK		0.90	5	4.50
3	RESISTOR	100 Ω	0.06	1	0.06
4	MICROCONTROLLER	PIC16F84A	10.50	1	10.50
5	IC REGULATOR	7805	1.00	1	1.00
6	CRYSTAL	4MHz	1.30	1	1.30
7	RESISTOR	10M Ω	0.06	1	0.06
8	RESISTOR	10k Ω	0.06	4	0.24
9	CAPACITOR	22pF	0.08	2	0.16
10	CAPACITOR	1μF	0.08	2	0.16
11	CAPACITOR	100μF	0.15	1	0.15
12	CAPACITOR	4.7μF	0.07	1	0.07
13	PULSE TRANSFORMER	1:1	28.28	4	113.12
14	PCB BOARD		3.00	2	5.00
15	HEADER		0.50	5	2.50
16	IC BASE	18 PINS	0.20	1	0.20
17	IC BASE	20 PINS	0.19	1	0.20
18	POWER TRANSFORMER	20:1	15.00	1	15.00
19	WIRE WRAP		15.00	1	15.00
20	STAND		0.70	4	2.80
21	DC MOTOR		3.00	1	3.00
TOTAL PRICE					**RM 218.88**

Obviously, there are many components needed to design and complete this project. Table 4.3 above shows the overall cost and list of the components that has been used for this project. So, the total cost of this project is RM 218.88.

4.11 Potential of Commercialization

For the commercialization, this project is very potential to commercialize in the market because most electronics devices are sold in the stores that require fixed rectifier. Although, the size and weight of this project is large but the empty space in the circuit board can be minimized in the future. Due to the cost, this project maybe expensive than others in the market but it still has potential to commercialize. This project is very useful because it used widely in the industries and domestic equipment.

CHAPTER 5

CONCLUSION & FUTURE WORK

5.1 Summary of the Project

At the end this project the knowledge about uncontrolled and controlled rectifier circuits have been discussed in this thesis. An introduction to the theory of diode and thyristor conduction has been presented to explain the important operating characteristics of these devices. Rectifier topologies employing both diodes and thyristors and their relative advantages and disadvantages also have been discussed.

Previously, diode is classified as uncontrolled rectifier. Once the source and the load parameter are established, the DC level of the output and the power transferred to the load are fixed quantities although their usefulness is widely used. The goal of this project is to design a single phase controlled AC to DC converter. The output is controlled by adjusting the delay angle, α of each SCR, resulting in an output voltage which is adjustable over a limited range.

Through this project, the ability of the single phase controlled rectifier is converting AC voltage to DC voltage with variable output voltages. Fortunately, this project is achieved the objectives and scopes that has been set. This project able to convert the AC voltage to DC voltage with variable output voltages. However, the output voltages were not fully achieved with the simulation result because of the programming in the PIC. The knowledge about programming the PIC to control the delay angle, α of each SCR is not mastered enough. Therefore, the practical measurement is not equal to the theory or simulation values.

Nevertheless, at the end of this project, the single phase controlled rectifier had been explored and based on the theory and practical had shown enough that this project can drive 12V DC motor.

5.2 Future Recommendation

For the future plan of this project, it is recommended to other candidate to do more studies on the related information. There are maybe some modifications that can be taken to make this project to look more outrageous and flexible for the users.

The recommendation is suggested for future work as below:

i. There are indicators such as LCD or 7-segment can be replaced on the indicator to display voltage or current.
ii. There is a special feature in PIC microcontroller which is Power-down mode (sleep) that can place the controller circuit into low power mode.
iii. Resize the size of the design so it is reasonable, useful, compact and flexible for user can bring it anywhere they go.

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