Faculty of Electrical and Electronic Engineering Technology

DEVELOPMENT OF AC MOTOR SPEED CONTROLLER USING MICRO CONTROLLER – BASED CYCLOCONVERTER

NUR TASNIM BINTI JOHARI

Bachelor of Electrical Engineering Technology with Honours

2022

DEVELOPMENT OF AC MOTOR SPEED CONTROLLER USING MICRO CONTROLLER – BASED CYCLOCONVERTER

NUR TASNIM BINTI JOHARI

A project report submitted
in partial fulfillment of the requirements for the degree of
Bachelor of Electrical Engineering Technology with Honours

Faculty of Electrical and Electronic Engineering Technology

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2022

DECLARATION

I declare that this project report entitled "Development of AC Motor Speed Controller Using Micro Controller – Based Cycloconverter" is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : [signature]

Student Name : NUR TASNIM BINTI JOHARI

Date : 13 JANUARI 2023

APPROVAL

I hereby declare that I have checked this project report and in my opinion, this project report is adequate in terms of scope and quality for the award of the degree of Bachelor of Electrical Engineering Technology with Honours.

Signature :

Supervisor Name : DR MOHD BADRIL BIN NOR SHAH

Date : 13 JANUARI 2023

DEDICATION

This report is specially dedicated to all those who have supported, encouraged, challenged and inspired me and specially to my beloved family, honourable tutor and friends for all their guidance, love and attention which made it possible for me to make it up to this point.

ABSTRACT

In both the industrial and home sectors, the induction motor is the most extensively utilised machine. It is known as a constant-speed machine, and one of its key shortcomings is the difficulty of adjusting its speed with a cost-effective device. By synthesising the output waveform from parts of the AC supply without an intermediate DC link, a cycloconverter or cycloinverter converts a constant amplitude, constant frequency AC waveform to another AC waveform of a lower frequency. A cycloconverter-based speed controller is suitable to be used to control the speed of AC motor since it is low cost and low losses as compare to other type of speed controller. In this project, an AC motor speed controller developed using a microcontroller-based Cycloconverter circuit. The circuit consists of Arduino UNO microcontroller and SCRs that can change the frequency of AC voltage to the load. The circuit will be connected to a single phase AC motor to test the efficacy of the proposed gadget. It is found that the developed device can reduce the frequency of input AC voltage, subsequently can control the speed of AC motor.

ABSTRAK

Dalam kedua-dua sektor perindustrian dan rumah, motor aruhan adalah mesin yang paling banyak digunakan. Ia dikenali sebagai mesin berkelajuan malar, dan salah satu kelemahan utamanya ialah kesukaran melaraskan kelajuannya dengan peranti yang menjimatkan kos. Dengan mensintesis bentuk gelombang keluaran daripada bahagian bekalan AC tanpa pautan DC perantaraan, penukar siklon atau penukar sikloin menukar amplitud malar, bentuk gelombang AC frekuensi malar kepada bentuk gelombang AC lain dengan frekuensi yang lebih rendah. Pengawal kelajuan berasaskan cycloconverter sesuai digunakan untuk mengawal kelajuan motor AC kerana ia adalah kos rendah dan kerugian yang rendah berbanding dengan jenis pengawal kelajuan yang lain. Dalam projek ini, pengawal kelajuan motor AC dibangunkan menggunakan litar Cycloconverter berasaskan mikropengawal. Litar ini terdiri daripada mikropengawal Arduino UNO dan SCR yang boleh menukar frekuensi voltan AC kepada beban. Litar akan disambungkan kepada motor AC satu fasa untuk menguji keberkesanan gajet yang dicadangkan. Adalah didapati peranti yang dibangunkan ini boleh mengurangkan frekuensi voltan masukan AC, seterusnya boleh mengawal kelajuan motor AC.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my gratitude to my supervisor, Dr Mohd Badril Bin Nor Shah for his precious guidance, words of wisdom and patient throughout this project.

I am also indebted to Universiti Teknikal Malaysia Melaka (UTeM) for the financial support through to enables me to accomplish the project. Not forgetting my fellow colleague, for the willingness of sharing his thoughts and ideas regarding the project.

My highest appreciation goes to my parents, and family members for their love and prayer during the period of my study.

Finally, I would like to thank all the staffs at the Universiti Teknikal Malaysia Melaka (UTeM), fellow colleagues and classmates, the faculty members, as well as other individuals who are not listed here for being co-operative and helpful.

TABLE OF CONTENTS

PAGE

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

f	-	Frequency
ms	-	Milisecond

LIST OF ABBREVIATIONS

V	-	Voltage
T	-	Time
rpm	-	Revolutions per minute

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

The method of controlling the current in an induction motor to control the speed is known as induction motor speed control. Although induction motors are normally employed in fixed frequency applications, they are popular for variable frequency applications such as industrial drives and electric cars. There are several methods to control the speed of an induction motor. We use a cycloconverter to control the speed of an induction motor using PWM approaches, among other methods. Traditionally, semiconductor switches have been used to convert ac to ac in one of two ways:

1. In two stages (ac-dc and then dc-ac) as in dc link converters
2. In one stage (ac-ac) cycloconverters.

A cycloconverter is a device that converts alternating current (AC) power at one frequency into alternating current (AC) power at a lower frequency with no direct current (DC) stage in between. It may also be used as a static recurrence charger because it contains silicon-regulated rectifiers. Cycloconverters are utilised in large variable frequency drives with power ratings ranging from a few megawatts to tens of megawatts. They are often phase-controlled, and thyristors have been used in the past because of their simplicity of phase commutation.

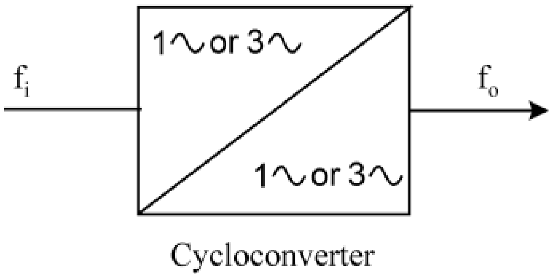


Figure 1.1 A cycolocnverter's Block Diagram

Other types of cycloconversion that use self-controlled switches are ac-ac matrix converters and high frequency ac-ac (hfac-ac) converters. However, these converters are not yet widely used.

The basic schematic diagram of cycloconverter is connectes to input 30 and 31 and for motor connection is between 25 and 26. Figure below show the basic schematic diagram.

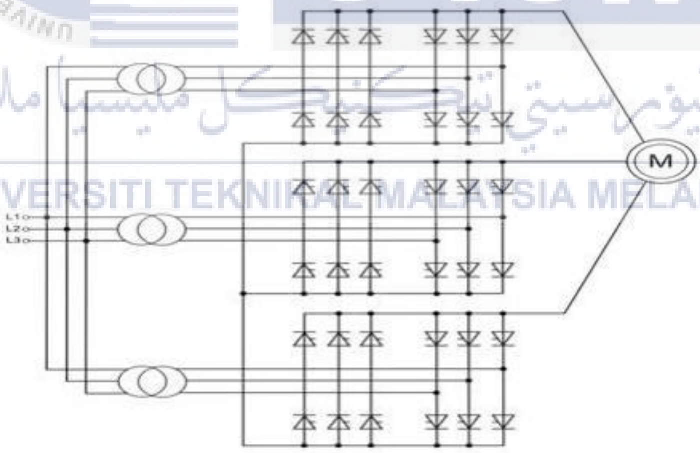


Figure 1.2 A Cycoloconverter's Basic Schematic Diagram

1.2 Problem Statement

Induction motor is a machine that is often used in various sectors especially the industrial sector. However, there are some drawbacks or disadvantages to be encountered when using or controlling induction motors. Among them is that the user will experience difficulty of difficulty to change especially during low-speed operation. Furthermore, the cost used for other types of speed controllers is also quite expensive as compared to using a cycloconverter. In addition to that, speed control of AC motor using cycloconverter is more efficient as compared to phase control angle or inverter technique.

1.3 Project Objective

The primary purpose of this research is to provide a way for controlling the speed of an AC motor using a microcontroller-based cycloconverter. The following are the specific objectives:

a) To design AC motor speed controller using a microcontroller - based Cycloconverter circuit.

b) To develop a hardware prototype of the designed cycloconverter circuit to verify the efficiency of the designed circuit.

1.4 Scope of Project

The explanation of the scopes in this project are consist of circuit design, program develop, software develops and hardware:

a) Type of Motor

A single-phase induction motor will be used in this project since it is widely used in many appliances such as fan, washing machine, air conditioning, to name a few.

b) Circuit Design

The fundamental theory of the cycloconverter will be used to design a circuit that consists of Arduino UNO microcontroller and SCRs that can change the frequency of AC voltage to the load.

c) Microcontroller Programming

To program algorithm for Arduino microcontroller in Arduino IDE Software to enable the speed control of AC motor using cycloconverter circuit.

d) Simulation

The developed circuit will be virtually simulated using proteus software.

e) Hardware

A prototype of the cycloconverter circuit designed combined with an Arduino microcontroller and another interfacing device will be developed in this project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

To convert alternating current to mechanical power should use AC motor. This is called the electromagnetic induction phenomenon. there are two important components of an AC motor, namely the stator and the motor. The stator is the motor's stationary component, while the rotor is the motor's revolving component. Single-phase or three-phase AC motors are available.

In industrial, three-phase AC motors are utilised to transform bulk power from electrical to mechanical. For low-power conversion, single phase AC motors are typically employed. The single-phase AC motor is a small motor that can be used in a range of contexts, including the house, office, enterprise, factories, and other places. Refrigerators, fans, washing machines, hair dryers, mixers, and other household appliances all use single phase AC motors [1]

The AC motor is divided into two categories. The synchronous and induction motors are the two types.

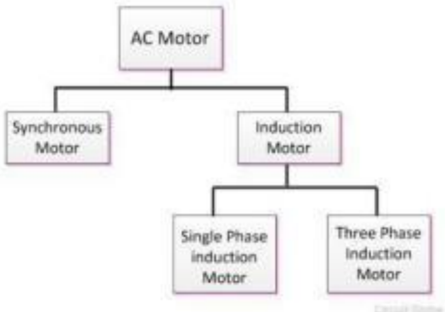


Figure 2.1 Type of AC Motor

2.2 Operation of AC Motor

The stator, or fixed outer drum, and the rotor, or revolving inner section coupled to the motor shaft, are the two primary components of an AC motorThe stator and rotor are surrounded by magnetic fields. The stator, which generates the rotating field, is wound with alternating current [2]

In an AC motor, the armature and field windings are combined. When an AC supply flux is linked to the stator, an air gap is created, which causes the flux to cycle at a fixed synchronous speed, resulting in voltages in the stator and rotor windings.

Single phase, three phase, braking, synchronous, asynchronous, customised two speed, and three speed single phase AC motors are all examples of this type of motor. The differentiation between the various categories is made depending on the job that must be done. Some AC motors are simple and designed for small jobs, while others are more complex and designed for larger, more demanding applications. The phase of the electrical feed differs for residential and industrial use, which is a significant distinction [2]

Residential power is either single or double phased, whereas industrial electricity is three phased. This divergence is responsible for the distinction between industrial and household AC motors [2]. Induction motors are a type of ac motor that uses electric current to generate torque, which is generated via electromagnetic induction from the magnetic field of the stator.

Figure 2.2 AC Motor

2.2.1 Star Up

An AC motor may be began with the aid of a simple on and stale switch, which can be a contactor or manual starter. A contactor allows the manage of toggle energy to an AC motor. Manual starters have a manual transfer that permits the operator to switch or change the power. This type of starting is known as a cross-road starter because it puts the engine under rapid stress from the power source. It links the motor's contacts directly to the entire voltage supply, which is usually six to eight times the rated current [2].

To reduce the value of the voltage supply during starting, a biting delta starter is used as the starter. The stator is connected in a star configuration, which switches to a delta configuration as soon as the motor reaches a certain speed. Thus, the line current drawn at the beginning is reduced.

A delta starting and an auto transformer starter both use the same mechanism. Again, the initial modern-day is constrained by the use of lower voltage in the stator. The torque and cutting-edge of a car transformer starter can be modified using the optimum tapping [2].

Through the slip rings and brushes, a rotor impedance starter is directly attached to the rotor. The rotor resistance is initially set to its maximum, but as the motor speed increases, it steadily declines. A rotor impedance starter is large and costly [2]

Soft starters are a more advanced type that provides for acceleration and deceleration control, as well as smooth and consistent motor stopping and starting, which is not possible with across-the-line variations [2]. The reduction of the wear on the motor and which device are connected is one of the advantages of soft starters.

2.2.2 Stator

The stator is one of the important parts in a motor. a three -phase supply is produced due to a rotating magnetic field. This is the main function of the stator. Electromagnetic energy is induced if the stator is stationary, this is called the phenomenon of electromagnetic induction.

The stator produces a rotating magnetic subject. It has a strong steel axle, a loop of cord, coils, squirrel cage, and interconnections. Though a squirrel cage is not located in all AC cars, it is the most not unusual type. In AC automobiles, strength is sent immediately to the outer coils of the stator. The stator has a couple of plates that enlarge out from its center with copper magnetic wire [2].

It has three phase windings, a core, and a housing for a three phase AC motor. The windings are 120 degrees apart and might be six or twelve. The coils are wrapped around a core of laminated iron. The creation of the core is shown in the diagram below.

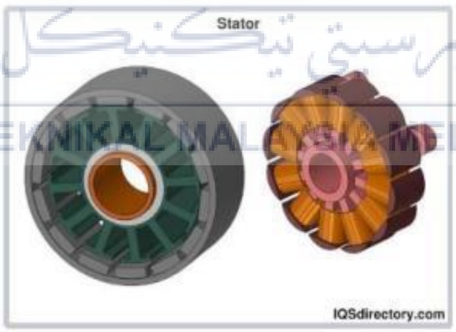


Figure 2.3 Stator

2.2.3 Rotor

A component of an electromagnetic system that rotates in an electric motor, electric generator or alternator is known as a rotor. The interaction between the winding and the magnetic field causes the rotor to rotate, producing torque around the rotor axis. The are two version of rotor in three phase induction motor, which is squirrel cage and wound version.

The squirrel cage motor is called because the output shaft is connected to a component in the rotor that looks like a cage. A rotor bar connects the two round -shaped ends. It hardens electromagnetism in order to induce movement [3]. Its actions are determined by the stator's EMF. The outside housing, which is comprised of laminated metal sheets and wire coiling, also generates EMF [3]Motors and rotors are essential components of any motor. The squirrel cage is a simple device that can be used to create electromagnetic induction. A 4-pole squirrel cage induction motor [3] is shown below.

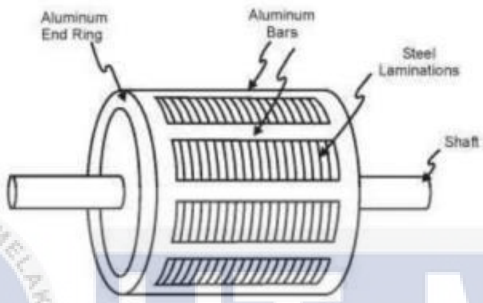


Figure 2.4 Squirrel Cage Motor Diagram

The rotating magnetic field in space is influenced by the windings of the stator given a three -phase supply. The synchronous speed is the rotational speed of this rotating magnetic field. The rotor bars are subjected to a spinning magnetic field, which produces voltage and causes short-circuit currents to flow. These rotor currents generate a magnetic field of their own, which interacts with the stator field. The rotor field will now try to counteract its cause, and the rotor will begin to follow the spinning magnetic field [4].

The value of the scattering current becomes zero when the rotor holds a magnetic field. This is because the relative movement between the purified magnetic field and the rotor has stopped. The tangent force becomes zero at that point and the rotor experiences deceleration.

The relative motion between the rotor and the rotating magnetic field reestablishes once the rotor decelerates, causing rotor current to be produced once more. As a result, the tangential force for rotor rotation is restored, and the rotor begins to follow the rotating magnetic field once more, maintaining a constant speed just below the synchronous speed of the spinning magnetic field. Slip is a degree of the distinction between the speed of the rotating magnetic subject and rotor pace. The frequency of the rotor current = slip × supply frequency [4].

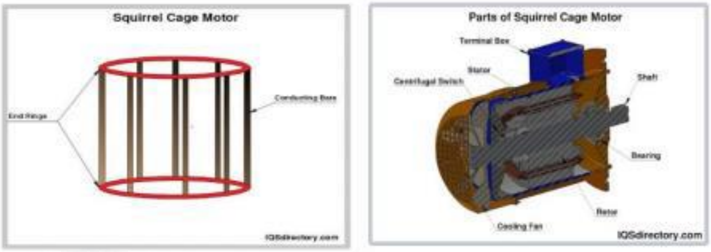


Figure 2.5 Squirrel Cage Motor

Slip ring rotor is another term for a wound rotor motor. A wound rotor motor is an induction motor with rotor windings connected to an external resistance by a slip ring. It is to control the motor's speed or torque characteristics by adjusting the resistance.

The stator will continuously work with the engine rotor twisted to work. The rotor windings are associated with an auxiliary circuit containing a slip ring, a brush, and an outside resistor, and are controlled by a different three - stage AC current [5]. Because of the outside opposition offered to the auxiliary circuit when it was first started, the rotor current reduces the stator's RMF strength (it runs more "in stage" with the RMF rotor). This demonstrates that the inside rotational speed is controlled simply by changing the obstruction. To keep that speed under control, the engine must reach a speed of 100 percent. The administrator can now select the starting force and run attributes. This outcomes in a smooth beginning up, high starting force, low introductory current, and the capacity to change rotational speed, which can't be accomplished with less complex plans, for example, the squirrel confine engines (more data on this plan can be found in our article on squirrel confine engines) [5].

Figure 2.6 Wound Rotor Motor

2.3 Type of AC Motor

AC motor also knows as induction motor. Mean function of AC motor is convert alternating current into mechanical energy. There are a few types of AC motor. For example, is single phase AC motor, polyphase AC motor, synchronous AC motor and etc.

2.3.1 Single Phase AC Motor

Figure 2.7 Single Phase AC Motor

The single - stage supply utilizes a solitary - stage AC engine. This sort of cooling engine is more modest and less expensive. Partial kilowatt limit is utilized to assemble this AC engine. The stator is initiated by a solitary stage AC power supply. It has primary windings and helper windings. The winding is opposite to the primary winding. The rotor turns as indicated by the amount of two oppositely pivoting fields, which is the two-fold rotating field hypothesis. The force that is delivered is equivalent and inverse [2].

2.3.2 Polyphase AC Motor

Figure 2.8 Polyphase AC Motor

Polyphase motors, also known as many phase motors, are a type of AC motor with two or three phases that work similarly to single-phase motors. Because the stator poles of the polyphase stator are not parallel to each other, the rotor passes the stationary pole at different times. The phase difference between adjacent electromagnetic fields (EMF) in a polyphase system with the same group of voltages at the same frequency is the same [2].

A polyphase system can have two, three, or six phases, with three being the most common. A polyphase system is usually referred to as a three-phase system. Its output will be 1.5 times that of a single-phase system. A polyphase system's current is constant, unlike a pulsed single-phase system.

2.3.3 Synchronous AC Motor

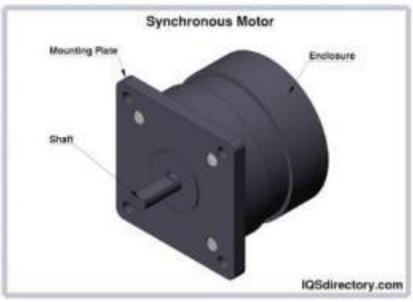


Figure 2.9 Synchoronous ac Motor

The properties of a synchronous AC motor are that the shaft rotates at the same frequency as the current supply and that the period of rotation is equal to the integral number of the AC cycle. The motor generates electromotive force while maintaining a constant speed. The speed of a synchronous motor is unaffected by the load, and load fluctuations have no effect on the motor's speed.

2.4 Method of Speed Controller

AC motors employ alternating current to generate a wide variety of mechanical output power. The mechanical output power ranges from fractional horsepower to hundreds of kW. This is the most common type of electric motor. This is due to the design and operation being relatively basic. It has a wide range of applications. Although it offers numerous benefits, it also necessitates some control. The motor AC controller is the control in question. This motor's AC controller assists in electrically controlling the machine's speed of operation. Its variable output enables for exact control of the motor speed, which is difficult with other AC motors [16].

2.4.1 Cycloconverter

One approach for controlling the AC speed of the motor is to utilise a cycloconverter to control the induction motor speed. This strategy makes the process easier and more cost-effective. However, multiple ways of managing motor performance are used in the functioning of this cycloconverter. The motor speed can be modified in two ways, according to the formula Ns = 120f/p. The first method is to alter the number of poles, while the second is to alter the frequency. The first method, on the other hand, is inefficient because the number of poles cannot be changed while the machine is running, and the machine will be large. On the other hand, the second technique is capable of resolving all of these concerns.

This technology allows the frequency to be altered while the machine is running without affecting the motor size. In this method, a frequency converting device, such as a cycloconverter, is used.

The cycloconverter's primary function is to convert a constant frequency AC power to an adjustable frequency AC power without the use of a DC link [15]. This is the simplest, most practical, and cost-effective way. A cycloconverter is used to adjust the supply frequency and thus the speed of the numerous induction motors.

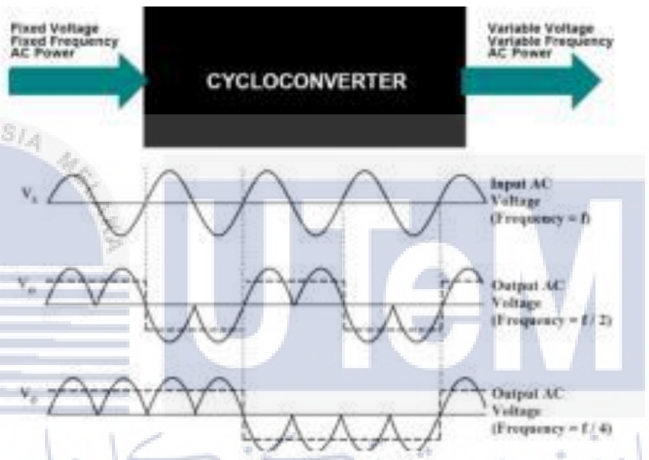


Figure 2.10 Cycolonverter

2.4.2 Phase Angle

The phase angle is the difference between the AC current and voltage at the observed impedance (50kHz). The phase angle is calculated using the formula: = arctg X/R. Resistance reflects the body's water or fluid, while reactance reflects the body's cell mass. As a result, the Phase Angle is affected by fluid and muscle mass.

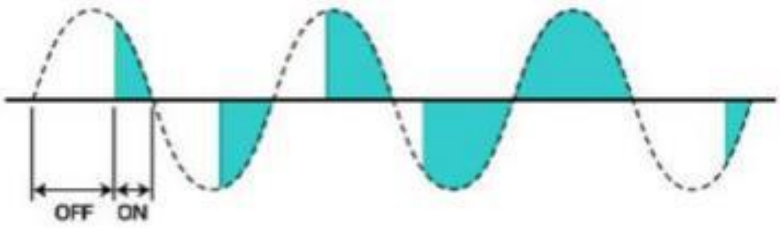


Figure 2.11 Phase Angle

The result voltage is controlled to set off SCR T1 and T2 in this stage point control strategy. By changing the point shots the rms worth of the result voltage is differed [8]. When the sine wave design changes, harmonics are given in the framework and impact the percent THD to increase. The expression for rms value of output voltage for resistive load is given by:

$$Vo\ (rms) = Vs\sqrt{\frac{(\pi - \alpha) + (sin2\alpha)/2}{\pi}} \ldots$$

Where, $Vs = \frac{Vm}{\sqrt{2}} = RMS$ Value of input supply voltage

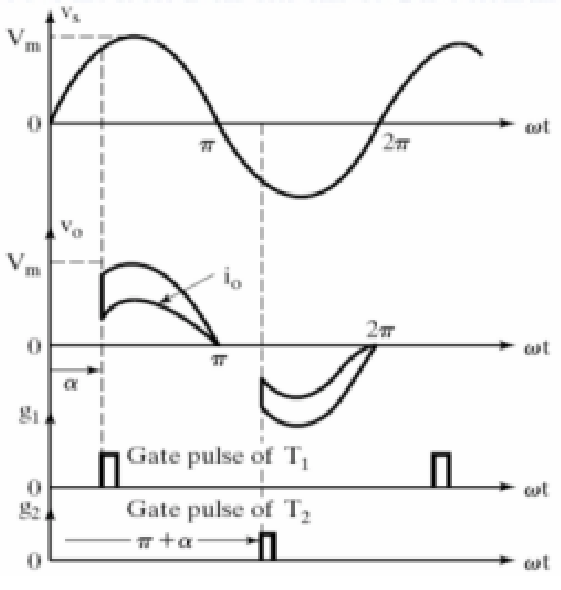


Figure 2.12 Input and Output Waveform

The upside of this strategy is the heap voltage variety is smooth however since the example of the info waveform is changed sounds will be presented in the framework.

2.4.3 Inveter

A frequency control inverter is used to control the rotational speed of the AC motor. In the absence of this converter, the AC motor runs at full speed. When opposed to motors that run at a constant speed, using an inverter to alter the speed and acceleration of an AC motor expands the motor's range of application. The number of rotations per minute is commonly used to measure motor speed (rpm). The change in speed over a certain amount of time is the acceleration rate.

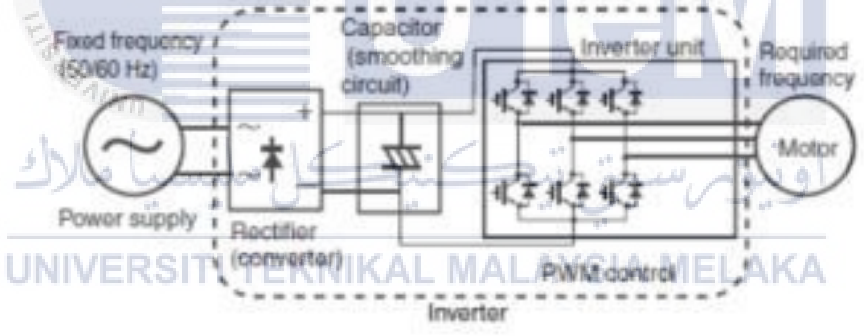


Figure 2.13 Inveter

Basically, there are three techniques by which the voltage can be controlled in an inverter. They are,

a) External Control of AC Output Voltage
b) External Control of DC Input Voltage
c) Internal control of Inverter

2.4.3.1 External Control of AC Output Voltage

In this technique of control, an ac voltage controller must be installed at the inverter's output to acquire the needed ac output voltage.

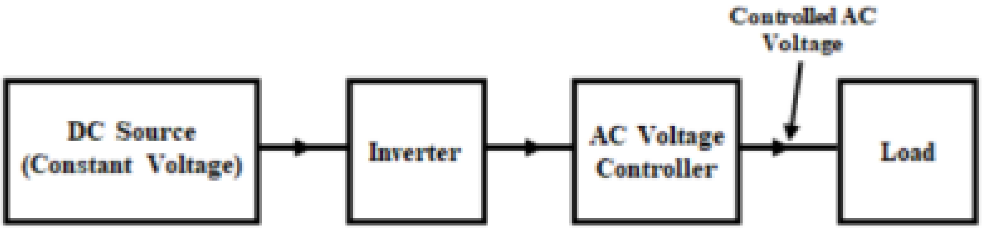


Figure 2.14 External Control of AC Output Voltage

Voltage control can be performed by adjusting the flame angle of the ac voltage controller that feeds the ac voltage. When the output voltage from the controller is low, there is a lot of harmonic content in this method [18]. This approach is only suitable for low-power applications.

2.4.3.2 External Control of AC Input Voltage

External control of the dc input voltage is a good technique to utilise to get the desired ac output voltage on the load side. Based on the type of source, this approach is classified into two types.

a) When Source is a Constant AC Voltage Source:

   The source's continuous ac voltage is rectified before being transmitted to the inverter. The input ac voltage can be corrected with the use of a controlled rectifier, an uncontrolled rectifier, or an ac voltage controller.

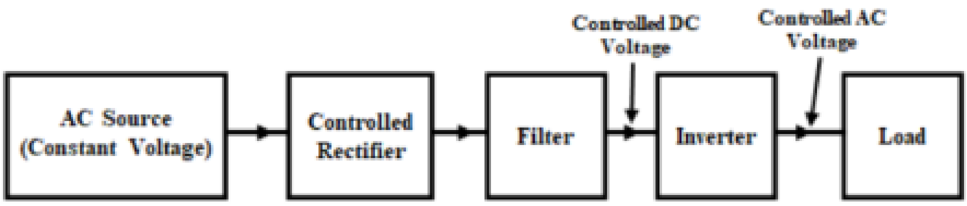


Figure 2.15 Using Controlled Rectifier

This technology made use of fully regulated rectifiers. The constant ac voltage from the source is fed into a controlled rectifier with a variable ignition angle to achieve the desired output voltage [18]. To obtain the controlled ac voltage, the controlled dc voltage acquired from the output of the controlled rectifier is routed to the inverter

b) When Source is a Constant DC Voltage Source:

When the available input voltage source is dc, a chopper can be used to control the inverter's input voltage. The constant DC type block diagram for managing the inverter's output voltage while the input voltage is constant is illustrated below.

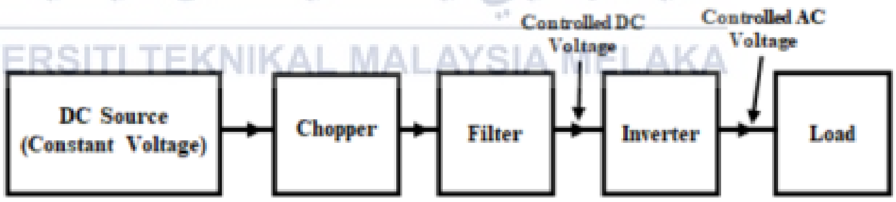


Figure 2.16 With Constant DC Voltage Source

The above-mentioned voltage control methods can be used in practise, but they require additional filters to eliminate dc voltage ripple, which increases the inverter's cost and weight. Furthermore, because of the increased power stages, the following approaches reduce the overall efficiency of the equipment [18].

2.5 Microcontroller

Compact integrated circuit microcontrollers are designed to control specific functions in embedded systems. On a single chip, microcontrollers combine a processor, memory, and input/output (I/O) devices. Vehicles, robots, office equipment, and other gadgets frequently use microcontroller units. It's essentially a little personal computer (PC) without a complicated front-end operating system for controlling the small characteristics of larger components (OS).

2.5.1 Arduino

Arduino is an open-source electronics platform that is easy to use, both in terms of the software and the hardware. An integrated programming system consisting of a programmable Arduino circuit board that runs on the user's computer is being developed. The integrated development environment (IDE) program is used for authoring and converting to circuit board machine code. The Arduino IDE makes use of a straightforward version of C++ and its straightforward, programmable environment. A microcontroller with an open package is also provided by Arduino, in addition to other features. Then, Arduino simplifies the process of working with microcontrollers and provides various advantages over other low-cost, open-source, and expandable hardware and software systems, as well as other open-source, and expandable software systems.

An excessive number of Arduino displays, which are extensively used in the business, are left unlocked. Programmer for Arduino, Arduino AT Mega 2560, Arduino UNO, Arduino NANO, and other Arduino-compatible boards. Take, for example, As a result of the fact that Arduino UNO is ready for use, this table is the most effective method to get started studying, and it is also the most popular of the Arduino microcontrollers. The Arduino Uno serves as a microcontroller board for the AT Mega328. The Arduino UNO has 14 digital input/output ports, six of which may be used as PWM outputs, making it a versatile 7 board.

In addition to the six analog inputs, there is a USB interface, a ceramic resonator operating at 16MHz, an ICSP header and a power connector. It is not necessary for Arduino UNO to make use of a USB-to-serial interface chip. In place of this, the AT Mega is employed as a USB to serial converter.

Arduino UNO is a board that is widely used for educational purposes and is readily accessible for purchase. This is due to the fact that there is no soldering or specific connections required on the breadboard circuit design. It has also been used to create designs for innovations and automated control equipment. The Arduino UNO's fundamental needs are listed in Table 2.1.

Table 2.1 Arduino UNO Specification

Parameter	Value
Microcontroller	ATMega328
Operating Voltage	5V
Supply Voltage	7-12V
Maximum Supply Voltage (not recommended)	20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40mA
DC Current for 3.3V Pin	50mA
Flash Memory	32 KB of which 0.5KB used by bootloader
EEPROM	1 KB (ATmega328)
SRAM	2 KB (Atmega328)
DC Current per I/O Pin	40mA

2.6 Cycloconverter

Cycloconverters are frequency converters that convert AC power of a certain frequency and voltage to AC power of a different frequency and voltage without the use of a DC connection. It is made up of two back-to-back coupled rectifiers, with the positive converter (P type) carrying positive currents and the negative converter (N type) carrying negative currents. Electric traction applications frequently use this type of cycloconverter. P and N converter types, like single-phase cycloconverters, conduct positive and negative currents, respectively. This type of cycloconverter is commonly used to drive huge motors.

Figure 2.17 Single Phase Output Cycoloconveter

2.6.1 Cycloconverter Basic Schematic

The cycloconverter is associated with input somewhere in the range of 30 and 31 as displayed underneath. The engine is associated between 25& 26. Depending upon the triggering pulses fed to a set of 8 SCRs between their gate and cathode we get F or F/2 or F/3 [3].

2.6.2 Principles of Cycloconverters

There are three different types of cycloconverters, although their function and operation are nearly identical. These three types of cycloconverters are distinguished by the number of electronic power switches contained in a circuit. A single phase to a single phase CCV, for example, will have just six power electronic switches (SCRs), whereas a three phase CCV might have up to 32 switches [13].

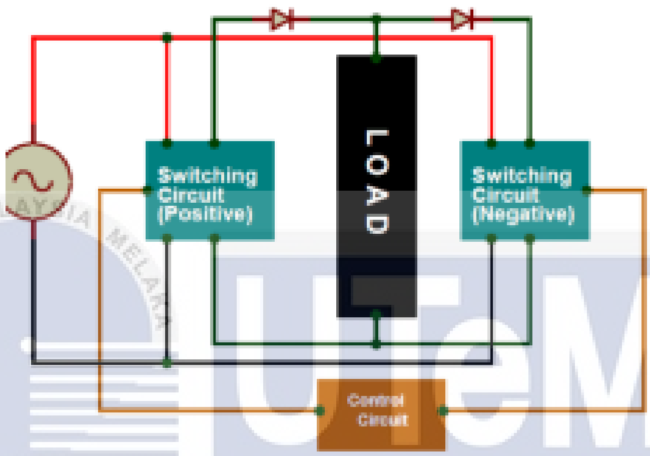


Figure 2.18 The bare minimum for a Cycoloconverter

The cycloconverter features switching on both sides of the load, as seen in the diagram above. The first circuit will operate during the AC power source's positive half cycle, while the second will operate during the negative half cycle. In these switching circuits, SCRs are widely used. SCR will be replaced with IGBT or MOSFET in modern CCV.

To complete the switching circuit, a control circuit is necessary. This control liter's job is to tell the power electrical gadget when to move and when to stop. This control circuit is frequently used as a microcontroller. It also has feedback from the output, resulting in a closed loop system [4]. The frequency value can be adjusted by modifying the circuit's parameters. The diode in the diagram above serves to illustrate the direction of current flow.

A positive switching circuit always feeds current into the load, while a negative switching circuit always drains current [4].

2.7 Previous Related Work of Cycloconverter

There are a few related works has been done on speed control of AC motor using cycloconverter technique as summarize in Table 2.1.

Table 2.2 Summary of Previous Work of Cycoloconverter

No	Authors	Tittle	Applications	Remark
1.	Ayebatonye Marttyns Epemu, Kingsley Okeoghene Enalume [1]	Speed Control of a Single Phase Induction Motor Using Step-down Cycloconverter	• The use of cycloconverters to vary the speed of single phase induction motors. Cycloconverters work on changing the supply frequency to vary the speed of the motor.	• The designed single phase to single phase step down cycloconverter was capable of producing output at frequencies lower than the supply frequency. When the relevant switch was selected, it successfully generated output frequency at F/2 and

				F/3. A single phase induction motor's speed could be varied effectively using a cycloconverter.
2.	Sathish Bakanagari, Jagadeesh Peddapudi, A. Mahesh Kumar [2]	A Novel Approch to Speed Control of Induction Motor by Cycloconverter with Thyristors	• Control The cycloconverter is a device that converts one form of energy into another. • converts input AC power at a single frequency to output AC power at a different frequency. With a one-stage conversion, AC power can be converted to a different frequency. A phase control approach is used to convert the frequencies.the speed of a single phase induction motor in	• The cycloconverter is a device that converts one form of energy into another. • converts input AC power at a single frequency to output AC power at a different frequency. With a one-stage conversion, AC power can be converted to a different frequency. A phase control

			three steps by using cycloconvertor technique by thyristors. • uses a thyristor controlled cyclo converter which enables the control	approach is used to convert the frequencies.
3.	Bhagawati Patil, Rushali Aute, Pramila Mhaske, Nitin Patil [3]	Cycloconverter to control speed of induction motor	• Control the speed of induction motor using PWM technique.	• Because the frequency of the AC supply cannot be adjusted, this project employs a MOSFET to drive the induction motor and control its speed using the PWM method. • Cycloconverters are used for single phase motors to generate torque that matches the demand torque of a

				specific machine through the use of a specially designed Cycloconverter.
4.	Rajib Baran Roy, Md. Ruhul Amin [4]	design and Construction of Single Phase Cycloconverter	• Design and construct a single phase cyclo-converter circuit which could generate variable frequency. The proper generation of the blanking and gate pulses of the switching devices and synchronizing them with the input signal is the most important • thing in designing a cyclo-converter circuit which becomes easier due to the availability of the integrated circuit (IC).	• The cyclo-converter is generally used for the speed control of motors, constant frequency power supplies, controllable reactive power supply for an ac system and induction heating system, VSCF (variable frequency input and constant frequency output) generation which is used in aircraft power

				suppliers, mobile power supplies and space vehicles.
5.	Nawale Tejashree L, Thorat Pranali R [5]	Design and Implementation of Cycloconverter	• To control the speed of an induction motor in three steps by using cycloconverter technique.	• The cycloconverter is a one-stage converter that converts input AC power at one frequency to output AC power at a different frequency
6.	P. R. Lole, K. D. Adhav,S. D. Gholap, S. R. Karkade, P. G. Medewar [6]	Speed Control of Induction Motor by Using Cyclo-converter	• To control the speed of the induction motor. The speed control of Induction Motor is simple and can be made economical by using different methods to control the operation of Cyclo-converter which in turn controls the performance of motor	• There are two ways to change the motor's speed: one is to change the number of poles, and the other is to change the frequency.

7.	S. V. Thigale, S. H. Tamhane, A. B.Bhapkar, Prof. D. R.Godase [7]	Speed control of Induction motor using Cycloconverter with thyristor	• How to control the speed of Induction motor in three steps by using AC to AC conversion i.e cycloconverter with the help of thyristors. And these three steps are F, F/2,and F/3	• The main problem of an induction motor is that changing its speed using other devices such as a VFD (variable frequency drive) is very expensive; however, we may remove this disadvantage by utilising a cycloconverter.
8.	Richa Gajbhiye, Rupali Malghati, Rupali Wadandre, Shalini Meshram, Shivani Wanker [8]	Speed Control of Induction Motor Using Single Phase Cycloconverter	• To control the speed of single-phase induction motor in three steps by using cycloconverter technique by thyristor.	• A cycloconverter has the ability to alter the output voltage and frequency in a continuous and independent manner.

9.	Tariqul Islam, Hady H. Fayek, Eugen Rusu, and Fayzur Rahman [9]	Triac Based Novel Single Phase Step-Down Cycloconverter with Reduced THDs for Variable Speed Applications	• A novel step-down Triac based cycloconverter for variable speed control applications.	• Because of its reduced size and components, the cycloconverter is a potential future replacement for the VFD.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The progress of software development is detailed in this chapter, which includes the design of software circuits, installation components, component testing, and a demonstration of the cycloconverter operation. The flow diagram method, as shown in Figure 3.1, is implemented separately and in accordance with the draft plan.

3.2 Methodology

The methodology flow chart for this project is shown in Figure 3.1. The following section will go over each step of the methodology in detail.

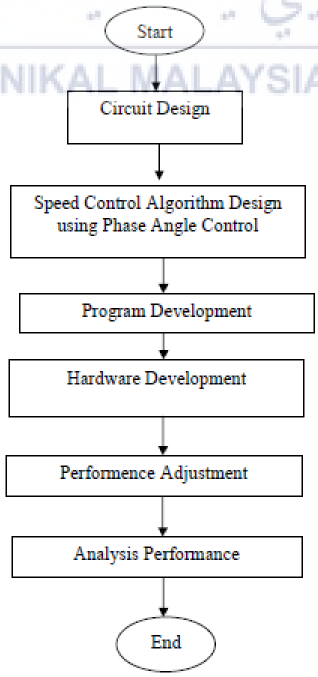


Figure 3.1 Flowchart of methology for the project

3.2.1 Circuit Design

The circuit design is required to refer to the hardware installation's connection. The circuit diagram for the overall project connection is shown in figure 3.2. Proteus 8 professional Software is used to generate the circuit connection for the circuit design. The circuit is designed to create a AC power supply by using a microcontroller as the primary component. Supply 240 V step down to 12 V. To control the four frequencies, four switches are needed. And the load is AC fan. The proposed circuit is divided into several parts, which are as follows:

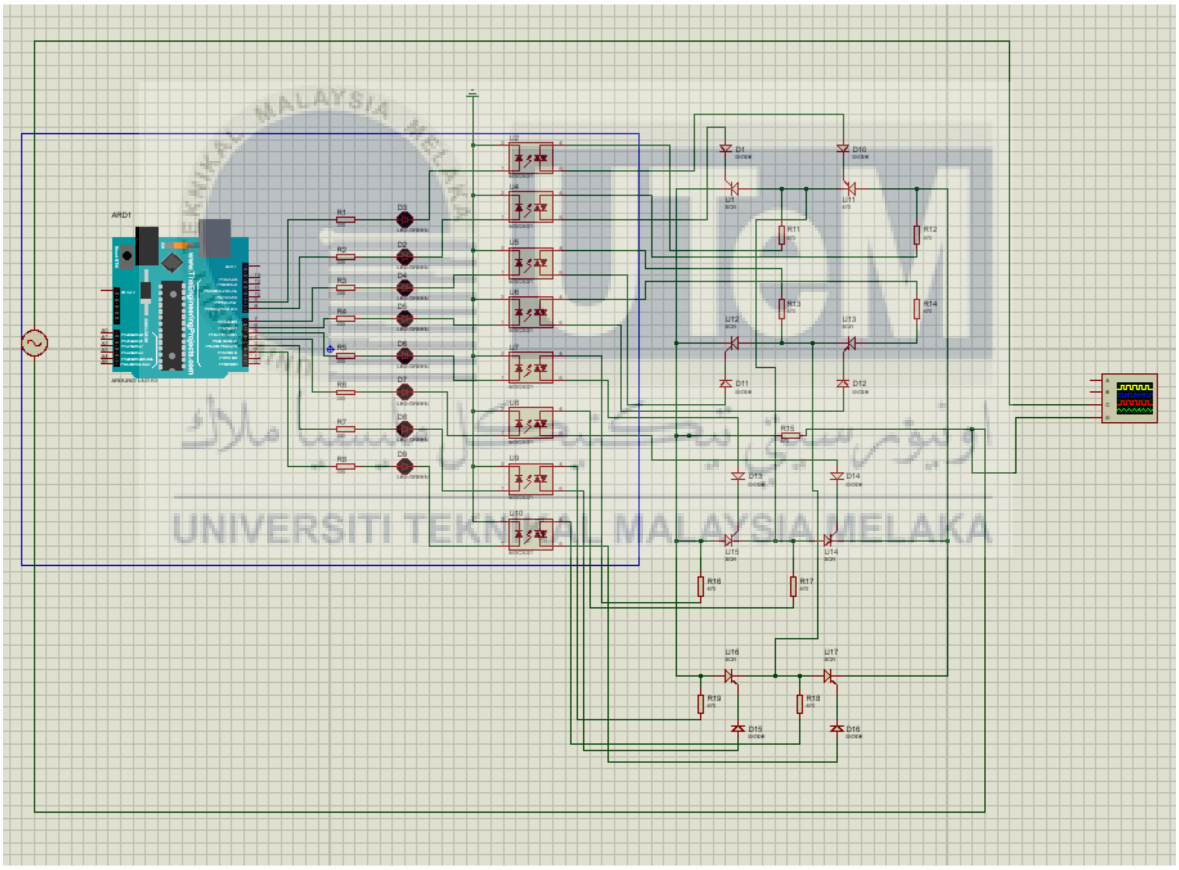


Figure 3.2 Circuit Design

3.2.2 Speed Control Algorithm Design using Phase Angle Control

The simplest way to control the speed of a universal motor is to use this method. The TRIAC's firing angle is adjusted to control speed. Although phase angle control is a low-cost solution, it is inefficient and susceptible to EMI.

3.2.3 Program Development

The microcontroller will be programmed to allow the operation of a specially designed circuit.

3.2.4 Hardware Development

To realize the design of variable power supply, a hardware prototype will be developed based on and Arduino microcontroller.

3.2.5 Performance Adjustment

To verify the efficacy of the developed device, the circuit will be connected to single phase AC motor.

3.2.6 Analysis Performance

The developed device's output will be measured by connecting it to a variety of single phase AC motor. The real-time results will be analyzed to ensure that the established device is efficient.

3.2.7 Project Architecture

Figure 3.3 shows the block diagram of step down cycloconverter in this the arduino microcontroller to be used.

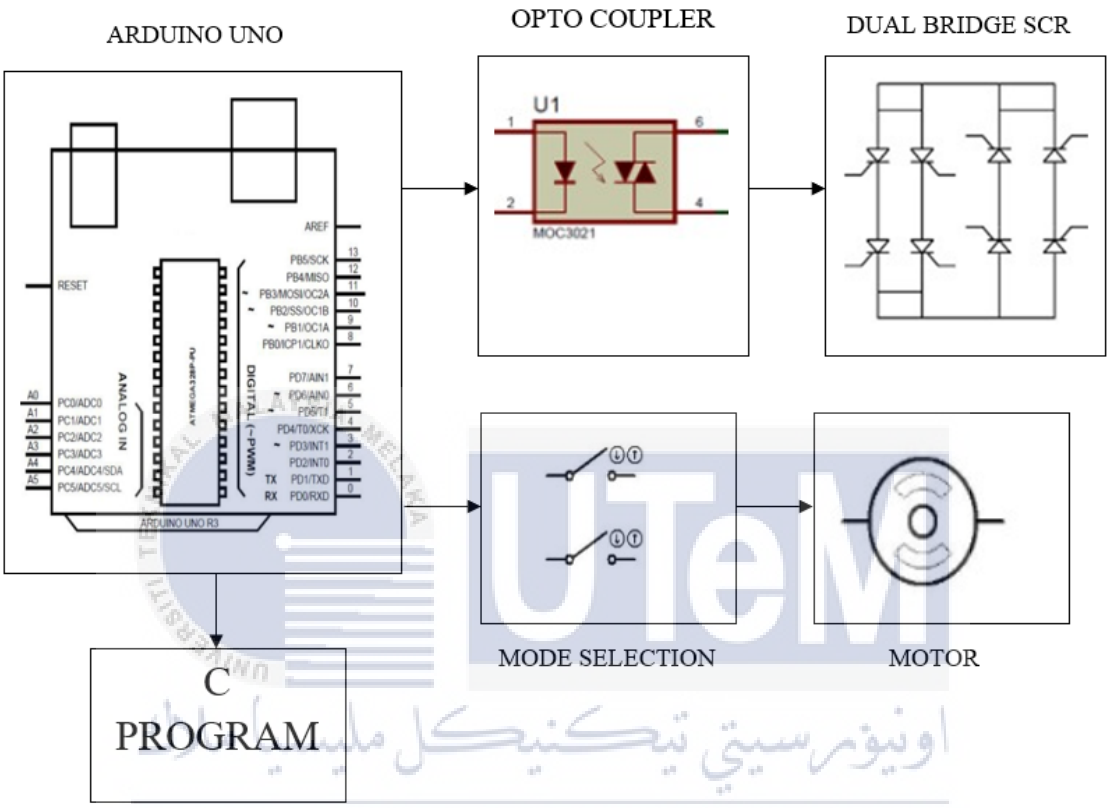


Figure 3.3 Block diagram

3.3 Experiment Setup

The circuit is constructed with the use of a microcontroller as main component to create an AC speed controller. The circuit in question is divided into various parts:

i. Arduino UNO microcontroller

ii. SCRs

iii. Optocoupler

3.3.1 Arduino UNO microcontroller

The main element in this project is Arduino UNO, which uses AT Mega 328 controller and able to utilize internal or external power supplies to detect and log voltage sags and swell. The optimized programming environment (IDE) for Arduino Uno is part of what makes Arduino Uno so easy to achieve. The system Arduino Uno provides 20 I / O pins, which are required for six physical exits to operate as PWM outputs and seven variable pins. Arduino UNO also displays the magnitude and the waveform of voltage and swells on the serial panel.

Figure 3.4 Arduino UNO

3.3.2 Optocoupler

An optocoupler is a six-pin integrated circuit. It is made up of one LED and one diac. Pin 5 is rarely used, and when light falls on the diac, it turns on the diac.

When logic zero is applied to the LED, the light does not fall on the diac, and the diac is turned off, indicating that no current flows through the diac. When logic 1 is applied to the LED, the light emitted by the LED falls on the diac, causing it to conduct, i.e., current to flow through the diac.

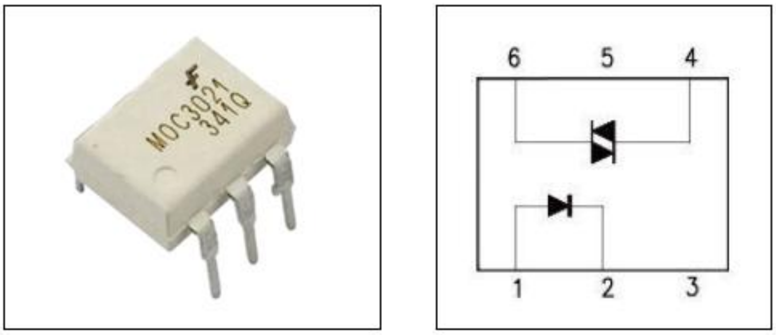


Figure 3.5 Optocoupler

3.3.3 SCRs

A four-layer solid-state device that controls current flow is known as a Silicon Controlled Rectifier. An SCR can be thought of as a conventional rectifier that is controlled by a gate signal. The device turns "on" and conducts current when the gate to cathode voltage exceeds a certain threshold. The SCR operates as a pair of tightly couple Bipolar Junction Transistors. 4 SCRs (silicon controlled rectifiers) used in full bridge are in antiparallel with another set of 4 SCRs. Triggering pulses generated by the MC in accordance with the programme provide input condition to the Opto - isolator, which drives the respective SCR.

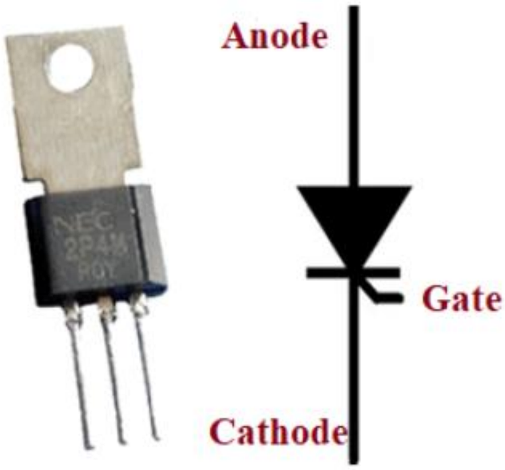


Figure 3.6 SCRs

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

In this chapter, the Arduino UNO microcontroller was chosen for this project. Several previous research have been compared. The language for this microcontroller is C language. The program has been done in Arduino IDE software. This software is easy to modify and compile. Therefore, the Arduino IDE is the most suitable microcontroller for this project.

4.2 Project Prototype

The hardware prototype of the project is shown in Figure 4.1, where a small AC motor is used a testbed. A multimeter is connected to the output of the circuit to measure the frequency of the voltage that is delivered to the AC motor. The output of the circuit also is measure by using oscilloscope to obtain the waveform. For safety purpose, the input voltage to the SCRs is step down to 12V AC voltage and the output of the circuit is then step up to 240V AC voltage to power up the AC motor.

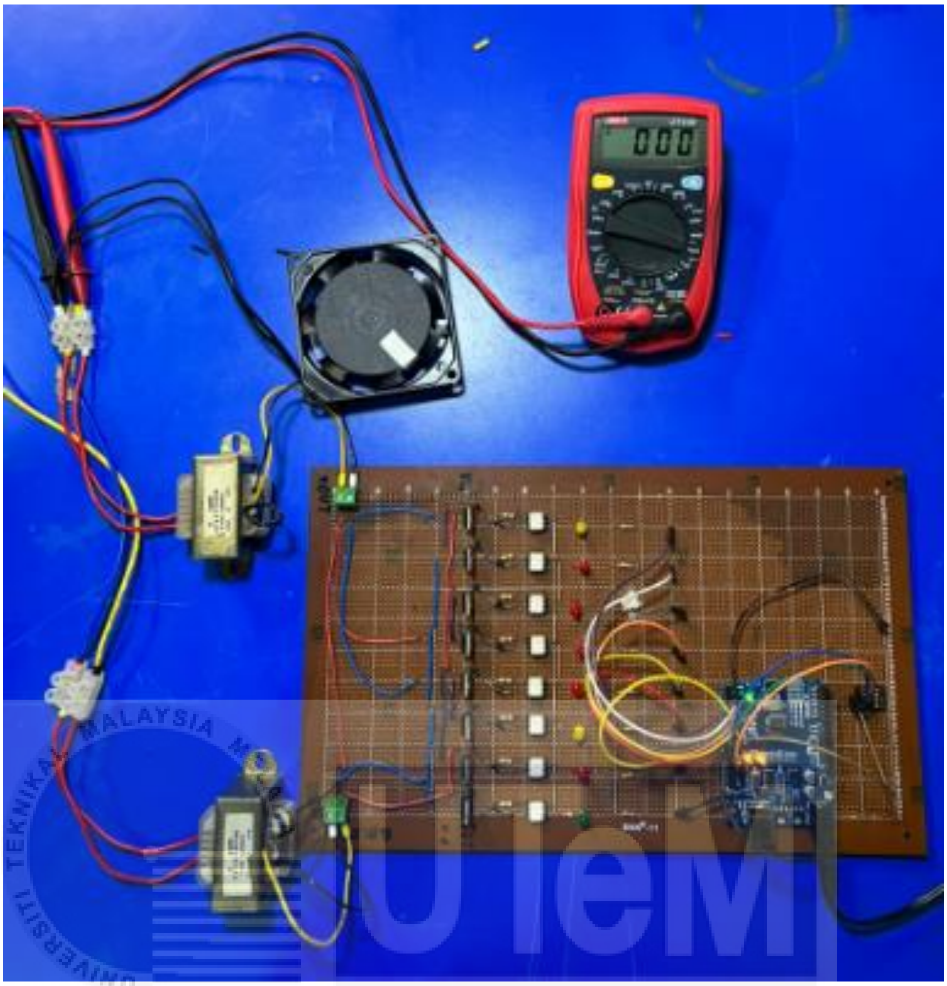


Figure 4.1 Project prototype

4.3 Overall Project and Operation

To operate this project, we have made the program and compile on the Arduino software. As there is no error during execution, the project run successfully. The program had uploaded to the Arduino UNO and it can start to run to the circuit. The circuit is connected to AC source of 240V and step down to 12V using transformer. And for the load, AC fan are used instead of AC motor.

There are four switches are needed to control the frequencies, labelled as ‘1’, ‘2’, ‘3’ and ‘4’ as shown in Figure 4.2 Those switch position is representing four different frequencies, which are 50 Hz, 25 Hz, 16.67 Hz and 12.5 Hz. These values correspond to f,

$\frac{f}{2}$, $\frac{f}{3}$ and $\frac{f}{4}$ and respectively, where f is the input frequency of 50 Hz. So, to get the required frequency, the period of the waveform needs to be determined first, known as T. The equation below is needed to do this. The switch to select the output frequency is labeled as shown in Figure 4.1.

$$T = \frac{1}{f}$$

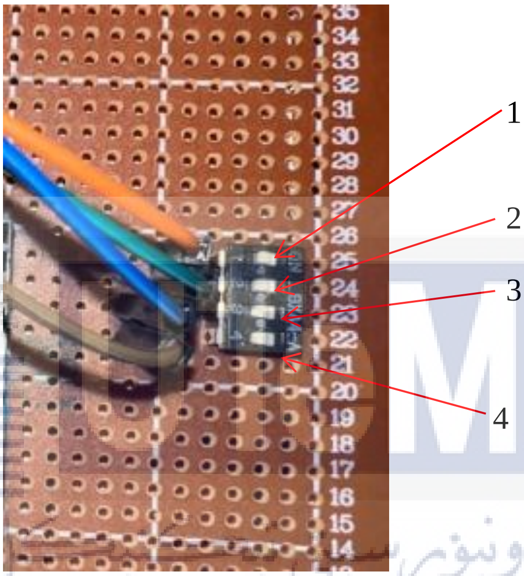


Figure 4.2 Switch label

The period for each half-bridge may be calculated using the required frequency. There must also be a little pause between turning on the opposite bridge. The first bridge must be switched off for a brief period of time before the second may be activated. The appropriate frequencies and switching position are shown in Table 4.1. With each half period discovered, the code needs to be changed to enable the first group of four SCRs to be one for this time, then all SCRs would be turned off for 0.5 ms, and the second bridge would be activated. switched on for the predicted half bridge duration, and this loop.

Table 4.1 Switch position vs freqeuncy

Switch Position	Expected output frequency
1	50 Hz
2	25 Hz
3	16.67 Hz
4	12.5 Hz

4.4 Experimental Result

To verify the efficacy of the developed device, the device is connected to oscilloscope, and it has successfully recorded. Figure 4.3 to Figure 4.6 show the results of output voltage waveform that are displayed by the oscilloscope.

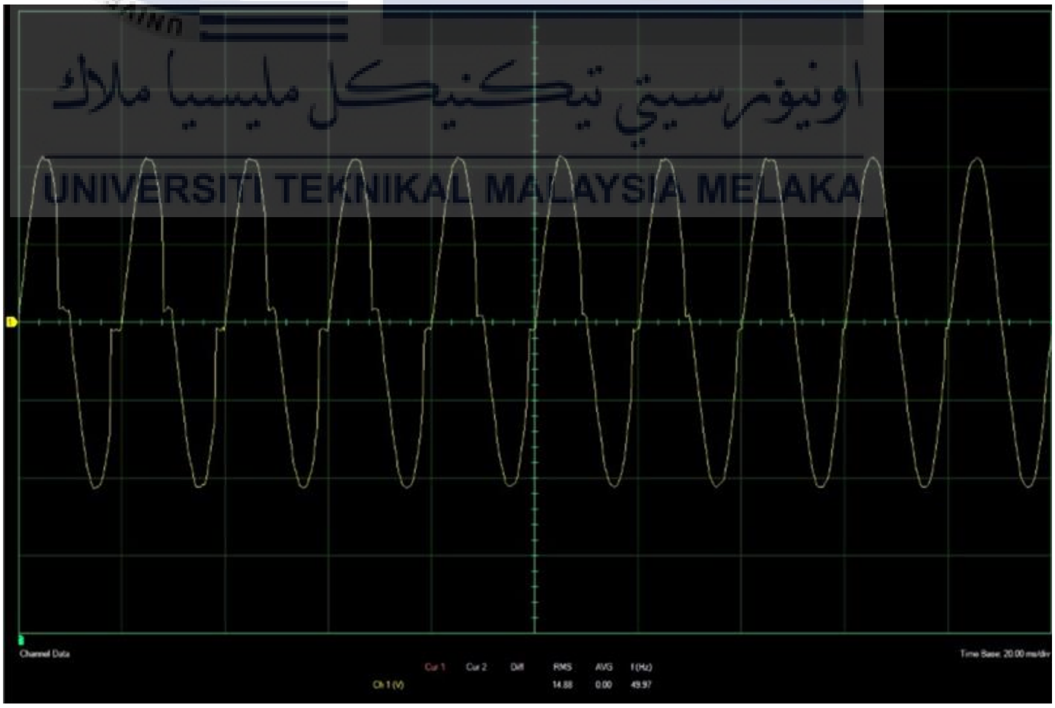


Figure 4.3 The voltage output waveform of 50 Hz when the switch is set to position '1'

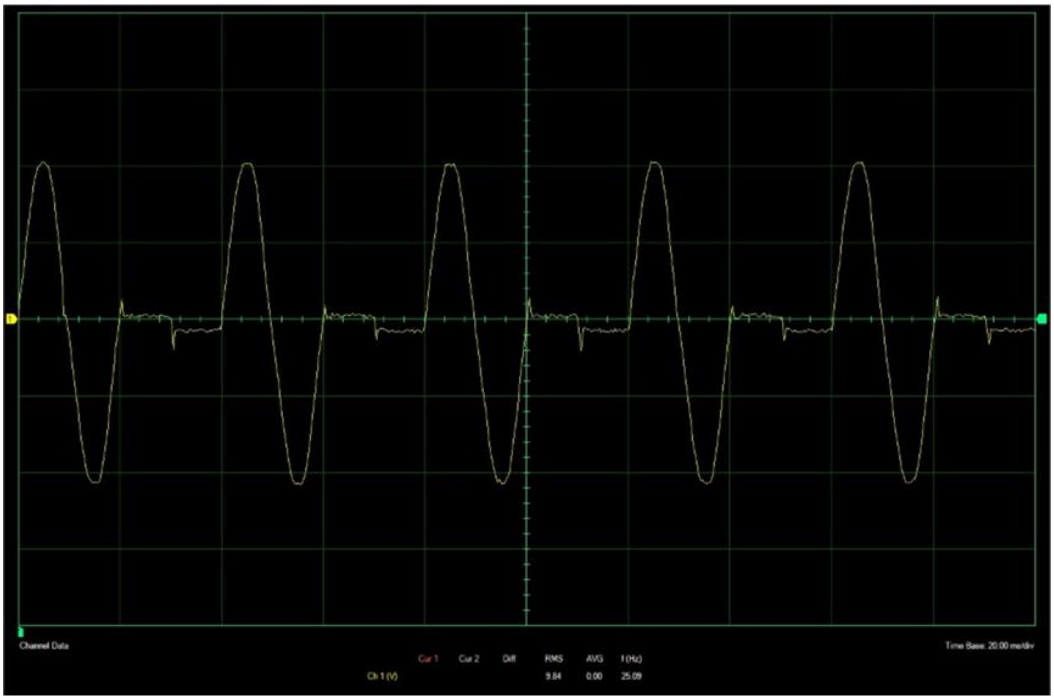


Figure 4.4a The voltage output waveform of 25 Hz when the switch is set to position '2'

Figure 4.4b The voltage output waveform of 25 Hz when the switch is set to position '2'

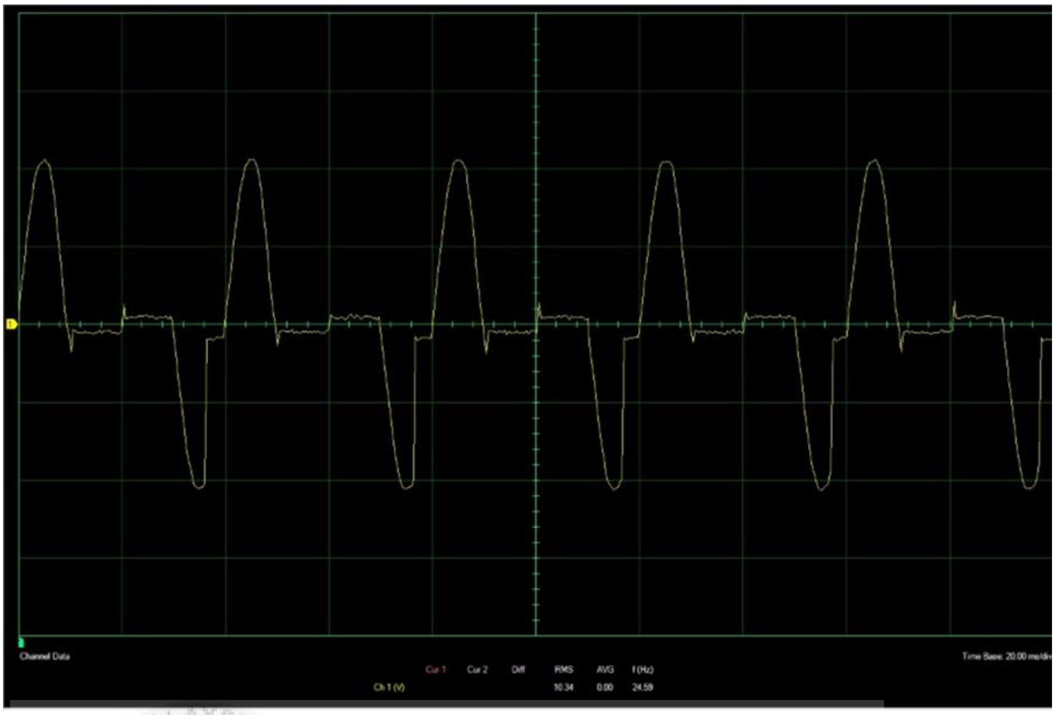


Figure 4.4c The voltage output waveform of 25 Hz when the switch is set to position '2'

Figure 4.5a The voltage output waveform of 16.67 Hz when the switch is set to position '3'

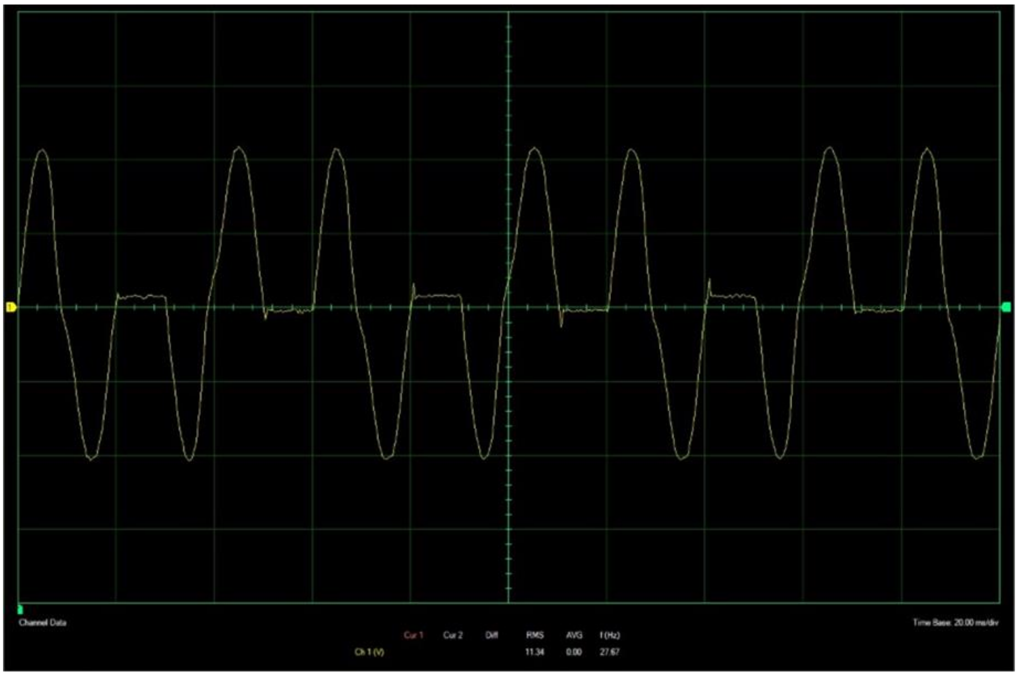


Figure 4.5b The voltage output waveform of 16.67 Hz when the switch is set to position '3'

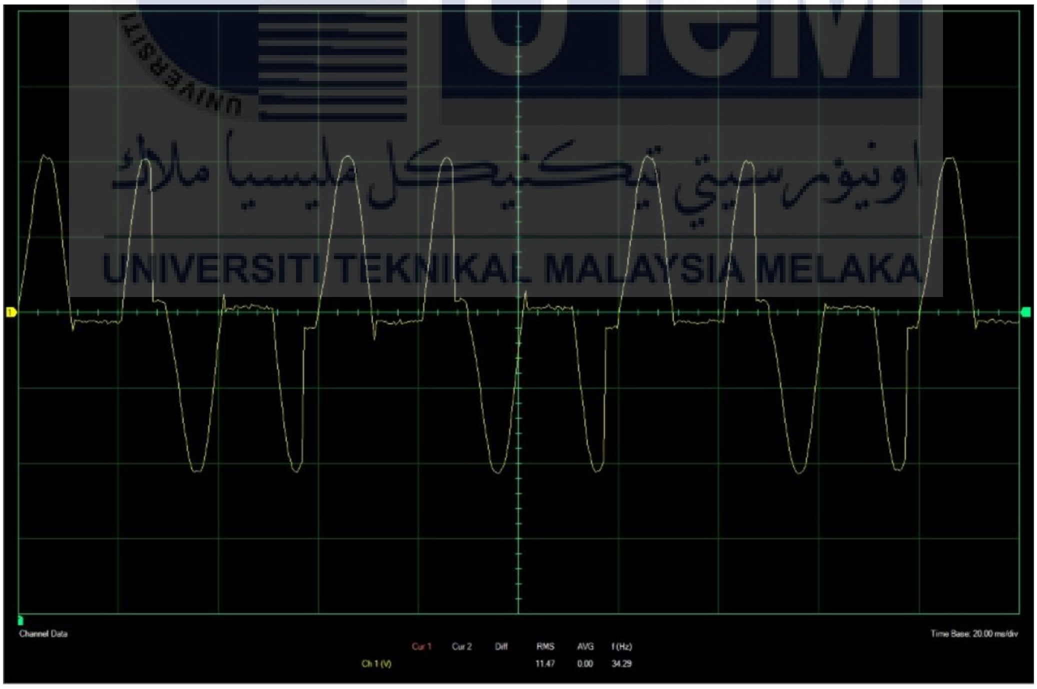


Figure 4.5c The voltage output waveform of 16.67 Hz when the switch is set to position '3'

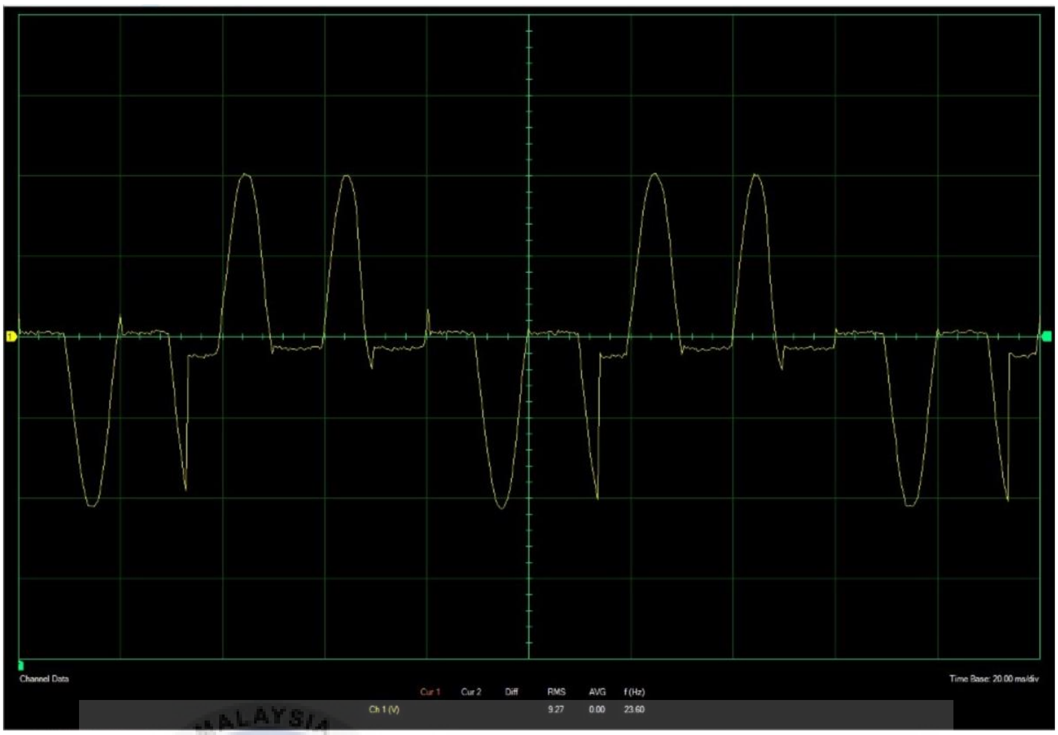


Figure 4.6a The voltage output waveform of 12.5 Hz when the switch is set to position '4'

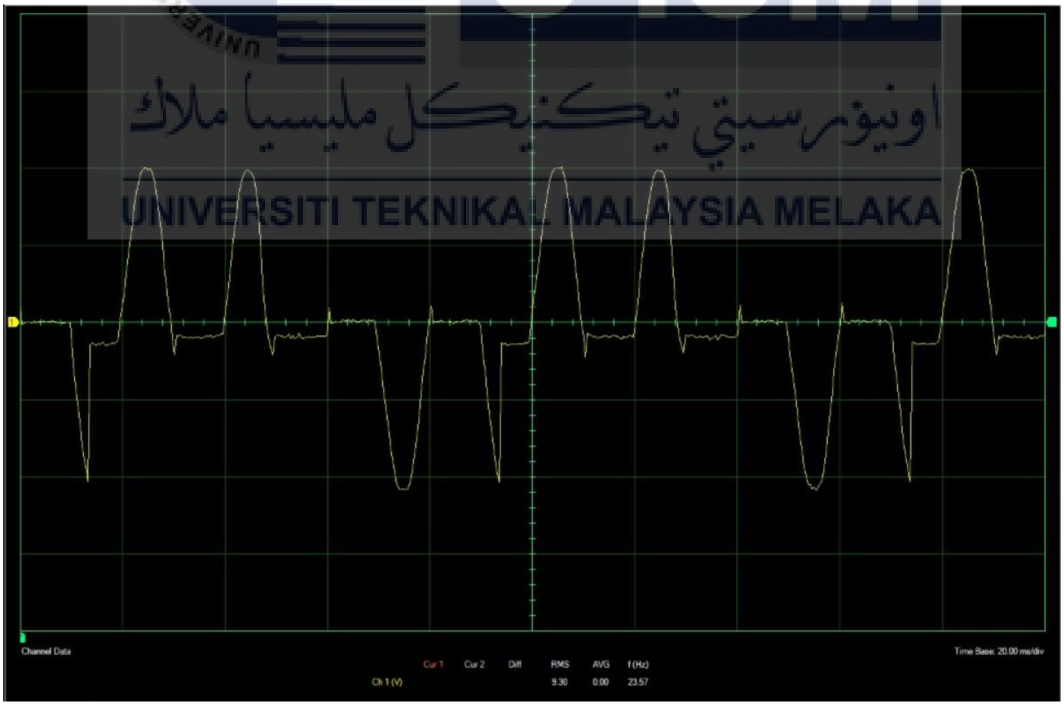


Figure 4.6b The voltage output waveform of 12.5 Hz when the switch is set to position '4'

The Arduino was then successfully powered with the input coming from a 240VAC outlet. The 240VAC are step down 12VAC by using step down transformer for safety. Then, everything was well with the Arduino being powered and the SCR bridge switching appropriately to get the necessary output frequencies with low voltage testing from the supply. The SCRs is made up of two full-wave, completely regulated bridge thyristors, each with four thyristors and coupled in the opposite way (back to back) so that both positive and negative voltages are present. Based on the Figure 4.3 to 4.11 shows the output waveform the waveforms of a cyclo-converter that generates one-fourth of the input frequency.

Then, the output of the circuit is connected to a small AC motor as shown in Figure 4.7. The result of the motor speed based on the switch position and output frequency is tabulated in Table 4.2. Based on the result, can conclude the higher output frequency, the RPM of the motor speed. Speed of a AC motor is directly proportional to back emf and is inversely proportional to flux per pole.

Table 4.2 The result of the motor speed based on the switch position and output frequency

Switch position	Output freqency (Hz)	Motor speed
1	50.0	Full speed
2	25.0	Medium speed
3	16.7	Low speed
4	12.5	Low speed

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Each component of the circuit was tested first, followed by portions of the circuit, and eventually the entire cycloconverter. This is crucial to detect any defects or mistakes so that the circuit does not fail or get damaged, and most importantly, to reduce the risk of safety.

The 240 VAC 50 Hz input was stepped down to 12 VAC 50 Hz using a transformer and powered the SCR bridge, and for powering the Arduino. The Arduino was programmed to implement the thyristor switching procedures for the necessary frequencies. To eliminate direct connection to the control circuit, isolators and diodes were used between the thyristors and the Arduino. The Arduino microcontroller was used to operate the SCR bridge, which outputs ais n AC waveform. LEDs were placed after the Arduino outputs to demonstrate how the thyristor switching mechanism worked in real time.

The cycloconverter effectively built and tested which can change the frequency of input 240V AC voltage of 50 Hz by using thyristors and a microcontroller for the switching technique. The attained frequencies were 30 Hz, 20 Hz, and 15 Hz. For safety reason, the input voltage to the SCRs is step down to 12V AC voltage and the output of the circuit is then step up to 240V AC voltage to power up the AC motor.

5.2 Future Works

For future improvements in term of enhancing the performance of this project, there are various recommendations that will be quickly presented in order to obtain better performance the AC Speed Controller Using Microcontroller based Cycloconverter.

First, the cycloconverter circuit can be used directly connected to live AC voltage 240 V without using step down and step up transformer. The circuit without the transformer is more practical and economical. However, to do that, a careful and precise circuit and program development has to be performed to ensure a safe and smooth operation of cycloconverter. To ensure that the cycloconverter circuit works effectively, every component used in the design must be correct. The created cycloconverter circuit can then be tested in a MATLAB simulation circuit or Proteus Professional software to evaluate the efficacy of the circuit before it is built in the real world.

Finally, utilizing a zero-crossing detector module is an efficient way to control the timing of the SCR activation. When the AC input crosses the zero-reference voltage, the zero-crossing detector circuit give a signal to microcontroller, and then an appropriate signal can be delivered to the SCR at the correct timing.

5.3 Potential of Commercialization

By performing the improvement to the developed device based on the recommendation explained in Section 5.2, the device will have a commercial value that can be used as a useful instrument for power system industry. The device can be used by technical or engineer to control the AC speed of motor or to identify the frequency of alternated current.

REFERENCES

[1] A. Maamoun, “DEVELOPMENT OF CYCLOCONVERTERS.”

[2] K. Sharma, B. Gupta, I. Gupta, and N. Gupta, “Issue 4 JETIR (ISSN-2349-5162),” JETIR, 2016. [Online]. Available: www.jetir.org

[3] IEEE Staff and IEEE Staff, *2012 IEEE International Power Engineering and Optimization Conference.*

[4] “Speed Control of Induction Motor Using Single Phase Cycloconverter,” 2017, [Online]. Available: www.ijaret.com

[5] P. R. Lole, K. D. Adhav, S. D. Gholap, S. R. Karkade, and P. G. Medewar, “Speed Control of Induction Motor by Using Cyclo-converter.” [Online]. Available: www.iosrjournals.org

[6] A. Marttyns Epemu, “Speed Control of a Single Phase Induction Motor Using Step-down Cycloconverter,” *International Journal of Industrial and Manufacturing Systems Engineering*, vol. 3, no. 1, p. 6, 2018, doi: 10.11648/j.ijimse.20180301.12.

[7] S. Bakanagari, J. Peddapudi, and A. M. Kumar, “OPEN ACCESS A Novel Approch to Speed Control of Induction Motor by Cycloconverter with Thyristors,” vol. 3, no. 6, pp. 2159–2164, 2013.

[8] O. Of, “Types of Cycloconverter :,” pp. 2444–2448, 2016.

[9] R. B. Roy and M. R. Amin, “Design and Construction of Single Phase Cycloconverter,” *International Journal of Recent Technology and Engineering(TM)*, vol. 1, no. 3, pp. 75–82, 2012.

[10] I. Of, “روطت م ةيسمش ة قحلا م ماظن ذيفنتو ميمصت Design and Implementation of,” vol. 2021, no. 8, pp. 0–70, 2020, doi: 10.15680/IJIRSET.2018.0711045.

[11] W. Section and S. Risk, “Pr oo f Re ad in Pr oo f R ea din,” vol. 1, no. 4, pp. 4–6, 2014.

[12] M. Mathur, V. K. Singh, A. Roy, and V. Singh, “Speed Control of Induction Motor Using,” vol. 4, no. 6, pp. 381–386, 2019.

[13] A. Sampathkumar, “Speed control of single phase induction motor using v/f technique,” *Middle - East Journal of Scientific Research*, vol. 16, no. 12, pp. 1807–1812, 2013, doi: 10.5829/idosi.mejsr.2013.16.12.114076.

[14] T. Islam, H. H. Fayek, E. Rusu, and F. Rahman, “Triac based novel single phase step-down cycloconverter with reduced thds for variable speed applications,” Applied Sciences (Switzerland), vol. 11, no. 18, 2021, doi: 10.3390/app11188688.

What is AC Motor? Definition & Types - Circuit Globe. (2017, January 18). Retrieved May 5, 2022, from Circuit Globe website: https://circuitglobe.com/ac motor.html

[15] What is AC Motor? - Circuit Globe. (2017, January 18). - Circuit Globe. (2017, January 18). Retrieved May 5, 2022, from Circuit Globe website: https://circuitglobe.com/ac-motor.html

[16] AC Motor: What Is It? How Does It Work? Types & Uses. (2022). Retrieved May 5, 2022, from Iqsdirectory.com website: https://www.iqsdirectory.com/articles/electric-motor/ac-motor.html

[17] Squirrel Cage Induction Motor : Construction, Working & Its Classification. (2020, May 22). Retrieved May 19, 2022, from ElProCus - Electronic Projects for Engineering Students website: https://www.elprocus.com/what-is-a-squirrel-cage-induction-motor-and-its

[18] (2020, August 19). Retrieved May 19, 2022, from Electrical4u.com website: https://www.electrical4u.com/squirrel-cage-induction-motor/

[19] What is a Wound Rotor Motor and How Does it Work? Retrieved May 21, 2022, from Thomasnet.com website: https://www.thomasnet.com/articles/machinery-tools-supplies/what-is-a-wound-rotor-motor-and-how-does-it-work/

[20] Sai, B., 1, S., Kartheek, B. N., & Professor, A. (2013). Speed Control of I induction Motor using Cycloconverter. *International Journal of Engineering Trends and Technology*. Retrieved from: http://www.ijettjournal.org/volume-4/issue-4/IJETT-V4I4P253.pdf

[21] All About AC Motor Controllers - What They Are and How They Work. (2022). Retrieved May 21, 2022, from Thomasnet.com website: https://www.thomasnet.com/articles/instruments-controls/ac-motor-controllers/#:~:text=How%20do%20AC%20Motor%20Controllers,the%20speed%20of%20the%20motor.

[22] M, N., R, V., & P, Y. (2015). Phase Angle Control Method of Speed Control of Single Phase Induction Motor. *IJIREEICE*, *3*(11), 111–114. https://doi.org/10.17148/ijireeice.2015.31123

[23] Electronics Mind. (2022, February 12). Voltage Control Methods of Inverter - PWM Technique. Retrieved May 21, 2022, from Electronics Mind - The World of Electronics Engineering website: https://www.electronicsmind.com/2022/02/voltage-control-methods-of inverter.html#:~:text=Basically%2C%20there%20are%20three%20techniques,Control%20of%20DC%20Input%20Voltage

[24] What is an Arduino? - learn.sparkfun.com. (2022). Retrieved May 21, 2022, from Sparkfun.com website: https://learn.sparkfun.com/tutorials/what-is-an-arduino/all

[25] Chattopadhyay, A. K. (2007). AC–AC Converters. *Power Electronics Handbook*, 487–521. https://doi.org/10.1016/b978-0-12-382036-5.00018-5

[26] Cycloconverters - Introduction with Schematic, Types and Application. (2013, October 24). Retrieved May 21, 2022, from ElProCus - Electronic Projects for Engineering Students website: https://www.elprocus.com/cycloconverters-types-applications/

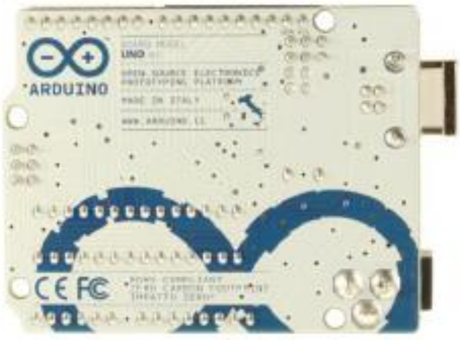
[27] Cycloconverters – Types, Working and Applications. (2021). Retrieved May 23, 2022, from Circuitdigest.com website: https://circuitdigest.com/tutorial/cycloconverter-types-working-circuits-applications#:~:text=Basic%20Principle%20behind%20Cycloconverters%3A&text=It%20will%20have%20a%20Switching,during%20the%20negative%20half%20cycle.

APPENDICES

Appendix A Data Sheet Arduino UNO

Arduino Uno

Arduino Uno R3 Front



Arduino Uno R3 Back

Arduino Uno R2 Front

Arduino Uno SMD

Arduino Uno Front

Arduino Uno Back

Overview

The Arduino Uno is a microcontroller board based on the ATmega328 (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.
The Uno differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega16U2 (Atmega8U2 up to version R2) programmed as a USB-to-serial converter.
Revision 2 of the Uno board has a resistor pulling the 8U2 HWB line to ground, making it easier to put into DFU mode.
Revision 3 of the board has the following new features:

- 1.0 pinout: added SDA and SCL pins that are near to the AREF pin and two other new pins placed near to the RESET pin, the IOREF that allow the shields to adapt to the voltage provided from the board. In future, shields will be compatible both with the board that use the AVR, which operate with 5V and with the Arduino Due that operate with 3.3V. The second one is a not connected pin, that is reserved for future purposes.
- Stronger RESET circuit.
- Atmega 16U2 replace the 8U2.

"Uno" means one in Italian and is named to mark the upcoming release of Arduino 1.0. The Uno and version 1.0 will be the reference versions of Arduino, moving forward. The Uno is the latest in a series of USB Arduino boards, and the reference model for the Arduino platform; for a comparison with previous versions, see the index of Arduino boards.

Summary

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V

Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328)
EEPROM	1 KB (ATmega328)
Clock Speed	16 MHz

Schematic & Reference Design

EAGLE files: arduino-uno-Rev3-reference-design.zip (NOTE: works with Eagle 6.0 and newer)
Schematic: arduino-uno-Rev3-schematic.pdf
Note: The Arduino reference design can use an Atmega8, 168, or 328, Current models use an ATmega328, but an Atmega8 is shown in the schematic for reference. The pin configuration is identical on all three processors.

Power

The Arduino Uno can be powered via the USB connection or with an external power supply. The power source is selected automatically.
External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the Gnd and Vin pin headers of the POWER connector.
The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.
The power pins are as follows:

- **VIN.** The input voltage to the Arduino board when it's using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). You can supply voltage through this pin, or, if supplying voltage via the power jack, access it through this pin.
- **5V.**This pin outputs a regulated 5V from the regulator on the board. The board can be supplied with power either from the DC power jack (7 - 12V), the USB connector (5V), or the VIN pin of the board (7-12V). Supplying voltage via the 5V or 3.3V pins bypasses the regulator, and can damage your board. We don't advise it.
- **3V3.** A 3.3 volt supply generated by the on-board regulator. Maximum current draw is 50 mA.
- **GND.** Ground pins.

Memory

The ATmega328 has 32 KB (with 0.5 KB used for the bootloader). It also has 2 KB of SRAM and 1 KB of EEPROM (which can be read and written with the EEPROM library).

Input and Output

Each of the 14 digital pins on the Uno can be used as an input or output, using pinMode(), digitalWrite(), and digitalRead() functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 kOhms. In addition, some pins have specialized functions:

- **Serial: 0 (RX) and 1 (TX).** Used to receive (RX) and transmit (TX) TTL serial data. These pins are connected to the corresponding pins of the ATmega8U2 USB-to-TTL Serial chip.
- **External Interrupts: 2 and 3.** These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the attachInterrupt() function for details.
- **PWM: 3, 5, 6, 9, 10, and 11.** Provide 8-bit PWM output with the analogWrite() function.

- **SPI: 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK).** These pins support SPI communication using the SPI library.
- **LED: 13.** There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.

The Uno has 6 analog inputs, labeled A0 through A5, each of which provide 10 bits of resolution (i.e. 1024 different values). By default they measure from ground to 5 volts, though is it possible to change the upper end of their range using the AREF pin and the analogReference() function. Additionally, some pins have specialized functionality:

- **TWI: A4 or SDA pin and A5 or SCL pin.** Support TWI communication using the Wire library.

There are a couple of other pins on the board:

- **AREF.** Reference voltage for the analog inputs. Used with analogReference().
- **Reset.** Bring this line LOW to reset the microcontroller. Typically used to add a reset button to shields which block the one on the board.

See also the mapping between Arduino pins and ATmega328 ports. The mapping for the Atmega8, 168, and 328 is identical.

Communication

The Arduino Uno has a number of facilities for communicating with a computer, another Arduino, or other microcontrollers. The ATmega328 provides UART TTL (5V) serial communication, which is available on digital pins 0 (RX) and 1 (TX). An ATmega16U2 on the board channels this serial communication over USB and appears as a virtual com port to software on the computer. The '16U2 firmware uses the standard USB COM drivers, and no external driver is needed. However, on Windows, a .inf file is required. The Arduino software includes a serial monitor which allows simple textual data to be sent to and from the Arduino board. The RX and TX LEDs on the board will flash when data is being transmitted via the USB-to-serial chip and USB connection to the computer (but not for serial communication on pins 0 and 1).
A SoftwareSerial library allows for serial communication on any of the Uno's digital pins.
The ATmega328 also supports I2C (TWI) and SPI communication. The Arduino software includes a Wire library to simplify use of the I2C bus; see the documentation for details. For SPI communication, use the SPI library.

Programming

The Arduino Uno can be programmed with the Arduino software (download). Select "Arduino Uno from the **Tools > Board** menu (according to the microcontroller on your board). For details, see the reference and tutorials.
The ATmega328 on the Arduino Uno comes preburned with a bootloader that allows you to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol (reference, C header files).
You can also bypass the bootloader and program the microcontroller through the ICSP (In-Circuit Serial Programming) header; see these instructions for details.
The ATmega16U2 (or 8U2 in the rev1 and rev2 boards) firmware source code is available . The ATmega16U2/8U2 is loaded with a DFU bootloader, which can be activated by:

- On Rev1 boards: connecting the solder jumper on the back of the board (near the map of Italy) and then resetting the 8U2.
- On Rev2 or later boards: there is a resistor that pulling the 8U2/16U2 HWB line to ground, making it easier to put into DFU mode.

You can then use Atmel's FLIP software (Windows) or the DFU programmer (Mac OS X and Linux) to load a new firmware. Or you can use the ISP header with an external programmer (overwriting the DFU bootloader). See this user-contributed tutorial for more information.

Automatic (Software) Reset

Rather than requiring a physical press of the reset button before an upload, the Arduino Uno is designed in a way that allows it to be reset by software running on a connected computer. One of the hardware flow control lines (DTR) of the ATmega8U2/16U2 is connected to the reset line of the ATmega328 via a 100 nanofarad capacitor. When this line is asserted (taken low), the reset line drops long enough to reset the chip. The Arduino software uses this capability to allow you to upload code by simply pressing the upload button in the Arduino environment. This means that the bootloader can have a shorter timeout, as the lowering of DTR can be well-coordinated with the start of the upload.
This setup has other implications. When the Uno is connected to either a computer running Mac OS X or Linux, it resets each time a connection is made to it from software (via USB). For the following half-second or so, the bootloader is running on the Uno. While it is programmed to ignore malformed data (i.e. anything besides an upload of new code), it will intercept the first few bytes of data sent to the board after a connection is opened. If a sketch running on the board receives one-time configuration or other data when it first starts, make sure that the software with which it communicates waits a second after opening the connection and before sending this data.
The Uno contains a trace that can be cut to disable the auto-reset. The pads on either side of the trace can be soldered together to re-enable it. It's labeled "RESET-EN". You may also be able to disable the auto-reset by connecting a 110 ohm resistor from 5V to the reset line; see this forum thread for details.

USB Overcurrent Protection

The Arduino Uno has a resettable polyfuse that protects your computer's USB ports from shorts and overcurrent. Although most computers provide their own internal protection, the fuse provides an extra layer of protection. If more than 500 mA is applied to the USB port, the fuse will automatically break the connection until the short or overload is removed.

Physical Characteristics

The maximum length and width of the Uno PCB are 2.7 and 2.1 inches respectively, with the USB connector and power jack extending beyond the former dimension. Four screw holes allow the board to be attached to a surface or case. Note that the distance between digital pins 7 and 8 is 160 mil (0.16"), not an even multiple of the 100 mil spacing of the other pins.

Appendix B Data Sheet BT 151

BT151-650R

SCR, 12 A, 15mA, 650 V, SOT78

Rev. 05 — 27 February 2009 Product data sheet

1. Product profile

1.1 General description

Planar passivated SCR (Silicon Controlled Rectifier) in a SOT78 plastic package.

1.2 Features and benefits

- High reliability
- High surge current capability
- High thermal cycling performance

1.3 Applications

- Ignition circuits
- Motor control
- Protection Circuits
- Static switching

1.4 Quick reference data

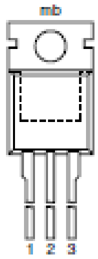
Table 1. Quick reference

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{DRM}	repetitive peak off-state voltage		-	-	650	V
$I_{T(AV)}$	average on-state current	half sine wave; $T_{mb} \leq 109$ °C; see Figure 3	-	-	7.5	A
$I_{T(RMS)}$	RMS on-state current	half sine wave; $T_{mb} \leq 109$ °C; see Figure 1; see Figure 2	-	-	12	A
Static characteristics						
I_{GT}	gate trigger current	$V_D = 12$ V; $T_j = 25$ °C; $I_T = 100$ mA; see Figure 8	-	2	15	mA

founded by Philips

2. Pinning information

Table 2. Pinning information

Pin	Symbol	Description	Simplified outline	Graphic symbol
1	K	cathode	 SOT78 (TO-220AB; SC-46)	
2	A	anode		
3	G	gate		
mb	mb	anode		

3. Ordering information

Table 3. Ordering information

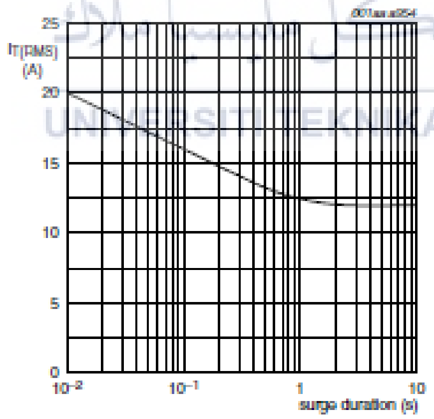
Type number	Package		
	Name	Description	Version
BT151-650R	TO-220AB; SC-46	plastic single-ended package; heatsink mounted; 1 mounting hole; 3-lead TO-220AB	SOT78

4. Limiting values

Table 4. Limiting values

In accordance with the Absolute Maximum Rating System (IEC 60134).

Symbol	Parameter	Conditions	Min	Max	Unit
V_{DRM}	repetitive peak off-state voltage		-	650	V
V_{RRM}	repetitive peak reverse voltage		-	650	V
$I_{T(AV)}$	average on-state current	half sine wave; $T_{mb} \leq 109$ °C; see Figure 3	-	7.5	A
$I_{T(RMS)}$	RMS on-state current	half sine wave; $T_{mb} \leq 109$ °C; see Figure 1; see Figure 2	-	12	A
dI_T/dt	rate of rise of on-state current	I_T = 20 A; I_G = 50 mA; dI_G/dt = 50 mA/µs	-	50	A/µs
I_{GM}	peak gate current		-	2	A
P_{GM}	peak gate power		-	5	W
T_{stg}	storage temperature		-40	150	°C
T_j	junction temperature		-	125	°C
I_{TSM}	non-repetitive peak on-state current	half sine wave; t_p = 8.3 ms; $T_{j(init)}$ = 25 °C	-	132	A
		half sine wave; t_p = 10 ms; $T_{j(init)}$ = 25 °C; see Figure 4; see Figure 5	-	120	A
I^2t	I2t for fusing	t_p = 10 ms; sine-wave pulse	-	72	A^2s
$P_{G(AV)}$	average gate power	over any 20 ms period	-	0.5	W
V_{RGM}	peak reverse gate voltage		-	5	V



f = 50Hz; T_{mb} = 109 °C

Fig 1. RMS on-state current as a function of surge duration; maximum values

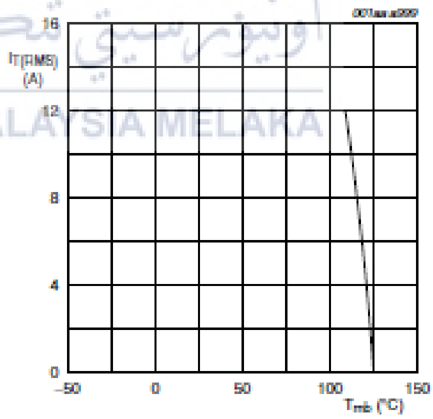


Fig 2. RMS on-state current as a function of mounting base temperature; maximum values

Appendix C Data Sheet MOC 3021

FAIRCHILD
SEMICONDUCTOR®

GlobalOptoisolator™

VDE | UL | CSA | SETI | SEMKO | DEMKO | NEMKO | BABT

MOC3021
MOC3022
MOC3023

6-Pin DIP Random-Phase Optoisolators Triac Driver Output
(400 Volts Peak)

The MOC3020 Series consists of gallium arsenide infrared emitting diodes, optically coupled to a silicon bilateral switch.

- *To order devices that are tested and marked per VDE 0884 requirements, the suffix "V" must be included at end of part number. VDE 0884 is a test option.*

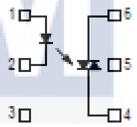
They are designed for applications requiring isolated triac triggering.

Recommended for 115/240 Vac(rms) Applications:

- Solenoid/Valve Controls
- Lamp Ballasts
- Interfacing Microprocessors to 115 Vac Peripherals
- Motor Controls
- Static ac Power Switch
- Solid State Relays
- Incandescent Lamp Dimmers

STANDARD THRU HOLE

SCHEMATIC



1. ANODE
2. CATHODE
3. NC
4. MAIN TERMINAL
5. SUBSTRATE DO NOT CONNECT
6. MAIN TERMINAL

MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
INFRARED EMITTING DIODE			
Reverse Voltage	V_R	3	Volts
Forward Current — Continuous	I_F	60	mA
Total Power Dissipation @ T_A = 25°C Negligible Power in Triac Driver Derate above 25°C	P_D	100 1.33	mW mW/°C
OUTPUT DRIVER			
Off–State Output Terminal Voltage	V_{DRM}	400	Volts
Peak Repetitive Surge Current (PW = 1 ms, 120 pps)	I_{TSM}	1	A
Total Power Dissipation @ T_A = 25°C Derate above 25°C	P_D	300 4	mW mW/°C
TOTAL DEVICE			
Isolation Surge Voltage(1) (Peak ac Voltage, 60 Hz, 1 Second Duration)	V_{ISO}	7500	Vac(pk)
Total Power Dissipation @ T_A = 25°C Derate above 25°C	P_D	330 4.4	mW mW/°C
Junction Temperature Range	T_J	−40 to +100	°C
Ambient Operating Temperature Range	T_A	−40 to +85	°C
Storage Temperature Range	T_{stg}	−40 to +150	°C
Soldering Temperature (10 s)	T_L	260	°C

1. Isolation surge voltage, V_{ISO}, is an internal device dielectric breakdown rating. For this test, Pins 1 and 2 are common, and Pins 4, 5 and 6 are common.

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
INPUT LED					
Reverse Leakage Current (V_R = 3 V)	I_R	—	0.05	100	μA
Forward Voltage (I_F = 10 mA)	V_F	—	1.15	1.5	Volts
OUTPUT DETECTOR (I_F = 0 unless otherwise noted)					
Peak Blocking Current, Either Direction (Rated V_{DRM}(1))	I_{DRM}	—	10	100	nA
Peak On–State Voltage, Either Direction (I_{TM} = 100 mA Peak)	V_{TM}	—	1.8	3	Volts
Critical Rate of Rise of Off–State Voltage (Figure 7, Note 2)	dv/dt	—	10	—	V/μs
COUPLED					
LED Trigger Current, Current Required to Latch Output (Main Terminal Voltage = 3 V(3))	I_{FT}				mA
MOC3021		—	8	15	
MOC3022		—	—	10	
MOC3023		—	—	5	
Holding Current, Either Direction	I_H	—	100	—	μA

1. Test voltage must be applied within dv/dt rating.
2. This is static dv/dt. See Figure 7 for test circuit. Commutating dv/dt is a function of the load–driving thyristor(s) only.
3. All devices are guaranteed to trigger at an I_F value less than or equal to max I_{FT}. Therefore, recommended operating I_F lies between max I_{FT} (15 mA for MOC3021, 10 mA for MOC3022, 5 mA for MOC3023) and absolute max I_F (60 mA).

TYPICAL ELECTRICAL CHARACTERISTICS

T_A = 25°C

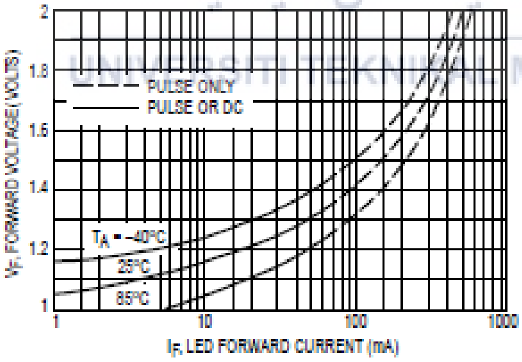


Figure 1. LED Forward Voltage versus Forward Current

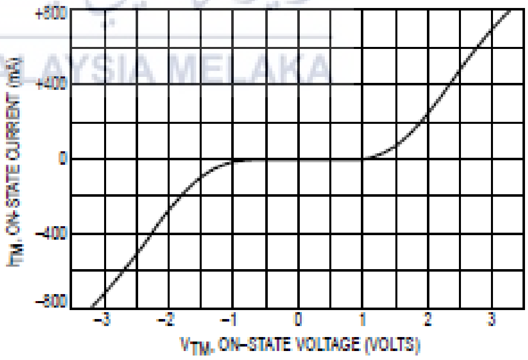


Figure 2. On–State Characteristics