PI VOLTAGE CONTROL TECHNIQUE FOR 3 PHASE INDUUCTION MOTOR USING SIMULINK AND ARDUINO

WAN AHMAD KHUSAIRI BIN WAN CHEK

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Faculty of Electrical and Electronics Engineering
UniversitiTun Hussein Onn Malaysia

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ABSTRACT

Induction motor is the most used in industry because of its high robustness, reliability, low cost, high efficiency and good self starting capability. However is also has its own limitation which can be divided into three categories which is nonlinearity, complex computation and uncertainty system. The development of this project is to control the 3 phase induction motor by using Arduino Uno controller and also using Simulink in MATLAB. Arduino Uno also is a part from series of controller where it is connected to the PWM inverter and also connected to motor driver as to turn the 3 phase induction motor on. Voltage sensor is used as to detect any changes that are supplied from the motor driver to the induction motor as to ensure that the voltage that is supplied to a constant voltage value to the induction motor. This method is known as voltage control. The measured voltage is then compared with the desired reference voltage. The error that is produced is than corrected as to minimize the existing error by using a controller is design using Simulink in Matlab and than is interfaced into the Arduino Uno. Arduino Uno will create PWM signal that is sent to the PWM inverter as to improve the induction motor performance. Based on the result obtain shows that the error from reference voltage and measured voltage is minimized and the PWM that is produced also has differences in term of width.

ABSTRAK

Motor aruhan adalah yang paling banyak digunakan dalam industri kerana keteguhan tinggi, kebolehpercayaan , kos rendah , kecekapan tinggi dan keupayaan permulaan diri yang baik. Walau bagaimanapun juga mempunyai had tersendiri yang boleh dibahagikan kepada tiga kategori iaitu ketaklelurusan , pengiraan kompleks dan sistem yang tidak menentu. Pembangunan projek ini adalah untuk mengawal motor aruhan 3 fasa dengan menggunakan Arduino Uno pengawal dan juga menggunakan Simulink dalam MATLAB. Arduino Uno juga adalah sebahagian dari siri pengawal di mana ia disambungkan ke penyongsang PWM dan juga disambungkan kepada pemandu motor untuk menghidupkan motor aruhan 3 fasa. Sensor voltan digunakan untuk mengesan apa-apa perubahan yang dibekalkan dari pemandu motor kepada motor induksi bagi memastikan voltan yang dibekalkan kepada nilai voltan tetap untuk motor aruhan. Kaedah ini dikenali sebagai kawalan voltan. Voltan yang diperolehi kemudiannya dibandingkan dengan voltan rujukan yang dikehendaki. Kesilapan yang dihasilkan adalah daripada diperbetulkan untuk meminimumkan ralat yang sedia ada dengan menggunakan pengawal adalah reka bentuk menggunakan Simulink dalam Matlab dan daripada yang diantaramukakan ke Arduino Uno. Arduino Uno akan mewujudkan isyarat "PWM" yang dihantar kepada penyongsang "PWM" untuk meningkatkan prestasi motor induksi. Berdasarkan kepada keputusan mendapatkan menunjukkan bahawa kesilapan itu daripada voltan rujukan dan voltan yang diukur dikurangkan dan "PWM" yang dihasilkan juga mempunyai perbezaan dari aspek lebar.

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LIST OF SYMBOLS AND ABBREVIATIONS

PWM	-	Pulse Width Modulation
PIC	-	Peripheral Interface Controller
HP	-	Horse Power
IM	-	Induction Motor
FLC	-	Fuzzy Logic Controller
CM	-	Common Mode
AC	-	Alternating Current
DC	-	Direct Current
PID	-	Proportional – Integral - Derivative
PI	-	Proportional – Integral
e.m.f	-	Electromagnetic Field
r.m.f	-	Rotating Magnetic Field
AR	-	Auto Regressive
MA	-	Moving Average
PEF	-	prediction error filter
DTC	-	Direct Torque Control
ANN	-	Artificial Neural Network
Vgs		Gate Voltage
IO	-	Input Output
Kp	-	Proportional gain
KI	-	Integral gain
MOSFET	-	Metal–Oxide–Semiconductor Field-Effect Transistor
LC	-	Inductor - Capacitor

INTRODUCTION

1.1   Project Background

Since its invention, the three phase induction motor (IM) has been widely used in industry because of its simple construction and low maintenance machine. Although three phase induction motor is widely used, it also has its limitations such as the motor speed decreases as the load increases, low starting torque and high starting current. To increase the efficiency and performance of induction motor, controller system has been developed. There are two types of controller system which is adaptive and passive controller. The fuzzy logic controller (FLC) and the Proportional − Integral − Derivative (PID) controller are examples for adaptive controller and meanwhile relay, sliding mode control and hysteresis are examples for passive controller. Three phase induction motor has variable speed and the best way to control the speed of induction motor drives using converter − inverter system [1]. It is known that by using inverter to generate three phase AC supply from a single DC source it introduces common mode (CM) voltage at the stator star point of the IM with respect to the ground[1]. To control the three phase inverter is by injecting pulse width modulation (PWM) signal from any existing microcontroller that exists in the market. For an example PIC, Arduino, Altera board are examples of PWM generating devices that can be used to control the inverter as to increase the performance of a three phase induction motor. Arduino DSP controller has been chosen because Arduino provides platform that helps users to understand the workflow for designing an embedded system without using manual programming. By using Simulink in Matlab user able to create algorithms for their desired control system by just using the block that exists in the library as to create or design their own control system.

1.2   Problem Statement

Nowadays three phase induction motor is a common device in industries. It works on the principle of induction where electro-magnetic field (emf) that is induced in to the rotor conductors when rotating magnetic field of stator cuts the stationary rotor conductors. Induction motors are characterized by highly non-linear, complex and time-varying dynamics and inaccessibility of some of the states and outputs for measurements, and hence it can be considered as a challenging engineering problem [2].Three phase induction motor were ideally used because of its simple construction and free maintenance. Not only that since the induction motor has no brushes and easy to control, many older DC motors are being replaced with induction motors and accompanying inverters in industrial applications. In induction motor problems still exist in an induction motor such as improper voltage value, motor has inadequate torque to drive the load, overload or can be instantaneous trip. Low voltage is normally not the direct cause of motor overheating since the overload relays will turn the motor off line when the current exceeds rated amps. As a result, the motor will not generate rated HP. The motor slip also increases proportionally to the square of the voltage drop resulting, the motor will be running slower with a lower output and the process would not be producing as expected [3]. The need of variable frequency machine parameter variations and the difficulties of processing feedback signals in the presence of harmonic create the complexity [4]. It was difficult to vary the frequency to the motor and therefore make the uses for the induction motor were limited. To control the speed of a motor and as well other parameter normally uses a power electronic device which is known as an inverter. A typical unit will take the mains AC supply, rectify and smooth it into a "link" DC voltage, and, then convert it into the desired AC waveform. In general, a DC-to-AC converter is called an inverter, which is probably where the motor-control inverter gets its name. But in order to control the switching of power transistor in the inverter, we need to supply PWM signal to the power transistor. To generate this PWM signal, normally microcontroller is used as to create the switching sequence to the power transistor.

1.3   Objective

The objectives of this project are listed as follows:

    1.3.1   To learn and develop PWM using PI controller for induction motor.

    1.3.2   To control the induction motor using voltage source controller method.

    1.3.3   To interface the Arduino Uno controller with MATLAB

1.4   Scope

In this project the scope of work:

    1.4.1   To develop PI controller using Simulink in Matlab.

    1.4.2   To develop voltage controller method for induction motor.

    1.4.3   To develop the PWM inverter and 3 phase motor driver.

    1.4.4   Interfacing the Simulink in Matlab with Arduino IO.

CHAPTER 2

LITERATURE REVIEW

2.1 Electric Motor

Motor mostly found in applications as diverse as industrial fans, blowers and pumps, machine tools, household appliances, power tools, and disk drives. Electric motors can be powered by direct current (DC) sources, such as from batteries, motor vehicles or rectifiers, or by alternating current (AC) sources, such as from the power grid, inverters or generators. Small motors may be found in electric watches. General-purpose motors with highly standardized dimensions and characteristics provide convenient mechanical power for industrial use. The largest of electric motors are used for ship propulsion, pipeline compression and pumped-storage applications with ratings approaching a megawatt. Electric motors may be classified by electric power source type, internal construction, application, type of motion output, and so on.

2.2   Induction Motor
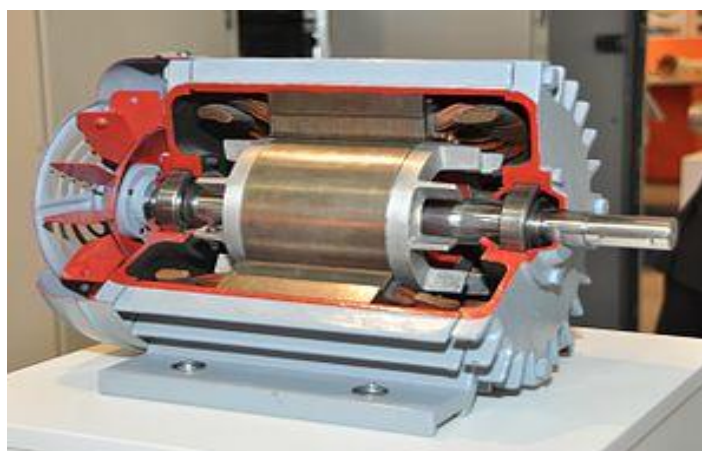
Figure 2.1: Three Phase Induction Motor

A three phase induction motor is one of an electric motor that converts electrical energy into a mechanical energy which is then connected with different load, that's why we described as transformer type. The three phase induction motors are most widely used for industrial applications mainly because they do not require a starting device. The operating principle of a 3 phase induction motor is based on the production of r.m.f.. It has a stator that carries a three phase winding and rotor that carries a short circuited winding. Only the stator winding is fed from 3-phase supply. The rotor winding derives its voltage and power from the externally energized stator winding through electromagnetic induction. The advantages and disadvantages of the three phase induction motor are stated below:

2.2.1   Advantages of Induction Motor

(i) It has simple and rugged construction.
(ii) It is relatively cheap.
(iii) It requires little maintenance.
(iv) It has high efficiency and reasonably good power factor.
(v) It has self starting torque.

2.2.2   Disadvantages of Induction Motor

(i) It is essentially a constant speed motor and its speed cannot be changed easily.

(ii) Its starting torque is inferior to dc shunt motor.

2.3   Inverter

An inverter is an electrical device that converts direct current (DC) to alternating current (AC); the resulting AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits Static inverters have no moving parts and are used in a wide range of applications, from small switching power supplies in computers, to large electric utility high-voltage direct current applications that transport bulk power. Inverters are commonly used to supply AC power from DC sources such as solar panels or batteries.

2.4   Three- Phase Inverter

A basic three-phase inverter consists of three single-phase inverter switches each connected to one of the three load terminals. For the most basic control scheme, the operation of the three switches is coordinated so that one switch operates at each 60 degree point of the fundamental output waveform. This creates a line-to-line output waveform that has six steps. The six-step waveform has a zero-voltage step between the positive and negative sections of the square-wave such that the harmonics that are multiples of three are eliminated as described above. When carrier-based PWM techniques are applied to six-step waveforms, the basic overall shape, or *envelope*, of the waveform is retained so that the 3rd harmonic and its multiples are cancelled.
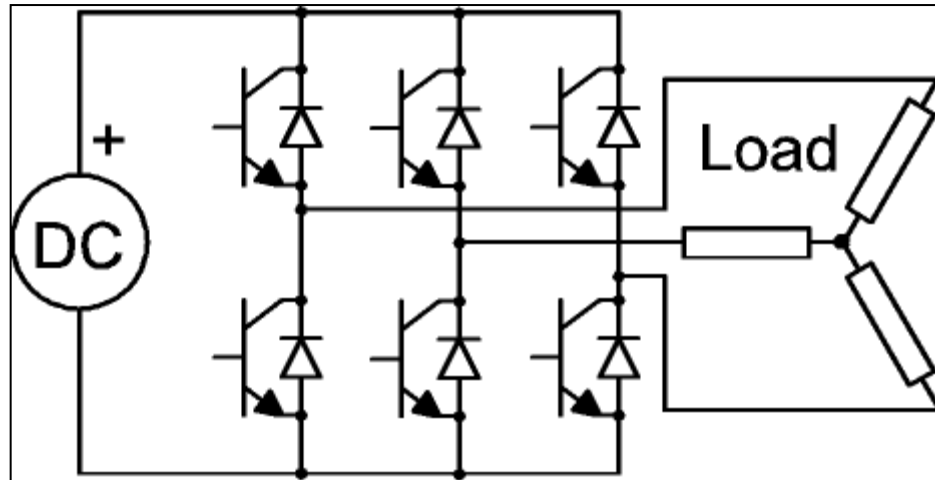
Figure 2.2: Schematic Diagram of Three Phase Inverter

2.5 Types Of Controller

There are many kinds of controllers that have been studied as to improve performance of a system. Among popular type of controller is PID controller and fuzzy logic controller (FLC).

2.5.1 PID controller

Proportional-Integral-Derivative (PID) controller is well known for its simplicity. The popularity of PID controller can be attributed partly to their robust performance in a wide range of operating conditions and partly for their simplicity engineers can operate them in a simple and straightforward manner. From it s name itself PID algorithm consist of three coefficients; proportional, integral and derivative which are varied to get optimal response. Basic idea of PID is to read a sensor, then compute the desired actuator output by calculating the proportional' integral, and derivative responses and summing those three components to compute the output [5].

A comparison paper [4] based on speed control of induction motor using PI controller and PID controller. And from their finding they come with a conclusion that PID controller gives better speed response in terms of settling time, rise time and steady state error.

A study [6] on a predictive PID controller for DC-DC converters using an adaptive prediction error filter (PEF) in the controller feedback loop has been presented. They use specific mathematical analysis such as Auto Regressive (AR) process generator and Moving Average (MA). They come out with a result that their controller has superior performance over a classical PID approach in terms of system disturbance rejection, improved stability and output regulation.

A paper [7] on controlling ac servo motor using neural network PID controller stated that in the industry, the PI or PID controller is widely used by means of servo system control. These controllers enable excellent ability if a simple control algorithm be implemented.

A paper [8] titled Design of Robust PID Controller With Disturbance Rejection For Motor Using Immune Algorithm stated that A Proportional – Integral – Derivative (PID) controller has been widely used in the most industrial processes despite continual advances in control theory. This is not only due to the simple structure which is theoretically easy to understand but also to the fact that the tuning technique provides adequate performance in the vast majority of applications.

This paper [9] presents a rule-based Mamdani type fuzzy logic controller applied to closed loop Induction Motor model. The motor model is designed and membership functions are chosen according to the parameters of the motor model. The results obtained in Simulation. The results obtained in the simulation are interesting, considering the presence of strong non-linearities in the IM Model. A conventional PI controller is compared practically to fuzzy logic controller using Simulink.

This paper [10] objective is to minimize transient response specifications chosen as rise time, settling time and overshoot, for better speed response of DC motor drive. The speed control of DC motor is done using PI and PID controllers. Implementation of PID controller for DC motor speed control is done using ZN and MZN tuning method.For PSO algorithm technique ,PI controller is used to improve the performance of DC motor speed control system. A comparison is made on the basis of objective function (rise time, settling time and overshoot) from output Step responses.

2.5.2   Fuzzy Logic Controller

Fuzzy Logic is a problem-solving control system methodology that lends itself to implementation in systems ranging from simple, small, embedded micro-controllers to large, networked, multi-channel PC or workstation-based data acquisition and control systems. It can be implemented in hardware, software, or a combination of both. Fuzzy Logic provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information. Fuzzy Logic incorporates a simple, rule-based IF X AND Y THEN Z approach to a solving control problem rather than attempting to model a system mathematically. The FL model is empirically-based, relying on an operator's experience rather than their technical understanding of the system.

A paper [11] on Fuzzy Logic Speed Control of Three Phase Induction Motor Drive where the paper present an intelligent speed control system based on fuzzy logic for a voltage source PWM. Using traditional indirect vector control system of induction motor introduces conventional PI regulator in outer space loop and PI proved that the low precision of the speed regulator debases the performance of the whole system. This problem is overcome by introducing fuzzy set controller theory. From their results, they have confirmed that the fuzzy logic controller has very good dynamic performance and robustness during transient period and sudden loads.

A paper [12] is presented on fuzzy logic speed control of an induction motor. The paper described on fuzzy logi techniques to control the three phase induction motor speed. They use Matlab/Simulink and fuzzyTECH MCU96 as software development tools for the system design. They evaluated the system performance in comparison with a traditional PI control scheme. From their result that concluded that fuzzy logic controller slightly dynamic performance when compared with a PI controller in terms of insensitivity to changes of model parameter and the speed noise. This finding can be important requirement in speed/position schemes using electrical machines, namely in robotic.

The paper [13] deals with the fuzzy logic controller (FLC) application to the field-oriented AC motor drive. Some fundamentals of the FLC are illustrated. The aspects of major importance in the application to field-oriented AC motor drives are pointed out and discussed. A FLC field-oriented drive is designed, simulated and experimented in a speed control loop. The results are compared with those obtained on the same drive with conventional digital PI type speed controller.

The paper [14] is meant to control the torque of induction motor using fuzzy logic controllers by Direct Torque Control (DTC). DTC method yields slow response during start up and change in either direction of torque and flux. Also large and small errors in flux and torque are not distinguishable so to overcome these drawbacks, fuzzy logic is applied to DTC method. Two of the most common applications are in fans and pumps in industries like Heating, Ventilating and Air Conditioning etc. In these applications, DTC provides solutions to problems like harmonics and noise. In this project we have used fuzzy logic based duty ratio controller whose optimum duty ratio is determined every switching period for the inverter.
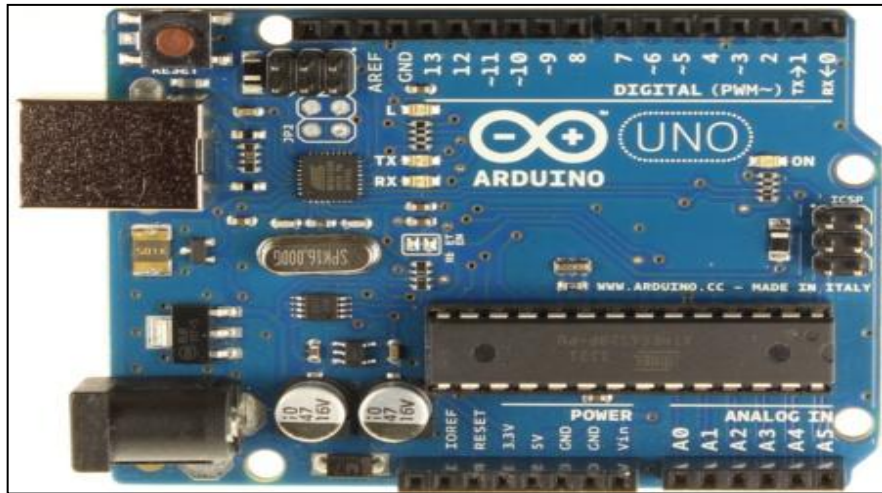
2.6   Arduino Uno

Figure 2.3: Arduino Uno Board

Arduino is an inexpensive, open-source microcontroller board that provides flexibility for introducing concepts such as control systems and mechatronics design. The Arduino platform has wide adoption and support from numerous websites, newsgroups, and user forums. Additionally, Arduino is easy to setup and use for many engineering projects. Arduino boards feature an Atmel ATmega processor and provide digital and analog connectivity and serial communications. Using the Arduino platform helps users understand the workflow for designing an embedded system without using manual programming which sometimes is hard to do the troubleshooting when error occurs. User can simply use Simulink to create algorithms for control system and robotics applications. Users can apply industry-proven techniques for Model-Based Design to verify that their algorithms work during simulation. They can then implement the algorithms on the ATmega processor on the Arduino board as standalone applications.

The advantages of the Arduino are stated below:

(i)   Inexpensive - Arduino embedded devices are inexpensive compared to other microcontroller embedded devices.

(ii)   Cross-platform - Most microcontroller systems are limited to Windows. Different with Arduino, it can runs on Windows, Macintosh OSX, and Linux operating systems.

(iii)   Simple, clear programming environment - The Arduino programming environment is easy to use for beginners.

(iv)   Open source - The Arduino software is published as open source tools, so the user easy to get the information experienced programmers.

To implement Simulink with Matlab using Arduino, only two type of Arduino were compatible with the Matlab programming which is Arduino Mega 2560 and Arduino Uno. But since three phase inverter has carrier-based PWM techniques are applied to six-step waveforms, becomes the main reason on selecting Arduino Uno as the microcontroller since 6 of its digital port, were specified for generating PWM.

Table 2.1: Arduino Uno specifications

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

A paper[15] based on Fuzzy control based solar tracker using Arduino Uno stated that Arduino Uno has open source software that is why it's quiet easy to implement control logics on this microcontroller board.

Paper on Neural Network based Closed loop Speed Control of DC Motor using Arduino Uno [16] stated that the PID algorithm and ANN controller is implemented in Arduino Uno because of its easy compatibility and portability.

A paper on Hardware Implementation of a Single Phase Inverter [17] uses Arduino to control a PS21765 Inverter. The Inverter is operated by using Arduino which generates PWM pulses. As Arduino does not accept negative signals, an offset circuit is designed to shift the Sine wave and is given as input to the Arduino kit. The use of Arduino makes the process of using electronics in multidisciplinary projects more accessible. It is well suited for processing control parameters such as speed of an Induction Motor.

In this paper [18] a novel Open loop phase control method is developed by coding a program using ARDUINO software in which ARDUINO controller takes input from the user and generates firing pulses for the TRIAC which controls the speed of the Induction motor.

CHAPTER 3

CONTROLLER DESIGN AND DEVELOPMENT

3.1   Block Diagram of the Project

Figure 3.1: Project block diagram.

Figure 3.1 shows the connection of the project. The main setup of the project is the inverter, the gate driver and the three phase induction motor and also the dc supply. Based from the block diagram the line to line voltage is measured using the voltage sensor. The measured is than compared with the reference voltage that has been set in the Simulink. All of the controller design will be downloaded into Arduino Uno. PWM is generated from the Arduino into the gate driver. The gate driver will supply a higher

PWM value that is used to turn on the 3 phase inverter. The switching signal from gate driver is used to convert the dc voltage to ac voltage thus turning on the induction motor.
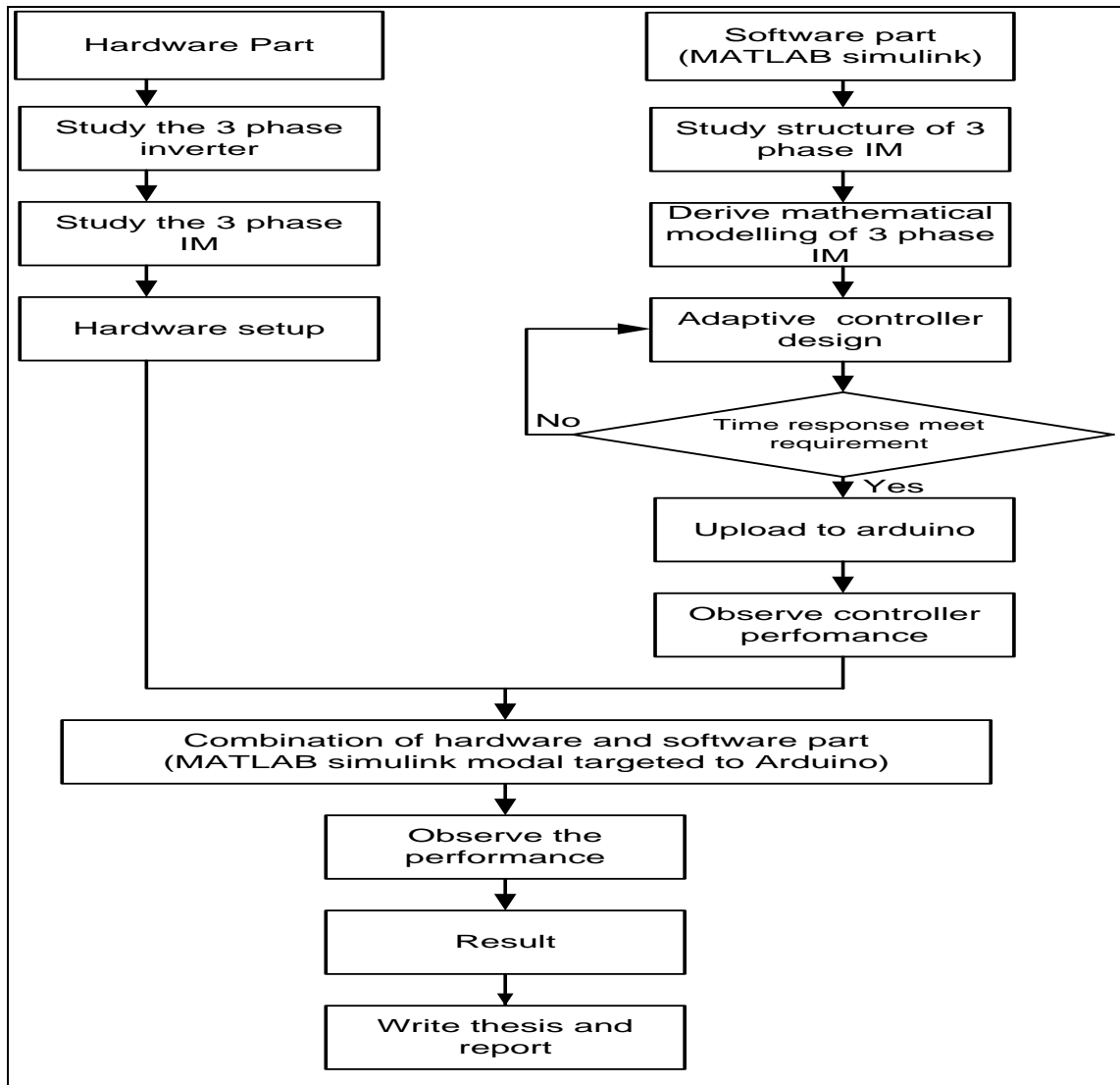
3.2   The Project Flowchart

Figure 3.2: Project flowchart

The flowchart in Figure 3.2 above shows the frame work to achieve the project objectives. For earlier stage, the task is divided into two parts, which are hardware and software. For the software part, MATLAB Simulink are the major part that needed to be

cover since most of the analysis is done by using Simulink in Matlab. The process starts with modeling process using the Simulink program based on equation, and then do the simulation as to obtain the expected output. For hardware part is to test the Simulink program from using the existing 3 phase induction motor using the Arduino microcontroller.

3.3 Arduino IO Library

In MATLAB Support Package for Arduino (also can be referred to as "ArduinoIO Package") in Figure 3.3 allows user to communicate with an Arduino Uno or Arduino Duemilanove over a serial port. It consists of a MATLAB API on the host computer and a server program that runs on the Arduino. This allow user to access Arduino analog input and ouput , digital input and ouput, operate servo motors, read encoders, and even handle dc and stepper motors using the adafruit motor shield, all from the MATLAB command line. Arduino IO also has it own Simulink library that user can used as to design their own desired control system. One advantage of using Arduino IO is that user can see the simulation based on real time.
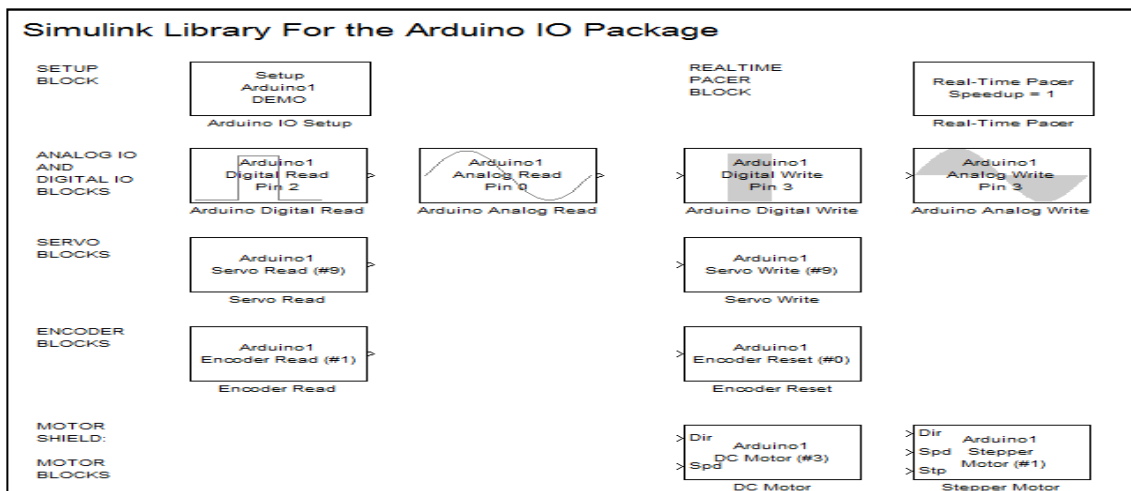

Figure 3.3 Arduino IO Simulink Library
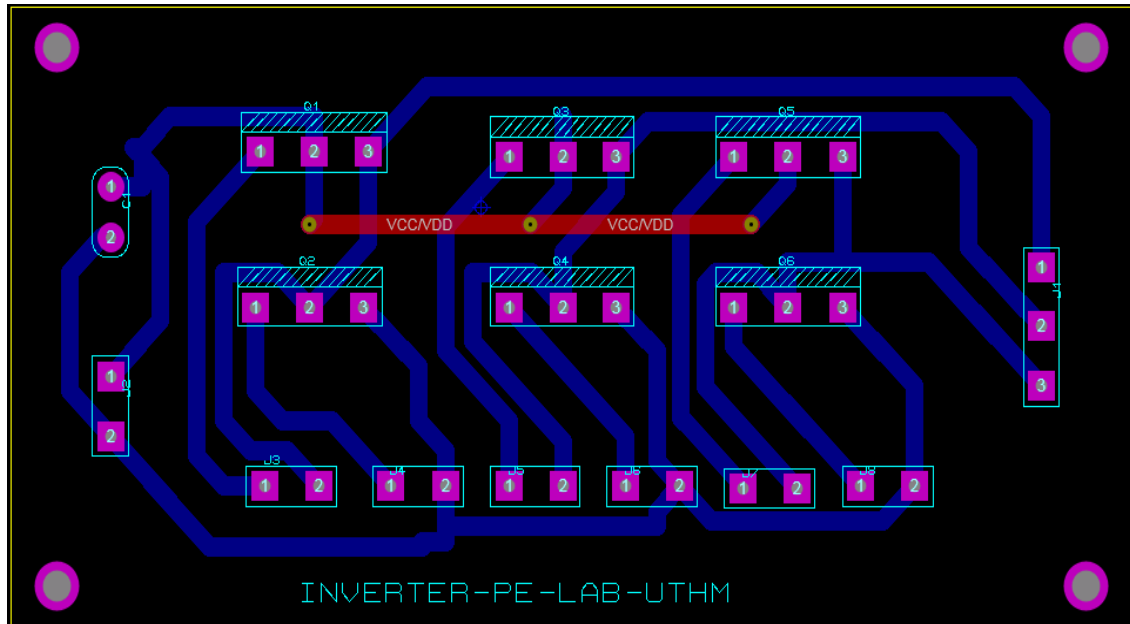
3.4   Inverter Design

Figure 3.4: six level 3 phase inverter design

Figure 3.4 shows the inverter that is used in the project. The function of the inverter is to convert any given dc voltage to ac voltage. The main power electronic device that is used SPP11N60C3 N channel MOSFET. The reason SPP11N60C3 MOSFET is used because it has a maximum drain voltage of 600V. The voltage that is needed in order to turn on the gate voltage (Vgs) for the SPP11N60c3 MOSFET is supplied from the PWM gate driver which higher than 10V.

3.4.1   Part List for Inverter

Table 3.1: Component for inverter design

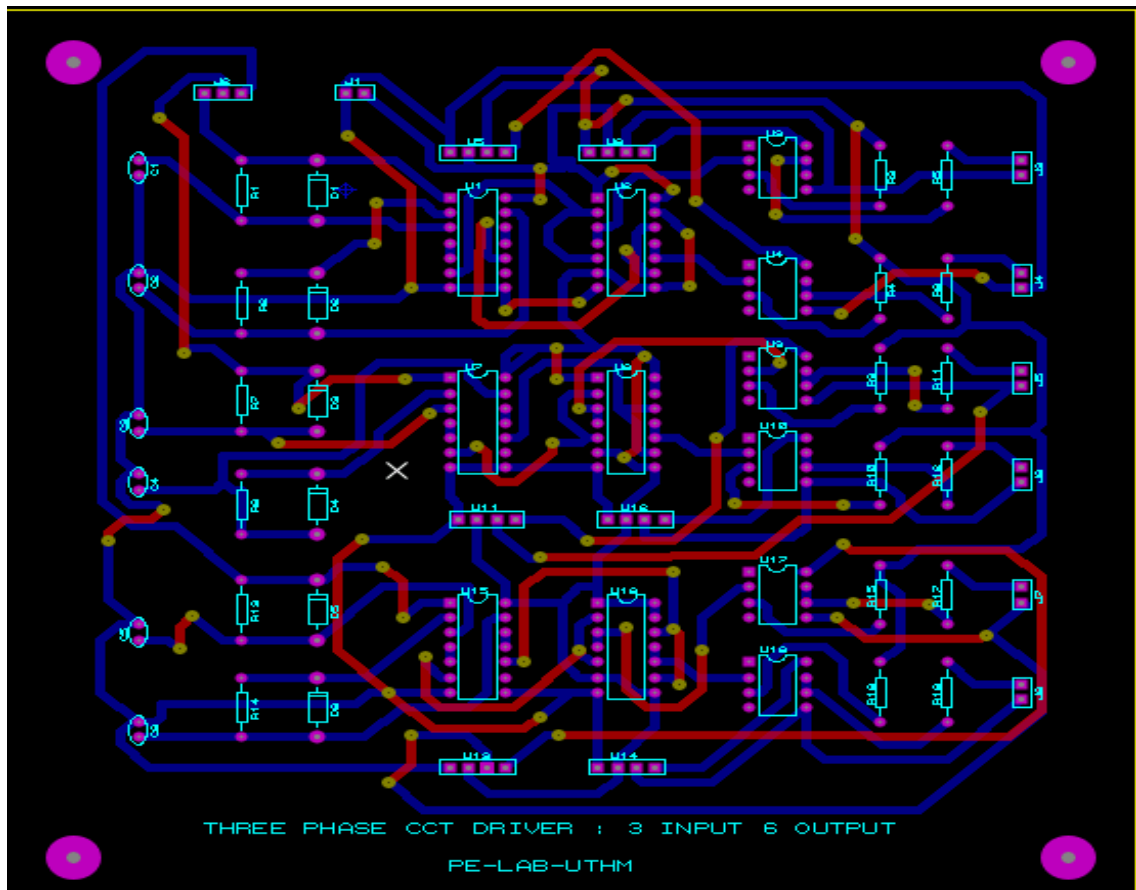| BIL	PART LIST	QUANTITY
1	SPP11N60C3 MOSFET	6
2	Capacitor 470uF	1

3.5   Gate Driver Design

Figure 3.5: 3 phase (3 input 6 output) circuit driver

Figure 3.5 shows the circuit design for the 3 input 6 output PWM gate driver. The input of the gate driver is connected to the Arduino Uno and meanwhile the output is connected to inverter. The output that is produced from the gate driver is fed to the inverter as to generate ac voltage as to generate output voltage higher than 10V which is the minimum voltage value needed to be supplied to MOSFET, IE0515S converter is used. This component converts the 5 Vdc input from the Arduino and than converts it to 15Vdc which is enough to turn on the the gate voltage of the MOSFET.

The gate driver also creates 2 PWM pulses which consist of positive pulse and also the inverted PWM pulse that needed to be sent to the MOSFET for switching action. Since

there 6 MOSFET is used. The input for the gate driver comes from the digital output pin of Arduino.

3.5.1 Part List for Gate Driver Design

Table 3.2: Component gate driver design

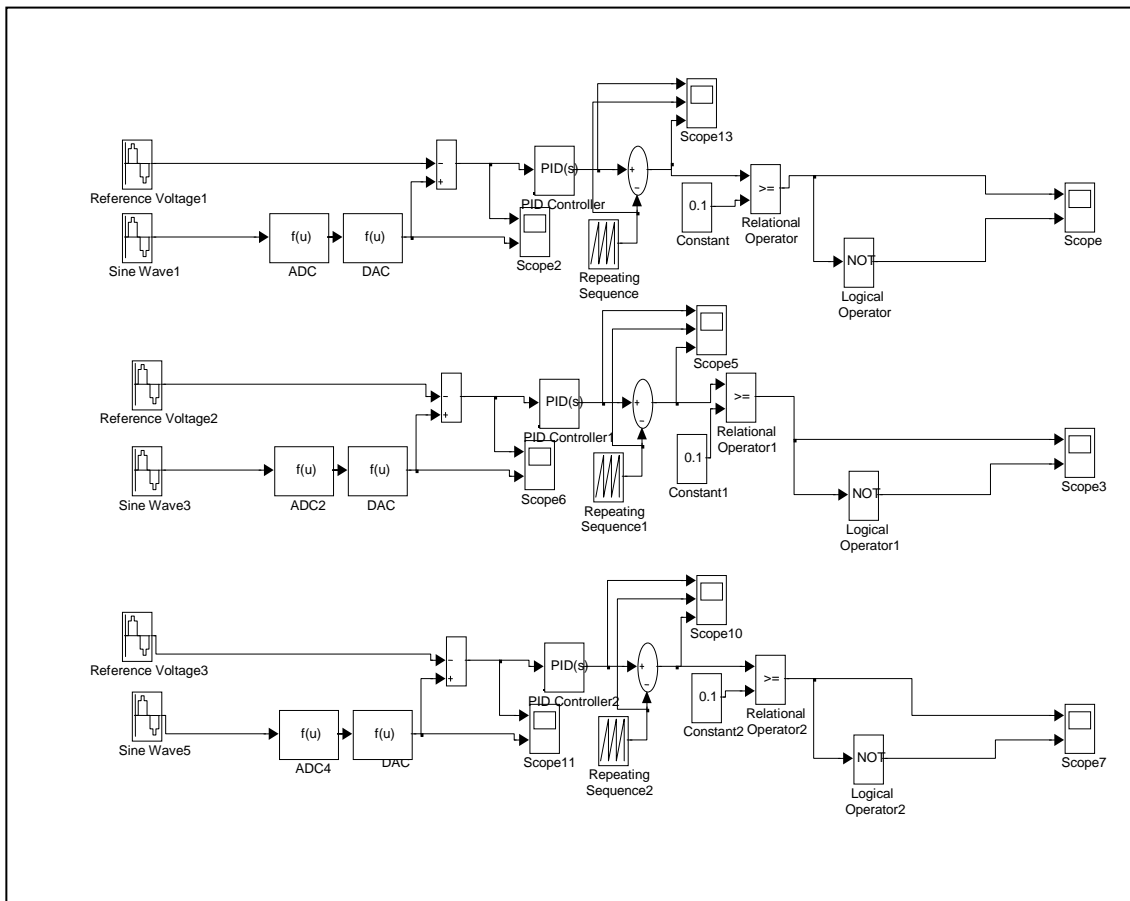| BIL	PART LIST	QUANTITY
1	1N4748	6
2	IC7414	3
3	IC4081	3
4	HCPL3120	6
5	Resistor 4.3k ohm	2
6	Resistor 560 ohm	2
7	Resistor 10 ohm	2
8	Resistor 10 k	12

3.6   Proposed Controller

Figure 3.6: The Proposed Controller

Although many researchers have been done on developing new control method for induction motors, the proportional –integral- derivative controller (PID) is still widely used in industry due to its simplicity and popularity. Over 85% of all dynamic (low level) controllers are of the PID variety. Reason on choosing PID because of their simplicity where we can operate them in a simple and straightforward manner A PID controller attempts to correct the error between a measured process variable and a desire then produces a corrective action that can adjust the process accordingly.

The PID controller calculation (algorithm) involves three separate parameters: the Proportional, the Integral and Derivative values. The Proportional value determines the

reaction to the current error, the Integral value determines the reaction based on the sum of recent errors, and the Derivative value determines the reaction based on the rate at which the error has been changing. Defining $u(t)$ as the controller output, the final form of the PID algorithm is:

$$u(t) = MV(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{d}{dt} e(t) \qquad (3.1)$$

K_p = proportional gain, a tuning parameter.

K_i = integral gain, a tuning parameter.

K_d = derivative gain, a tuning parameter.

e = error.

τ = time or instantaneous time.

The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve or the power supply of a heating.

By "tuning" the three constants in the PID controller algorithm, the controller can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set point and the degree of system oscillation.
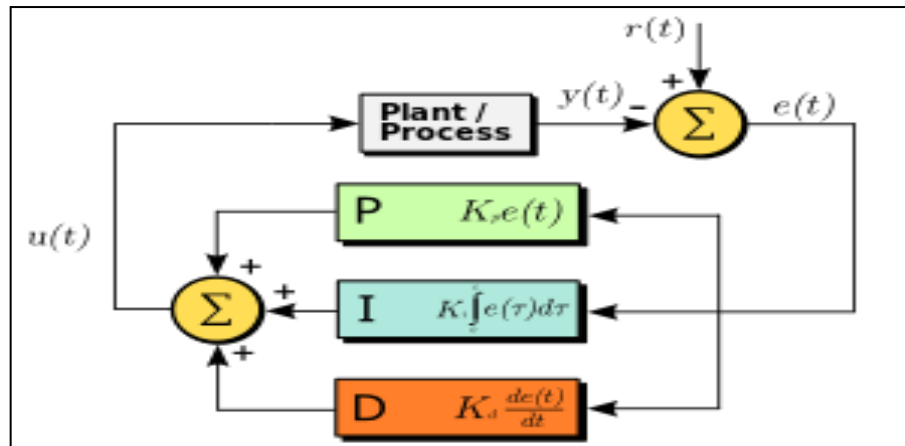
Figure 3.7: PID controller System

PID also is more practical than the typical on/off controller, PID controllers allow for much better adjustments to be made in the system.

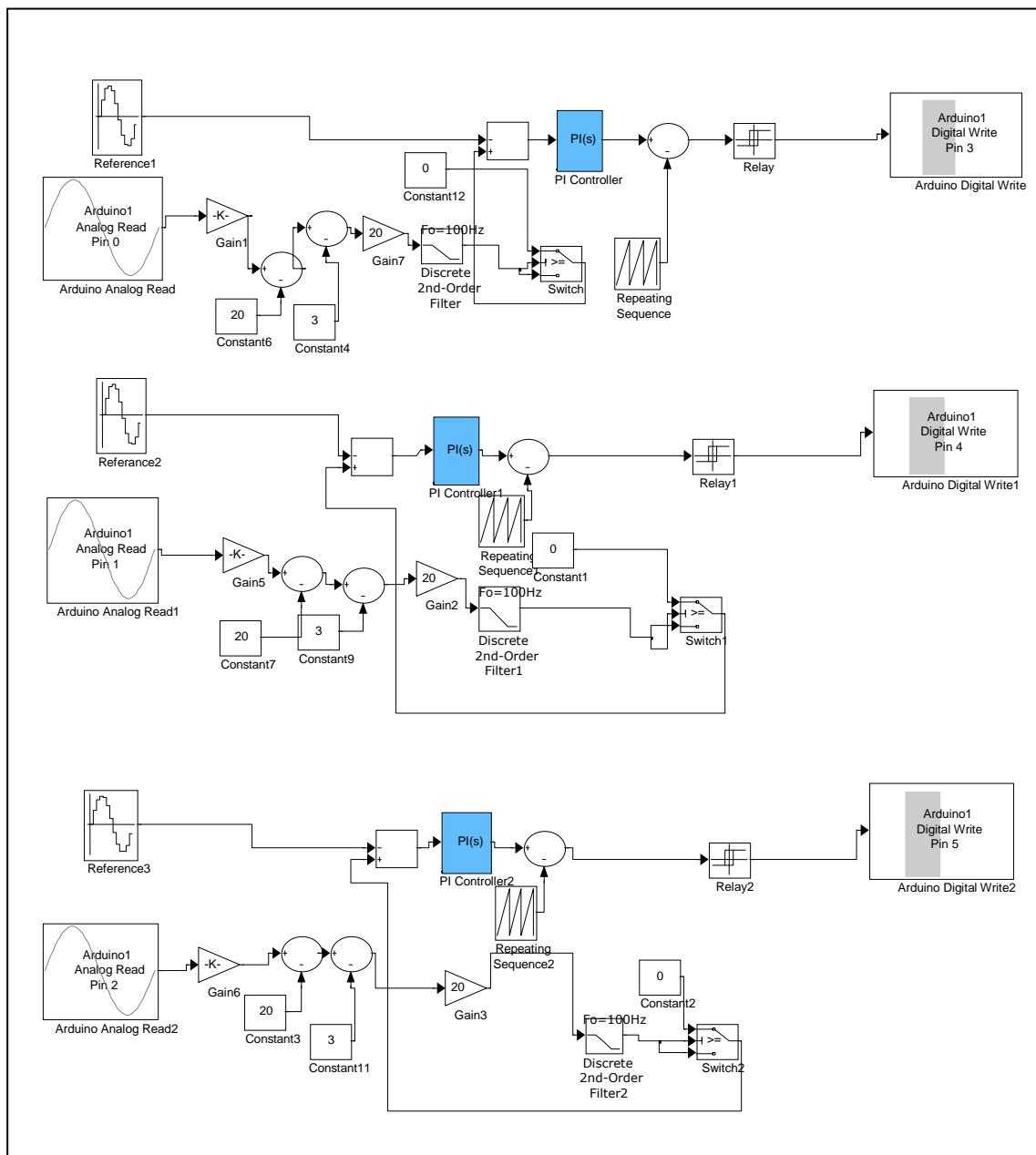## 3.7   PI Controller Design Using Arduino IO

Figure 3.8: The controller design

The controller part in Figure 3.8 is designed using Simulink tool in MATLAB 2012a by using Arduino IO block. Two blocks from ArduinoIO tools is used in the controller design which is the analog input block and also the digital output block. The analog

input block is connected directly to the voltage sensor and meanwhile the digital block output is connected directly to the gate driver circuit as to inject the PWM that is produced. The PWM is produced by injecting a saw tooth signal to the output from the PI controller. From Figure 3.8 shows the controller design that is downloaded into the Arduino Uno. The reference voltage value is compared from the value of the voltage sensor in the Matlab Simulink. The difference which is the error from reference value and measured value is then injected into a PI controller as to minimize the error that is produced.
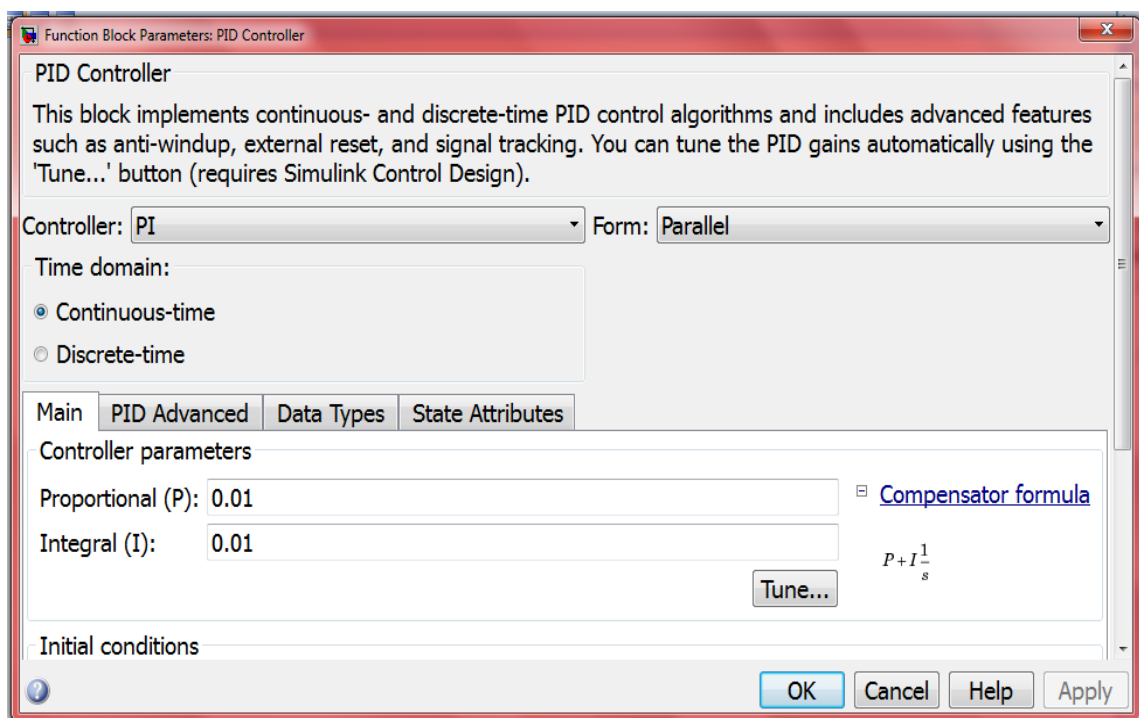

Figure 3.9: PI controller setting

Figure 3.9 shows the value that is chosen for the controller setting. The value of the proportional control and integral control that is chosen as to obtain minimum error is for proportional gain Kp = 0.01 and meanwhile for integral gain KI = 0.01. In the design also relay is used as a switching device in order to generate the PWM waveform. The PI controller is chosen because of the integral action enables PI controller enables to eliminate offset which is a major weakness in P controller. PI controller also provides

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