INTELLIGENT CONTROL OF DC MOTOR

By

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FINAL PROJECT REPORT

Submitted to the Department of Electrical & Electronic Engineering
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CERTIFICATION OF APPROVAL

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Department of Electrical & Electronic Engineering
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Approved:

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May 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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AHMAD IQBAL FAHMI BIN AHMAD KHALIL

ABSTRACT

DC Motor still plays a very important instrument in industrial field though many new designs have been develop. The current way of controlling DC Motor is by using PI feedback controller in order to achieve the set point. PI controller has been selected as the result of it advantages compare with the other types. However PI controller also contain a lot of disadvantages thus which proposed the author to proposal a new intelligent type of DC Motor controller which use Fuzzy Logic algorithm and called Fuzzy Logic Controller (FLC). Due to this thesis, Fuzzy Logic Controller has been design and fabricate. This new controller is using microcontroller, PIC 16F877A as the main device to do the decision making and been programmed using C language. The test then been conducted on PI Controller and Fuzzy Logic Controller to compare the efficiency in controlling the DC Motor. Based on the result, Fuzzy Logic Controller gives better performance compare with PI Controller. For the further studies other intelligent approach was been suggested instead of using Fuzzy Logic algorithm.

ACKNOWLEDGEMENTS

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LIST OF ABBREVIATIONS

$\emptyset_f$	Influence field flux
ω	Speed in Radian per Second
DC	Direct Current
DC Motor	Direct Current Motor
EMF	Electro Magnetic Field
FLC	Fuzzy Logic Controller
Ia	Armature Current
Iamax	Maximum Armature Voltage
I_f	Field current
K_f	Field constant
Kv	Back EMF Constant
LCD	Liquid Crystal Display
PI	Proportional Integral
PI Controller	Proportional Integral Controller
PID	Proportional Integral Derivative
PIC Controller	Proportional Integral Derivative Controller
PWM	Pulse Width Modulation
Ra	Armature Resistant
R_f	Field Resistant
t_{on}	The time taken for the switch to be on one cycle
tr	Rise Time
ts	Settling time
T_s	Time taken for a cycle
Va	Armature Voltage
Vd	Input Voltage
Vo	Output Voltag

CHAPTER 1: INTRODUCTION

1.1. Background of Study

DC Motor has played a very major part in present days. Although many new motor's design has been created, none of the designs created have being able to really replace DC Motor as a motor. DC Motor characteristic of able turning on clock direction and anti-clock direction made DC Motor special compare with the other motor. This ability made DC Motor still being used in much equipment such as elevator, crane, and electric cars. In additional to that it is important to control DC Motor in order to able DC Motor to function at maximum optimization. Besides that, the controller also needs to take care of the safety and the working specification in order to able the DC Motor to function at maximum period.

At the present technology, the common type of controller that being use is Proportional Integral Derivative (PID) feedback controller which has been used few years backward [21]. Proportional Integral Derivative (PID) type of controller becomes popular due to it characteristic that makes it simple, robust and practical in real device, thus make it become conventional kind of controller [23]. However, Proportional Integral Derivative (PID) is far from prefect and consists of disadvantages that make it replaceable. A new way of controlling DC Motor will be proposed which use Fuzzy Logic Algorithm to create Fuzzy Logic Controller (FLC).

One of major concern in using Proportional Integral Derivative (PID) controller is the complexity to use it in bigger environment which require higher capability controller. More than that, Proportional Integral Derivative (PID) controller is harder to be tuned and sometimes required more time, thus produce loss [21]. Due to this defect, many major researches have been done in order to counter the problem thus achieve better result. This development then bring artificial intelligent technology such as Neural Network Controller (ANN) [2], Model Predictive Controller (MPC) [3], Genetic Algorithm (GA) [22] and Fuzzy Logic Controller (FLC) [23].

Compare with the conventional controller, Fuzzy Logic Controller (FLC) is easier to be used as it is closer to human way of decision making. This is because, Fuzzy Logic Controller (FLC) use approximation instead of absolute decision. Besides that, Fuzzy Logic Controller (FLC) is able to be used with complex system by using Fuzzy Logic Controller's quantitative technique. Additional to that, experiment has already proved that Fuzzy Logic Controller (FLC) give better result than conventional controller in many fields. Fuzzy Logic Algorithm has been taken as in involvement between mathematical machine's ways of controlling into human's approximation decision making [16].

1.2. Problem Statement and Identification

DC Motor is currently widely used in industry due to DC Motor specific advantages. Due to that, it is important for the controller to function properly in order to gain maximum output without sacrificing DC Motor life span. Based on the current technology, the conventional controller for DC Motor is using Proportional Integrated (PI) Feedback controller [23]. However, due to it characteristics, Proportional Integrated (PI) Feedback controller gives few problem in controlling the system and DC Motor specifically.

First and for most, DC Motor have the disadvantage of giving nonlinearity effect for example dead zone, saturation, and friction thus disturb the performance of the convention controller. Additional to that, DC Motor characteristics is not easy to be extract thus makes the tuning process become hard [1] [18]. On the other hand, without properly tune, the controller would not be able to generate maximum output. Normal Proportional Integral (PI) feedback controller took time in order to settle where else Proportional Integral Derivative (PID) feedback controller tend to give overshoot [9].

Due to this defect, it is important to generate a new way of controlling the system without neglecting DC Motor requirement need to be generated.

1.3. Significant and Feasibility of the Project

Fuzzy Logic Controller is one of intelligent types of controller. Fuzzy Logic Controller (FLC) use approximation technique in order to generate the result [6]. Compare with conventional controller, Fuzzy Logic Controller (FLC) do not require specific model in order to form it controller setting. By this way, Fuzzy Logic Controller (FLC) will be able to reduce the complication of a complicated system. Besides that, according to Shaker, Fuzzy Logic Controller (FLC) has the ability to reduce the effect of nonlinearity in DC Motor when nonlinear defuzzification is being used [5]. By this way, the system will be smoother thus gain better gain in the output.

Similarly, by using Fuzzy Logic Controller (FLC) the system will have faster dynamic response but without overshoot. By this way, the system will be more practical and stable [1] [6] [18-19]. The logic works by scaling the output based on the input thus will be user friendly towards the operator as it is similar to how their work was done [23].

The overall project has been divided into two part which is the simulation part and real fabricating part. For Final Year Project One (FYP1), the project will be focus on simulation. Simulation is important in order to experiment the data and design in order to the functioned system without theoretical problem. The project then continue with fabrication and prototype analysis on Final Year Project Two (FYP2)

1.4. Objective and Scope of Study

The main objective of this project is to develop a control system a control system on DC Motor by using Fuzzy Logic Controller (FLC) on microcontroller, PIC16F877A. The improvement in this system is being conducted by substituting the present conventional control system that used Proportional Integral Derivative (PID) Feedback Controller with Fuzzy Logic Controller (FLC).

Besides that, the new system is necessary to be able to obey all the safety rules and procedures. Every system especially DC Motor have their own safety requirement. This rules and procedure is very important to be followed in order to ensure the safety of the devices and the users.

Last but not least, the objective in this project is also to observe and supply additional improvement that can be conduct and being improvise for future research. Continuity is important in order to ensure humans advancement. By this way the participation of Fuzzy Logic on control system and other field will keep continue growing and improve.

The study begins by understanding and simulating conventional control of DC Motor. The study was continued by doing research on Fuzzy Logic Controller (FLC) in control system and specifically for DC Motor. By using the research data, the Fuzzy Logic Controller (FLC) for DC Motor has being designed and being simulated in MATLAB. The result then was being observed and analysed in order to generate the best outcome. At the end, the design was t fabricated and was ensure it generate the simulated outcome. The duration of the project is two semesters which divided into FYP 1 and FYP 2.

CHAPTER 2: LITERATURE REVIEW

2.1 Controller

As for human’s body being control by brain, it is important for today’s machine to have a great control system. The controller makes sure that the machine operates by following the correct procedures, obeying all the safety measurement and be able to operate at maximum capacity. Based on this project, the controller should be able to control the speed of the motor, and must ensure that the armature current, Ia, is below the maximum armature current, Iamax.

2.1.1 Conventional Control

Commonly, the control technique that is use is by using Proportional Integral Derivative (PID) algorithm. PID algorithm function by correcting the error by comparing input and the output [9] [15]. There are three parts in the algorithm which are proportional, integral and derivative. Proportional correct the output by comparing the current value, where else integral part use the past value and derivative part conduct it by predicting the future value [9]. This condition make PID controller need memory to store the value and thus be able to conduct it calculation.

At the end side of the system sensors will be located in order to measure the output. The resulting value then will be feed back to the controller. By comparing the desire value with the resulting value, calculation will be made thus adjust the value that should be given [9]. For example, in motor controller, position sensor will be located at the end of the motor thus measures the position or the rotor or the load. The position then will be feed back to the controller thus give controller the important value to calculate the motor speed. The controller then will compare the resulting speed with the desired speed thus create adjustment in the motor speed [15]. The system design can easily view as fig. 2.1.1.

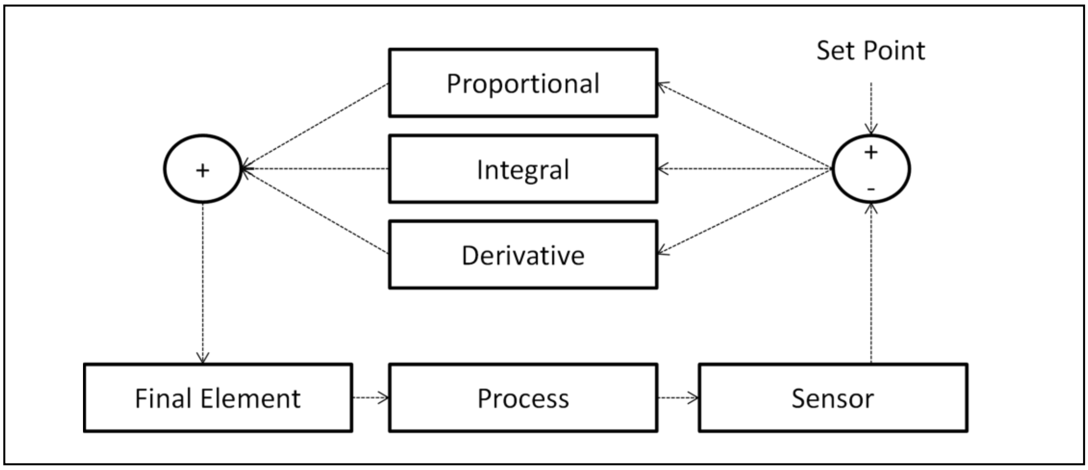

Figure 2.1. 1: Conventional PID Controller

2.1.2 Fuzzy Logic Control

Fuzzy logic was official created by Lotfi Zadeh thus bring improvement in decision making process. Normal decision making process in digital device usually only contain two resulting output which are either right or wrong, or being viewed either zero or one .Fuzzy logic however creates more detail output or can be viewed as fuzziness in the resulting output. Instead of given right or wrong decision, fuzzy logic gives partially right or partially wrong output. The result then will be ranked by it degree of truth [13] [25]. For example, in the tank, the normal result can be hot or cold. However, in fuzzy logic technique, partially hot or cold might be considered such as warm liquid. Fuzzy Logic is based on operator or researcher way of operating the system which usual does not need to understand the mathematical form of the system [2]. Fuzzy Logic Controller (FLC) can basically be divided into three parts which are Fuzzification, Fuzzy Interface Engine or also known as Rule Base and Defuzzification [5] [18].

Fuzzification is the first interface between the devices with the controller. Fuzzification interface generally will scale the input into several ranges that use linguistic variable as common operator use such as big, medium, slow, fast and etc. which need firstly been defined [1]. The common seven domains that usually used are Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (ZE), Positive Small (PS), Positive Medium (PM) and Positive Big (PB) [18-19].

Fuzzy Interface Engine or also known as Rule Base is the real controlling part of the controller. Fuzzy Interface Engine is the part that does the comparison based on the input to generate output. The general way to view the comparison is to generate the output based on IF condition. As an example, “If x is Negative Zero, Then y should be 1”, [1] [19].

Last but not least is the Defuzzification Interface. Defuzzication Interface played important role in translating Fuzzy Logic Controller (FLC) into non-Fuzzy control action [2] [4-5] [19]. Defuzzification is important in order to ensure that the controlling process run smoothly

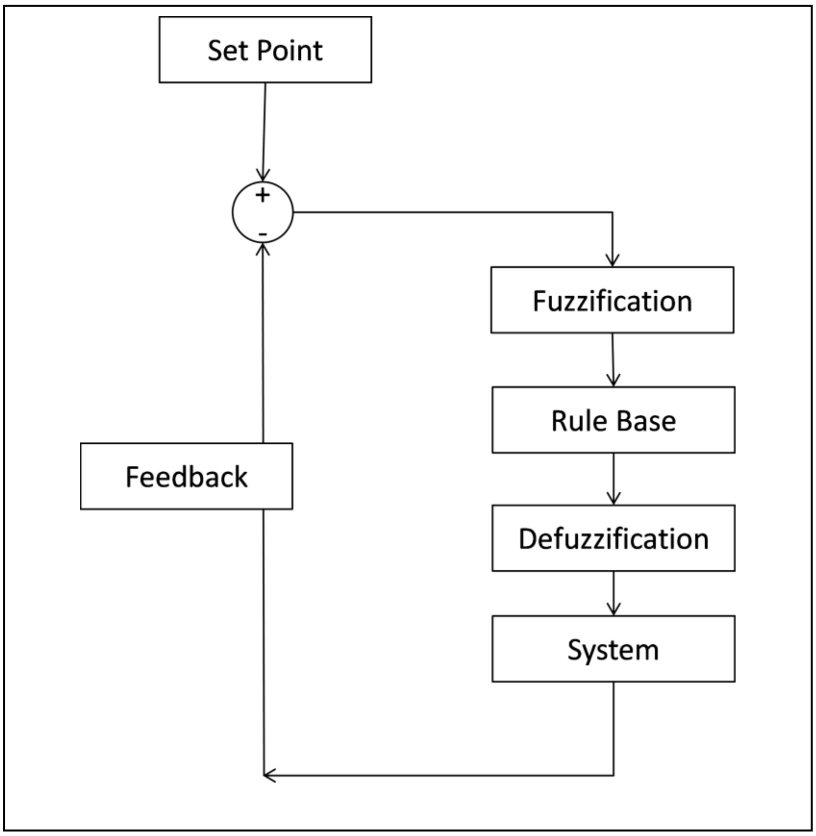

Figure 2.1. 2: Fuzzy Logic Controller Diagram

2.2 Converter

In order to control to control the speed of the motor it is necessary to have the average given voltage to be controlled. By using converter, Pulse Width Modulation (PWM) output will be generate thus will affected the speed. Converter will react as the interface between the controller and the motor. Generally there are two input type single phase converter which differentiate by the type of input which are DC input or AC input [15]. For this study, only DC input will be introduce as it will be used instead of AC input. Besides that, converter also being classified based on their characteristic and quadrant functionality. However, in this study only one of the types which are full-converter is going to be discussed.

2.2.1 DC-DC Mode Converter

Generally DC-DC converter functions by switching normal constant voltage into high speed alternating voltage. By doing so, the average given voltage will be lower than it should be thus able to control the speed of the motor [8]. The common switches that usually use are Metal-Oxide Semiconductor Field Effect Transistor (MOSFETs), Insulated Gate Bipolar Transistor (IGBTs) and Silicon Controlled Rectifier (SCR) [14]. According to Mohan, the average voltage for PWM signal's output is manipulate by the duration that the switch is on during it cycle or know as duty ratio [11]. The statement can be clearly visualized by equation (1).

$$V_O = \frac{t_{on}}{T_s} Vd \tag{1}$$

Where V_O is the output voltage, Vd is the input voltage, t_{on} the time taken for the switch to be on one cycle and T_s time taken for a cycle.

2.2.2 Full-Bridge Converter

The way that the bridge works is by switching on and off in order to give either maximum voltage or zero voltage. At the very beginning let assume that all the switches are off. In order to give positive cycle, switch one (SW1) and switch three (SW3) will be closed. The output then will received 240 V. When the output need to be 0V, the switch one (SW1) and switch three (SW3) will be open back thus generate 0V voltage at the load side [8] [11]. By changing the switches mode at high frequency, the average voltage will be affected thus affect the motor speed.

During negative cycle, the instead of switch one (SW1) and switch three (SW3) being closed, switch two (SW2) and switch four (SW4) being closed. By changing the switches, the polarity will change thus change the direction of the injected current given to the load. During this period, instead be given 240V, the load will received the value of -240V [11]. By receiving this condition, the motor can be conducted to rotate at inverse direction as the armature current and voltage are moving on different direction. Based on this characteristic and specification, by using full-bridge converter, it is possible to control four quadrant power flows for DC Motor [5] [11].

However, some safety consideration needs to take into action. For example during the changing from positive polarity, which mean to change the mode between the positive cycle to negative cycle, there must a single time for all the switches to be which called blanking time. This caution is important in order to avoid short circuit as for example switch one (SW1) and switch two (SW2) may be simultaneously close at the same time [11].

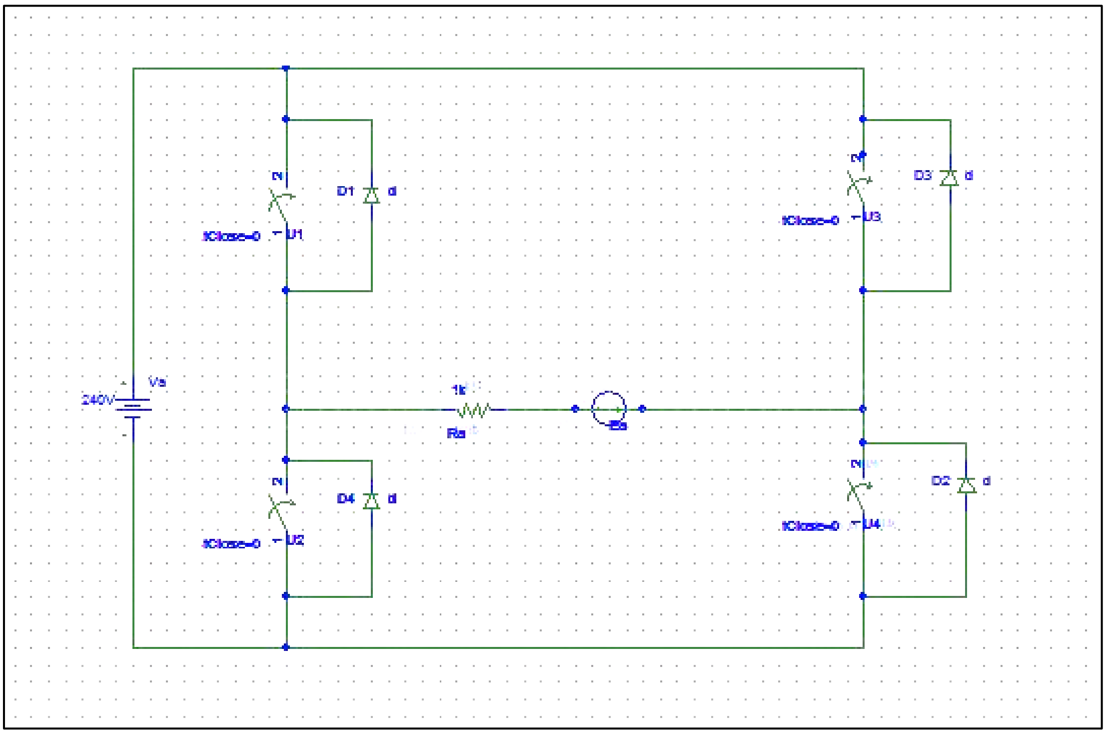

Figure 2.2.2 1: Full-bridge Converter

2.3 DC Motor

Motor is one of electrical machine that convert electrical energy in mechanical energy. DC Motor is a part of motor types that being widely used in industrial area and daily life. The ability to give two different directions makes it more applicable in certain area such as elevator, crane and etc. The basic principle of DC Motor is by generating two temporary magnets that reacting with each other by allowing current to move at certain path and direction. The force created can be control and adjust by manipulating the voltage and current value which creates different force value or by having permanent magnet that have constant value [10]. The magnetic field created provides influence field flux, $\emptyset_f$ which can be represented as equation (2).

$$\emptyset_f = kI_f \tag{2}$$

Where k_f is the field constant, and I_f is the field current. In this part, field flux is being control by field current, I_f[11].

Rotor on the other hand is the moving part or the DC Motor. Rotor consists of winding, armature winding which contain current thus resulting temporary magnet force.

2.3.1 Shunt DC Motor

Shunt DC Motor has a parallel winding between it armature winding and field winding [7] [9]. This way of connection makes sure that the induction voltage and field voltage always equally have the same and balance each other. The most advantage of shunt DC Motor is its ability to operate at constant speed. However, it is not advisable to be used in the heavy load process.

As it is parallel connected, the voltage drop is not affected by the field part. Based on voltage division, the loop can be viewed as equation (3)

$$\mathrm{V_a = E_a + I_a R_a} \tag{3}$$

Where V_T is equal to armature voltage, E_a is equal to Induction voltage, I_a is equal to armature current, and R_a is equal to armature resistant [7] [17]. The induction voltage then can be simplified by this equation (4)

$$E_a = K_v N \tag{4}$$

Where E_a is equal to induction voltage, K_v is equal to armature constant and N is equal to the speed of the motor [11]. Based on both equations, by rearrange the equation the armature constant can then be calculated and found.

$$V_a = E_a + I_a R_a$$

$$\mathrm{K_v = \frac{V_T - I_a R_a}{N}} \tag{5}$$

The equivalent circuit of Shunt DC Motor is as follow:

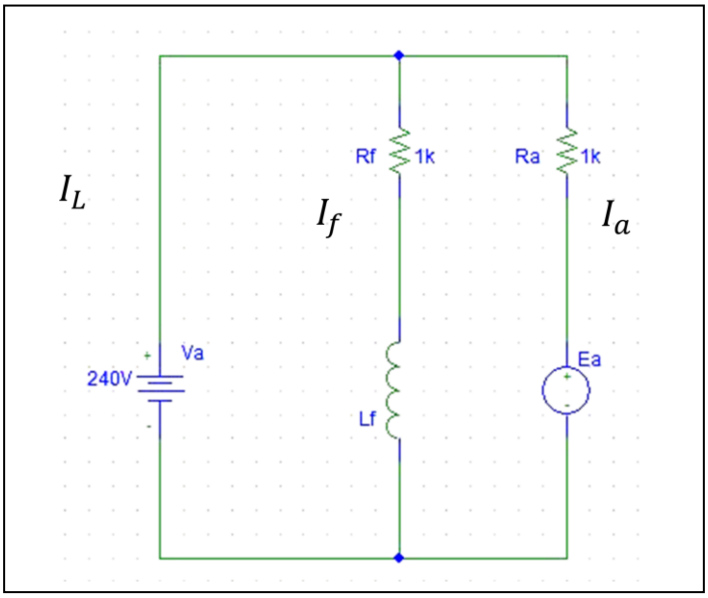

Figure 2.3. 1: Shunt DC Motor Equivalent Circuit

2.3.2 Series DC Motor

DC series motor is one of dc motor type. Compare with the other types, Series DC Motor series connection between field winding and armature winding [7] [10]. Difference winding connection gives DC Motor difference advantage compare with the other type. Due to this condition DC Motor is suitable to use for high torque function such as elevator and crane. However DC Motor have a very high changing speed between different load thus makes it harder to keep at a constant speed which make it not suitable to use in constant speed functionality. More than that, it is necessary to have load when using DC Motor as without load will make the motor speed keep increasing thus damage the motor [10]. Due to series arrangement, voltage division can be seen in equation (6).

$$V_a = E_a + I_a \, (R_a + R_f) \tag{6}$$

Where V_a is equal to armature voltage, E_a is equal to Induction voltage, I_a is equal to armature current, R_a is equal to armature resistant and R_f is equal to field resistant [7]. Additional to that, induction voltage can be calculated by another related equation (7)

$$E_a = K_a K_f I_f N \tag{7}$$

Where E_a is equal to induction voltage, K_a is equal to armature constant, K_f is equal to flux constant, I_a is equal to armature current and N is equal to the speed of the motor [13]. By rearrange all the equation, the constants, $K_a K_F$ can be found.

$$V_a = K_a K_f I_a N + I_a (R_a + R_f)$$

$$K_a K_f = \frac{V_a - I_a (R_a + R_f)}{I_a N} \quad (8)$$

The equivalent circuit of Series DC Motor is as follow:

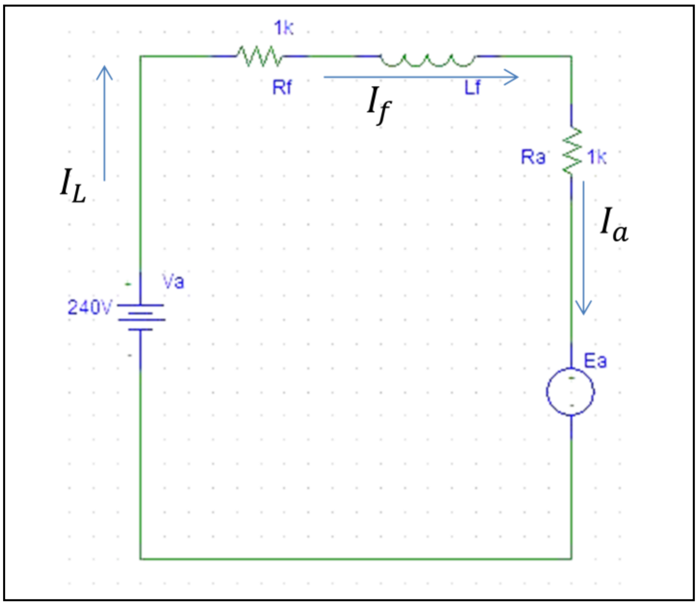

Figure 2.3. 2: Series DC Motor Equivalent Circuit

2.3.3 Safety Measurement

In dealing with DC Motor, safety measure needs to be taken in place in order to prevent the motor from damage. First and foremost the input current injected in the motor need to be control to be near to the rating current. However, at the beginning the induction voltage have not been generate yet as the motor still static thus would not have any counter EMF. This situation then creates a very high armature current as it is equal to the division armature voltage toward armature resistant. Due to that, starting resistant or know as stator is needed to control the current [7] [24]. The resistor also will be removed step by step as the current come near to the rating armature current and must be removed at the end so that the motor will gain rating speed and torque [24].

Besides that, breaking procedure need also to be well implicate in order to save the DC Motor thus keep in during it life span. In order to do so, the breaking process needs to be conduct slowly and step by step. Removing the armature voltage directly is not the right way to do it as the armature current will be too high thus damage the DC Motor. Due to that, instead of removing the armature voltage thus give zero armature voltage, the armature voltage need to be slowly reduced to lower than inductive voltage. The circuit then will give negative armature current. The DC Motor will like as a generator and reduce it speed. The process keep continue until the inductive voltage become zero which represent that the motor already stopped [21].

2.4 Four Quadrant Operations

Both converter operation and DC Motor drive operation mention about Four Quadrant Operations. This is because both converter operation and DC Motor drive operation are interacting with each other. In converter operation, the voltage output and current output is the ones that define quadrant position where else DC Motor drive is more on motor’s torque versus motor’s speed. The four quadrant operations are named based on the sequence.

2.4.1 First Quadrant

The most basic and important quadrant is the first quadrant. The first quadrant is viewed and evaluate by the armature voltage,V_a and output current, I_a or motor torque and motor speed. For first quadrant, the armature voltage,V_a and output current, I_a is positive thus the motor torque and motor speed is moving on forward direction [11-12]. This condition gives the motor torque and speed and the same direction which is clockwise direction. By this way, the motor then is accelerating on forward direction. As the armature voltage, V_a increase with motor flux, armature current,I_a flux current and torque remain constant, the speed will continue increasing. However, as the armature voltage, V_a achieved the rating voltage, it is not advisable to exceed armature voltage, V_a thus the will remain constant. The speed yet is possible to be increased by decreased the torque, motor flux and flux current [11]. The first quadrant is responsible for forward motor drive.

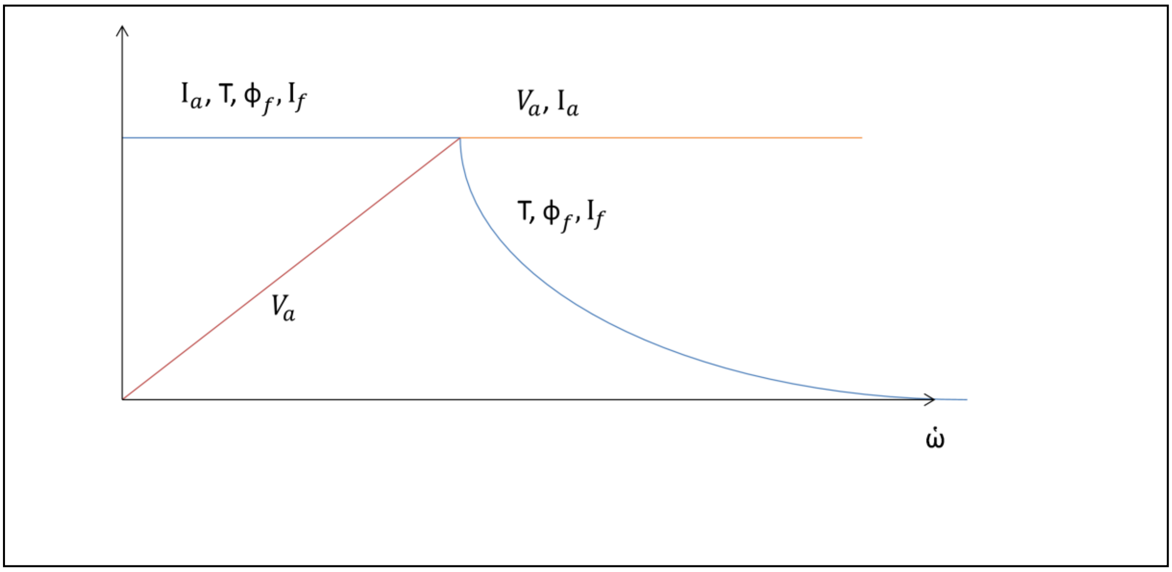

Figure 2.4. 1: Forward Drive Characteristic Graph vs. Speed

2.4.2 Second Quadrant

The second quadrant is responsible for forward breaking. During this moment, the armature voltage, V_a given is lower than induction voltage,E_a these condition make the motor react as generator. Due to that, the armature current, I_a will be negative as it coming from the induction voltage instead of the armature voltage [11-12]. The torque direction and speed direction will move on different direction. The torque direction is moving on counter clockwise where else the speed is on clock wise direction [3]. The motor then will decelerate and slowing down.

2.4.3 Third Quadrant

Third quadrant operation is almost equal with the first quadrant except the third quadrant is the inverse of the first quadrant. By the way, it's mean that the armature voltage, V_a of the motor drive will be negative. This situation then will inject negative armature current, I_a toward the system [11-12]. The torque, T and speed of the motor will be on counter clockwise direction [11]. The motor will accelerate until certain speed.

2.4.4 Forth Quadrant

As the third quadrant is inverse of first quadrant, the forth quadrant is inverse of second quadrant. Although the armature voltage given is negative, the inductive voltage is more negative than the armature voltage. This situation makes the armature current move on positive direction which is from induction voltage to armature voltage [11-12]. The torque and speed will counter each other. The torque will be on clockwise direction where else the speed is on counter clock direction [11]. The motor will then decelerate and slowing down.

The four quadrant operation for the system is summarized ain fig 2.4.2 and figure 2.4.3.

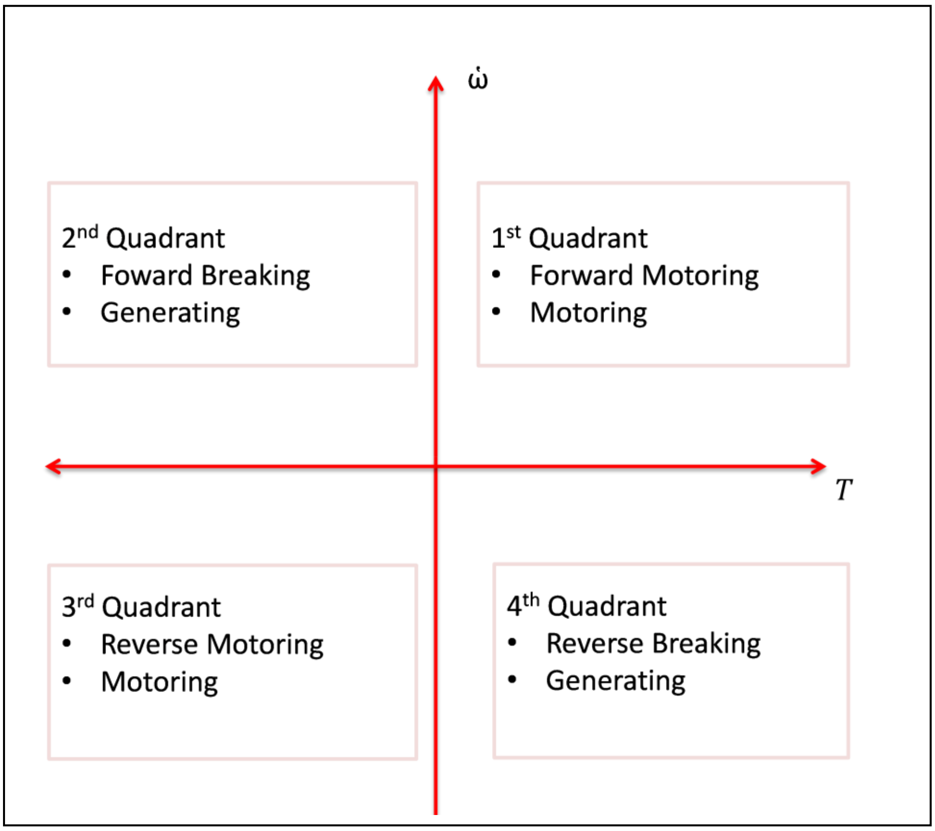

Figure 2.4. 2Quadrant Operation Modes Speed vs. Torque

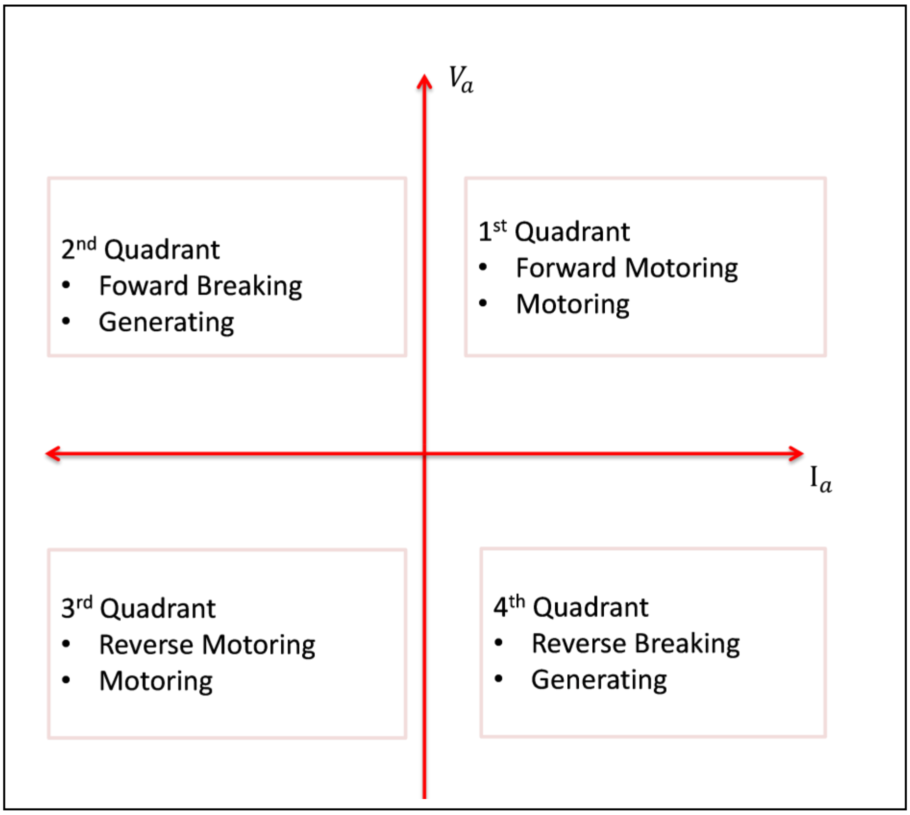

Figure 2.4. 3: Quadrant Operation Modes Armature Voltage vs Armature Current

CHAPTER 3: METHODOLOGY

3.1. Research Methodology

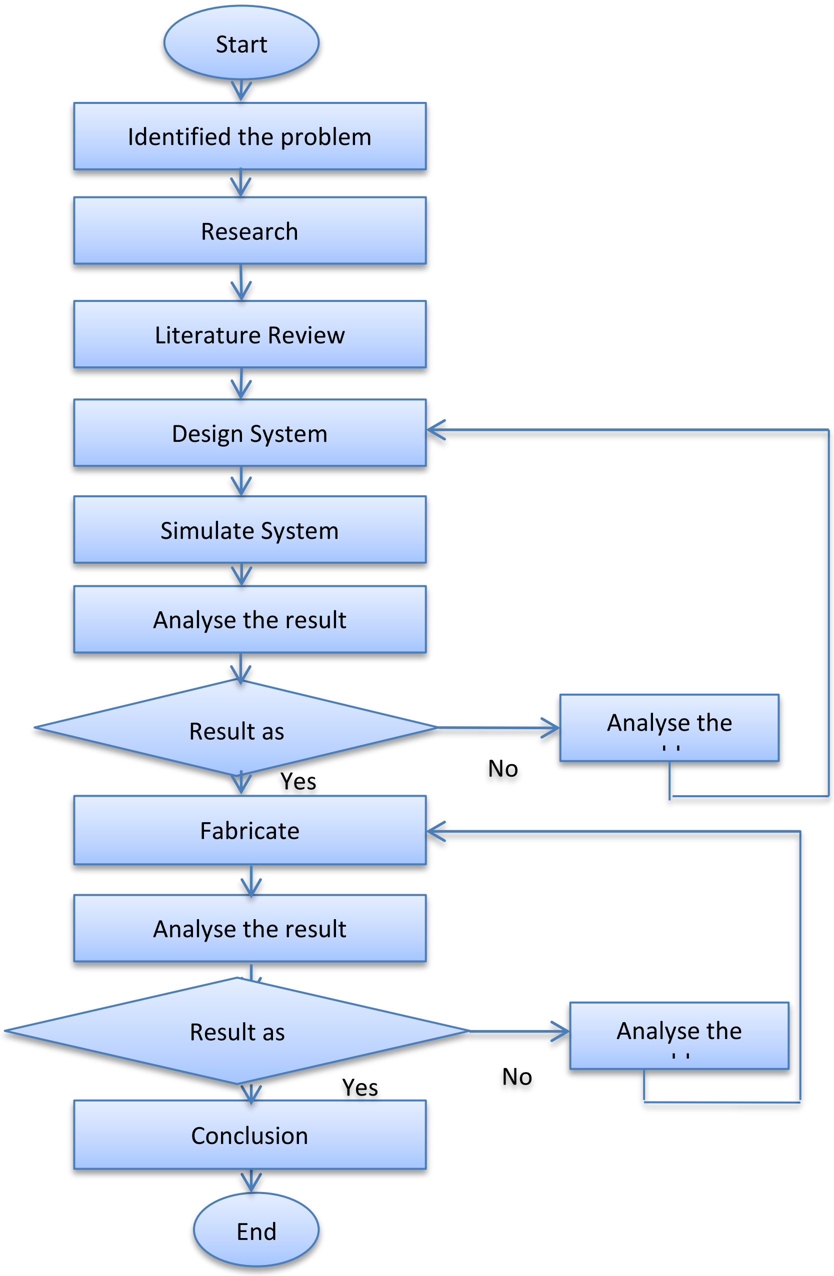

Figure 3. 1: Research Methodology

As in fig. 3.1, the research was started by identifying the problem. Through identifying the problem, the need for the project have been generate thus be able to compete in the market. Then research has been done in order to support the project needs. By doing research also more detail on the project has be known. The important data such as constant value and important steps has being gained. The data achieved then been collected and compiled in a single document which called literature review. In literature review, the similarity of the information been seen and support each other thus make a stronger base.

After that, important system specification been extracted from the data in order to make the design follow the requirement needed. Based on the design specification, the system then continue being design and being fabricated in the simulation software. The system then being simulate thus be able to demonstrate a step to be real product. The result then being analysed, if the result is as expected, the system can be fabricated, if the result is not expected, more analyses will be conducted and the simulation will be redone. After being fabricated, the fabricating output will the again being analysed either it is as expected or not as expected. If the result is correct, the project can be concluded. On the other hand, if the result is not as expected, further study on the result will be conducted and the loop will be continue until the result is satisfied.

3.2. Project activities

The project was begun by doing the research in order to gain knowledge on the involved field. The research was on DC Motor, converter, four quadrant system, and Fuzzy Logic Controller (FLC). The project then continued on collecting the data from the hardware instrument which the DC Motor and the full-bridge converter. By doing so, the experiments and design will be according to the desired instrument.

After that, simulation on the conventional control system being conducted which by using Proportional Integral (PI) feedback controller to control DC Motor. The system must be sure simulated properly and taking cared on every safety aspect.

The project activities then was continued by fabricating the conventional DC Motor controller which by using PI Controller. This fabricating is important in order to understanding the basic principle of conventional controller besides being able to prepare a benchmark for the new designed controller.

Next, the Fuzzy Logic Controller then was designed and fabricated. The new controller was designed by using microcontroller, PIC16F877A, as it main controller part. Then the comparison between conventional controller and Fuzzy Logic

Controller on the both performance has been conducted. This comparison is important to ensure that the new controller can give better performance compare with conventional controller.

3.3 Program Sequence

As the whole system was controlled by the microcontroller, PIC16F877A, the programming part is major part of this project. The programming was done by using MPLAB and using C language.

The programming sequence is been built based on Fuzzy Logic Theory thus create Fuzzy Logic Controller. The program at the beginning will compare the between the desired value (Sp) and resulting value (Mv). If the value is equal, which mean the desired value (Sp) is the resulting value (Mv), the action will be maintained which mean the current armature voltage, Va will remain the same. This state is labelled as Zero Error (ZE).

On the other hand, if SP is higher than Mv, the Va will be changed. The next comparison then will be conducted in order to know in which type is the different. If the different is big, the state will be labelled as Positive Big (PB), if it is medium, it will be Positive Medium (PM) and Positive Small (PS) is for small error. Big additional armature voltage will be fed in PB state, medium changes in PM and small additional value in the armature voltage in PS. However, the armature current, Ia also need to be considered, on each state the Ia need to be ensured below the maximum armature current, Iamax allowed. The Ia can be found as equation (9)

$$I_a = \frac{V_a - \omega K_v}{R_a} \tag{9}$$

Where Ia is equal to armature current, Va is armature voltage, Ra is armature resistant, Kv is back EMF constant, and ω is the motor speed in radian per second. By this condition, if the changes on armature voltage, Va is too big and exceed maximum armature current, the state will be change to the next lower state. For example, if the speed different is big and the state should be in Positive Big (PB) but the calculated value for armature current, Ia will exceed the maximum value allowed, the state for that condition will move to Positive Medium (PM) and will continue until the armature current under the safe range.

However, if the Mv is higher than Sp, the situation is different. If the difference is big the state will be Negative Big (NB), if it is medium it will be Negative Medium (NM) and it will be Negative Small (NS) for small difference. When the condition is NB, big value will be deducted from the current Va, medium value for NM and small value for NS. The Ia again need to be ensure below Iamax in order to avoid damaging the motor. The Ia direction however is inverse of normal Ia direction as the Back EMF is higher than the Va thus will make the current flow from the motor. The absolute Ia can be calculate based on the equation (10).

$$I_a = \frac{\omega K_v - V_a}{R_a} \tag{10}$$

Where Ia is equal to armature current, Va is armature voltage, Ra is armature resistant, Kv is back EMF constant, and ω is the motor speed in radian per second. This condition is breaking condition. In order to avoid that the armature current might exceed the maximum value allowed, the same procedure during acceleration condition also been conducted in breaking condition.

As the breaking happened, the armature voltage, Ia will be lower than back EMF value. However, if the difference is too big, the armature current will exceed the allowed range. In order to counter this problem, the state for this condition will move to the lower state. For example, if based on the speed difference, the state should be Negative Big (NB); however the armature current, Ia was calculated to exceed the maximum armature current value. Due to this condition, the state will change to Negative Medium (NM). The program sequence is visualized as in the flow chart as Appendix A.

3.4 Hardware Layout

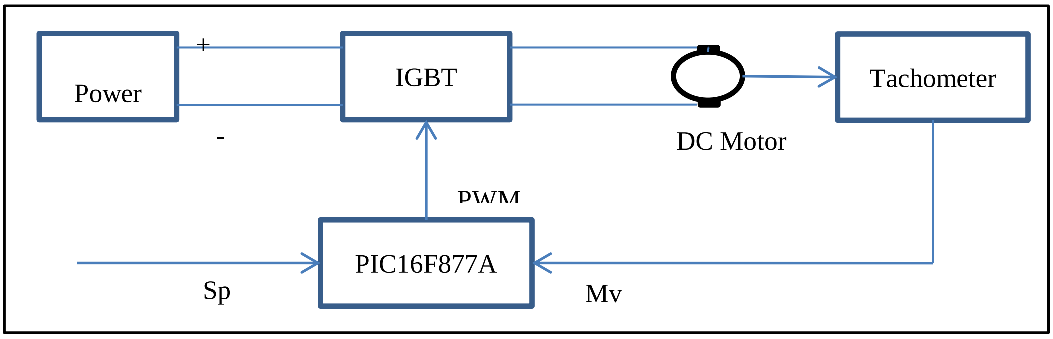

Figure 3.4: Hardware Layout

As shown in fig. 3.4, the power supply will provide 240 VDC toward the IGBT and then connected to the DC Motor. The IGBT will react as switch to control the motor either to turn it ON or OFF. The IGBT input will be controlled the Pulse Width Modulation (PWM) from the Programmable Interface Circuit (PIC). The PIC will give PWM value which are 0v and 5v to ON and OFF the IGBT based on the output wanted to be generated. The tachometer was connected with the DC Motor, the tachometer is to convert the kinetic energy in the motor speed to voltage value to be able to use by the PIC for further process. The PIC then will use reference speed value from the tachometer and desired value from the user to control the motor speed.

3.4. Gant Chart and Milestone for FYP 1

Table 3.3: Gant Chart and Milestone

No	Activities Details \ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Title Selection														
2	Preliminary Research Work														
3	Extended Proposal Submission														
4	Simulation on Conventional Control System														
5	Proposal Defence														
6	Analysing on The Result														
7	Draft Report Submission														
8	Final Report Submission														

Process	
Suggested	

3.5. Gant Chart and Milestone for FYP 2

Table 3.4: Gant Chart and Milestone for FYP 2

No	Activities Details \ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Model Development and Modification Work														
2	Testing and Validation work														
3	Submission of Progress Report														
4	Results Analysis and Discussion														
5	Pre-EDX														
6	Submission of Draft Report														
7	Submission of Dissertation														
8	Submission of Technical Paper														
9	Oral Presentation														
10	Submission of Project Dissertation														

Process	
Suggested	

3.6. Tools Used

The import tool that was being used in simulation part is Simulink which is a part of MATLAB version R2011a. MATLAB and Simulink are registered under MathWorks, Inc. Simulink is important in order to simulate the whole control system by using Simulink Library Tools.

One of the most important parts in the prototype is PIC16F877A which is a microcontroller produce by Microchip. This chip is important in order to programme the controller according to the desire system. The next instrument is PIC Start-up kit, SK400C and PIC Programmer which use to load the program into the PIC. The PIC however was programmed using MPLAB which was license under Microchip Technology Inc.

The next instrument the prototype is Lab-Volt Model 8837-B – IGBT Chopper/Inverter, Model 8211 – DC Motor/Generator, and Model 8931 – Speed Sensor / Tachometer.

CHAPTER 4: RESULT AND DISCUSSION

4.1 Extracting Data from Instruments

Armature Speed, Ra= 31Ω

Trial Speed, ω = $\frac{1025 \text{ x } 2\pi}{60} =$ 107.33 radian/second

Armature Current, Ia = 80mA

Maximum Armature Current, Iamax=2.2A

Armature Voltage, Va= 192 V

Back EMF constant value, Kv=

$$K_v = \frac{V_a - I_a R_a}{\omega} \tag{11}$$

$$K_v = \frac{192-(80m)(31)}{107.33} = 1.765 \text{ vs/rad}$$

4.2 Simulation Diagram on PI feedback controller

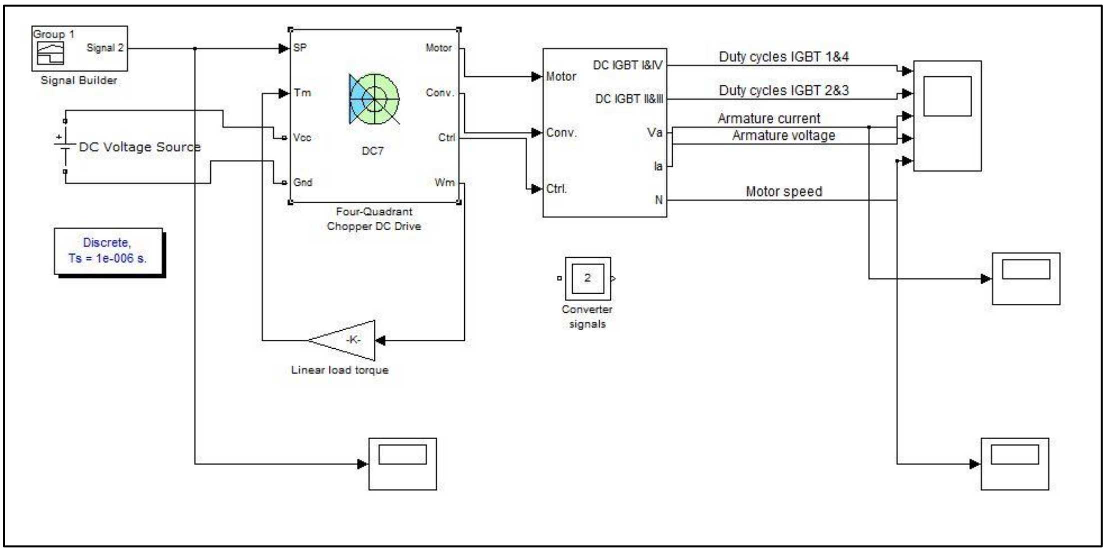

Figure 4.2: PI Feedback Controller Diagram

In order to visualize the conventional DC Motor control, the diagram to generate conventional type of speed output been generate first. In this diagram (fig 4.2), the given input will be steps changes of different speed reference which will be send to the controller. The controller then will control the PWM circuit and control the output of the full-bridge circuit which control the average output given to the motor. The current motor speed then will fed back to the PI controller and will be compared with set point in order to achieve the set point.

4.3 Simulated Generated Output on PI Controller

Based on the diagram, the output speed vs. time graph was able been generated. The step input has been generate so that the output can be varied based on the 4 quadrant operation mode

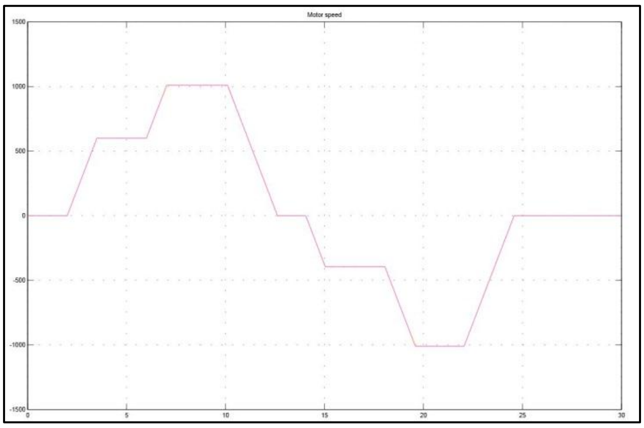

Figure 4.3: Motor Speed Output

In the first quadrant operation, the input speed has been change from 0 rpm to 600 rpm, and from 600 rpm to 100 rpm thus creates changes in the output accordingly. During this time the motor will accelerate in order to increase it speed thus able to achieve the set point value.

For second quadrant operation, the input has been change from 100 rpm to 0 rpm thus simulate the breaking procedure which show the output relationship versus time. The motor will decelerate to reduce it speed and finally stopped when the speed is zero. The state of motor it called breaking.

For the third quadrant operation, the input step changes have been given as from 0 rpm to -600 rpm and from -600 rpm to -1000 rpm. The negative sign is the representative of the inverse direction. The motor start to move at inverse direction and accelerating until it able to achieve the desired value and continuingly maintained it speed.

For the fourth quadrant operation, the breaking process occurs in the inverse direction as the motor is breaking from -1000 rpm to 0 rpm. After moving at inverse direction the set point has been set so that the motor will break from the reverse direction. The motor will decelerate until the speed is zero and would not move until new speed has been set up at the set point.

4.4 Discussion on Problem with PI Controller

Based on the result on fig 4.4.1, it seems that PI controller did not give a good input as overshoot been generated in order to achieve the set point. High overshot is will give a very bad effect towards the system as the output exceed the desire value and may disturb the system or reduce the motor's life span if it exceed the motor's maximum value.

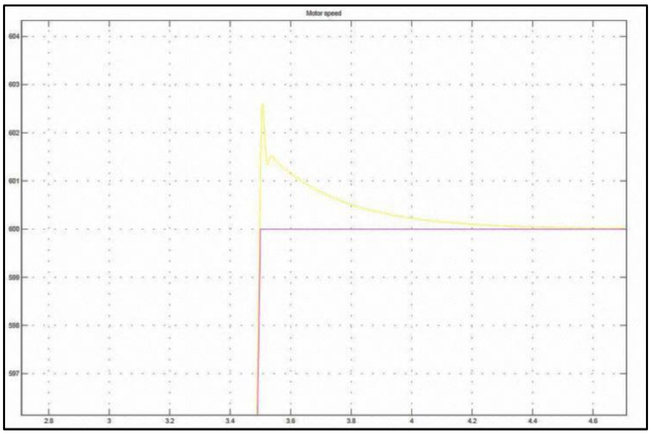

Figure 4.4.1: Overshoot

Besides that, PI controller also has slow time response which shown at fig 4.4.2. At certain scenario, this system is not appropriate and need to be better. In this system it took about 1.4 s for the output arise above the set point. Better system should have lower rise time and settling time which shows that the system has better dynamic response.

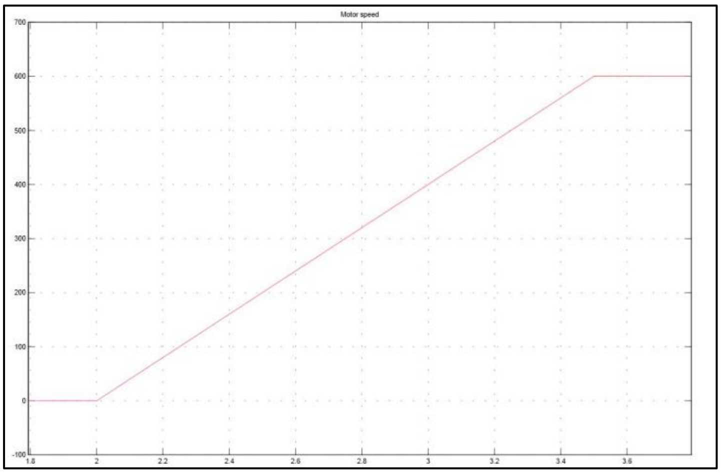

Figure 4.4.2: Rise Time

4.5 Fabrication Results and Discussion

4.5.1 Conventional PI Controller without Load

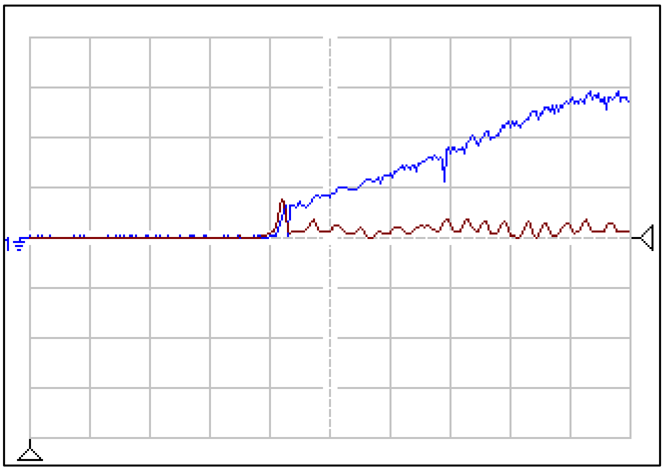

Figure 4.5.1: Conventional PI Controller without Load

Where: X-axis: Time 1 unit=0.5 s,

Y-axis: Speed (Blue) 1 unit=500rpm

Armature Current (Blue) 1 unit=1A

4.5.2 Fuzzy Logic Controller without Load

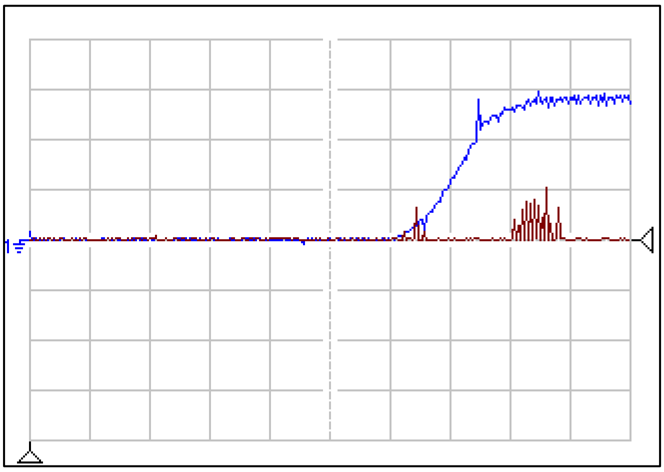

Figure 4.5.2: Fuzzy Logic Controller without Load

Where: X-axis: 1 unit=0.5 s,

Y-axis: Speed (Blue) 1 unit=500rpm

Armature Current (Red) 1 unit=1A

4.5.3 Conventional PI Controller with Load

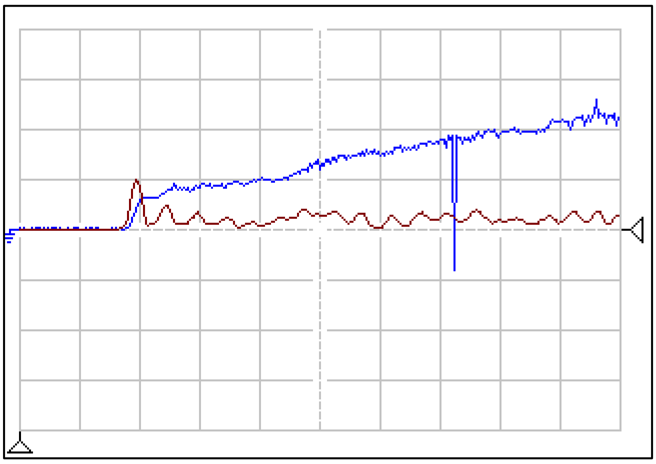

Figure 4.5.3: Conventional PI Controller with Load

Where: X-axis: Time 1 unit=0.5 s,

Y-axis: Speed (Blue) 1 unit=500rpm

Armature Current (Blue) 1 unit=1A

4.5.4 Fuzzy Logic Controller with Load

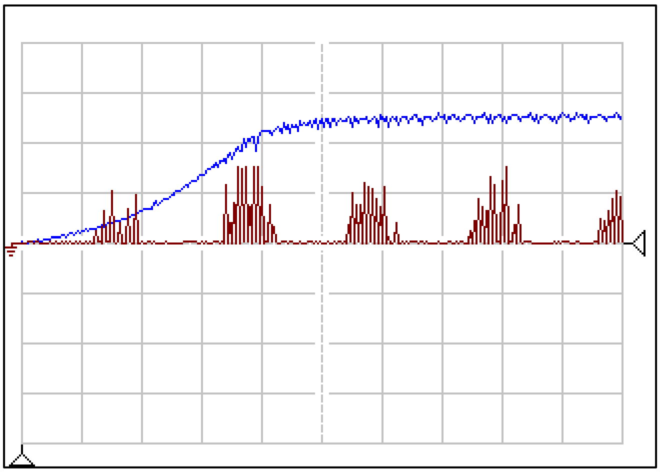

Figure 4.5.4: Fuzzy Logic Controller with Load

Where: X-axis: Time 1 unit=0.5 s,

Y-axis: Speed (Blue) 1 unit=500rpm

Armature Current (Blue) 1 unit=1A

4.5.5 Performance Analysis

The comparison was conducted between PI Controller and Fuzzy Logic Controller to determine the significant of the project. The test was divided into two categories which are without load step change and with load step change.

Based on without load experiment's result as in table 4.5.5a, Fuzzy Logic Controller give better result compare with Conventional PI Controller. Fuzzy Logic Controller give smaller rise time and settling which shows that Fuzzy Logic contain better dynamic response and more sensitive.

The same result also appears in with load test as on table 4.5.5b. Fuzzy Logic Controller gives better settling time and rise time. This test shows that Fuzzy Logic Controller able to perform better than conventional controller with and without load. However, with load test give bigger rise time and settling time due to the need of more power and time to move bigger load.

Table 4.5.5a: PI Controller and Fuzzy Logic Controller without Load

Performance	**Conventional Controller (fig 4.5.1)**	**Fuzzy Logic Controller (fig4.5.2)**
Settling Time, ts	2.14 s	0.89 s
Rise Time, tr	2.53 s	1.16 s
Offset	0	0
Overshoot	0.06%	0.06%
Feedback Needed	2 (Speed Feedback & Armature Current Feedback)	1 (Speed Feedback)

Table 4.5.5b: PI Controller and Fuzzy Logic Controller with Load

Performance	**Conventional Controller (fig 4.5.1)**	**Fuzzy Logic Controller (fig4.5.2)**
Settling Time, ts	3.07 s	1.90 s
Rise Time, tr	3.80 s	2.37 s
Offset	0	0
Overshoot	0.15%	0.06%
Feedback Needed	2 (Speed Feedback & Armature Current Feedback)	1 (Speed Feedback)

4.6 Prototype

The prototype was shown in fig. 4.6.1. The prototype contains two switches which are push ON and push OFF switch. The prototype also has a toggle switch for the user to decide the set point value. Before the push ON switch being pushed, the LCD screen will display welcome words to the user; the words however are adjustable according to the user or the company's desire. After the system was on, the LCD will display the set point and the feedback speed, by this way, it will be easy for the user to know and control the speed. When, the push OFF button being pushed, the LCD will again display as at the beginning and wait for the push ON button being pushed.

Figure 4.6.1: Prototype’s Picture

As shown in fig. 4.6.2, the prototype use 240v-50Hz power source and will supply PWM output to IGBT Bridge based on the feedback from the tachometer. The IGBT Bridge received 240v DC from power supply armature voltage towards the DC Motor. The DC Motor then will be controlled by the average speed from the IGBT Bridge.

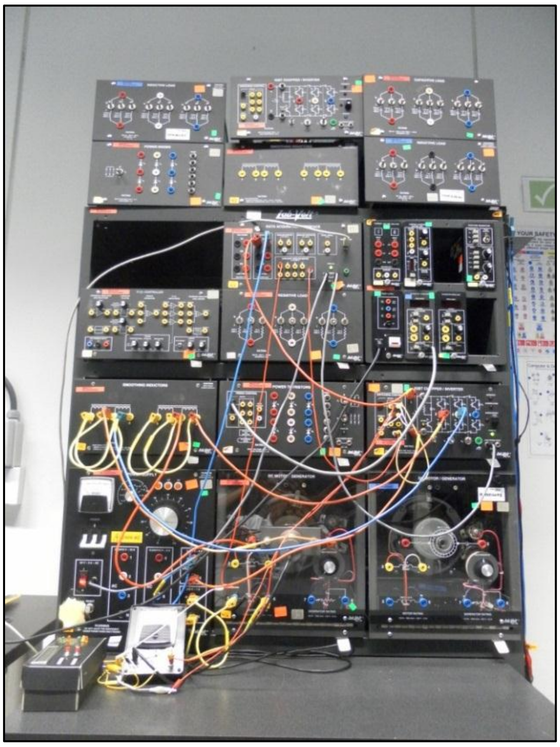

Figure 4.6.2: Prototype External Connection

The Prototype specification was summarized in Table 4.6. The prototype has followed common standard as it use 240 V-50 Hz input power which is standard power source in Malaysia. The prototype then will control the IGBT Bridge the give PWM output 5V for ON condition and 0V for OFF condition. The prototype can received the feedback speed as voltage input from 0 to 3 V which represent 500 rpm per volt which can be compared with the output range which are from 0 to 1500 rpm. Last but not least, the prototype is easy to carry as it has a very suitable dimension.

Table 4.6: Prototype Specification

Specification	**Value**
Input Power	240 V – 50 Hz
PWM Output	ON = 5V OFF= 0V
Speed Reference Input	0V (0 rpm)-3V (1500 rpm)
Speed Range Output	0rpm-1500rpm
Dimension	85 mm x 152 mm x 82 mm

4.7 Prototype Limitation

The product however contains a limitation due to PIC 16F77A memory limitation. The maximum memory allowed in the PIC is on 256 Byte. Due to this deficiency, this product only is able to conduct in first and second quadrant.

4.8 Problems and Solutions

During making this project, few unexpected problems occur. First and foremost, the different gap of time cycle between the field device and the controller. This difference makes the controller assume that the device did not do any changes when the situation is the opposite. In order to fix this problem, at certain time, the controller need to wait the changes created by the field device before continue with other action.

CHAPTER 5: CONCLUSION

5.1 Relevancy to the Objectives

Current DC Motor control use Proportional Integral (PI) Controller and the speed controller. However, the conventional controller is hard to be tuned and without proper tune the performance will not be optimized besides will give bad effect towards the system.

In order to counter this issue, a new controller using Fuzzy Logic Theory was generated to give better performance besides to upgrade the other ability. Fuzzy Logic Controller use human-like method to control the speed makes the system simpler and easy to be understood.

Based on the result, Fuzzy Logic Controller generated better performance compare conventional Proportional Integral (PI) Controller react better in speed control. This outcome concludes that the newly generated controller is a successful project.

5.2 Suggested Future Work for Expansion and Continuation

Proportional Integral (PI) has been well established as the best controller for speed controller. However, the new technology has generated new ways and methods to control the speed. New intelligent control's methods have keep generate time to time. Excluding using Fuzzy Logic Theory to create the controller, other intelligent control theory would like to suggest such as Neural Network Controller (ANN) [2], Model Predictive Controller (MPC) [3], Genetic Algorithm (GA) [22] and Fuzzy Logic Controller (FLC) [23]. These deferent algorithms have different approach in controlling the system thus will give different result. By doing so then the best controller for each device can be create and give the best performance for the system.

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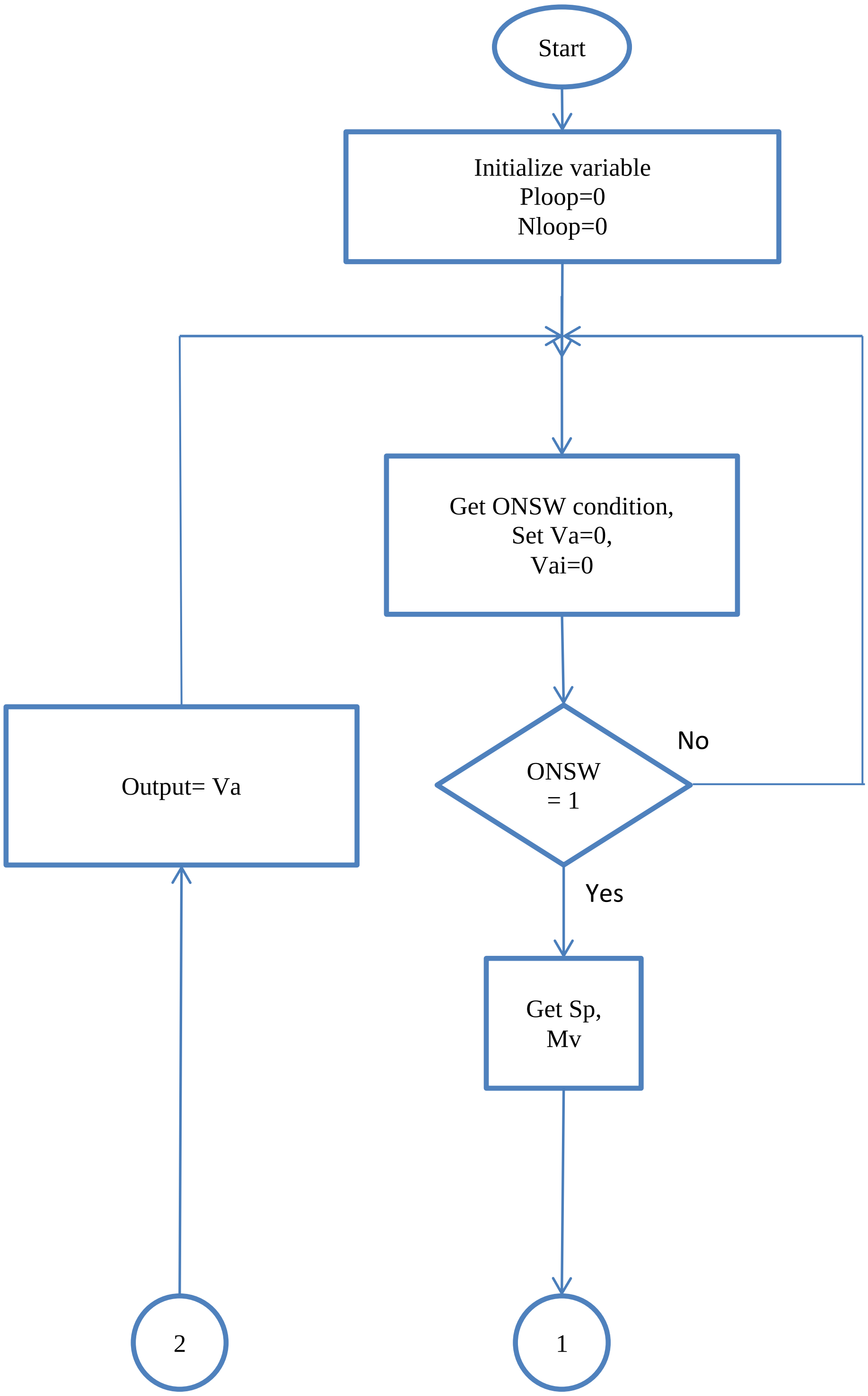
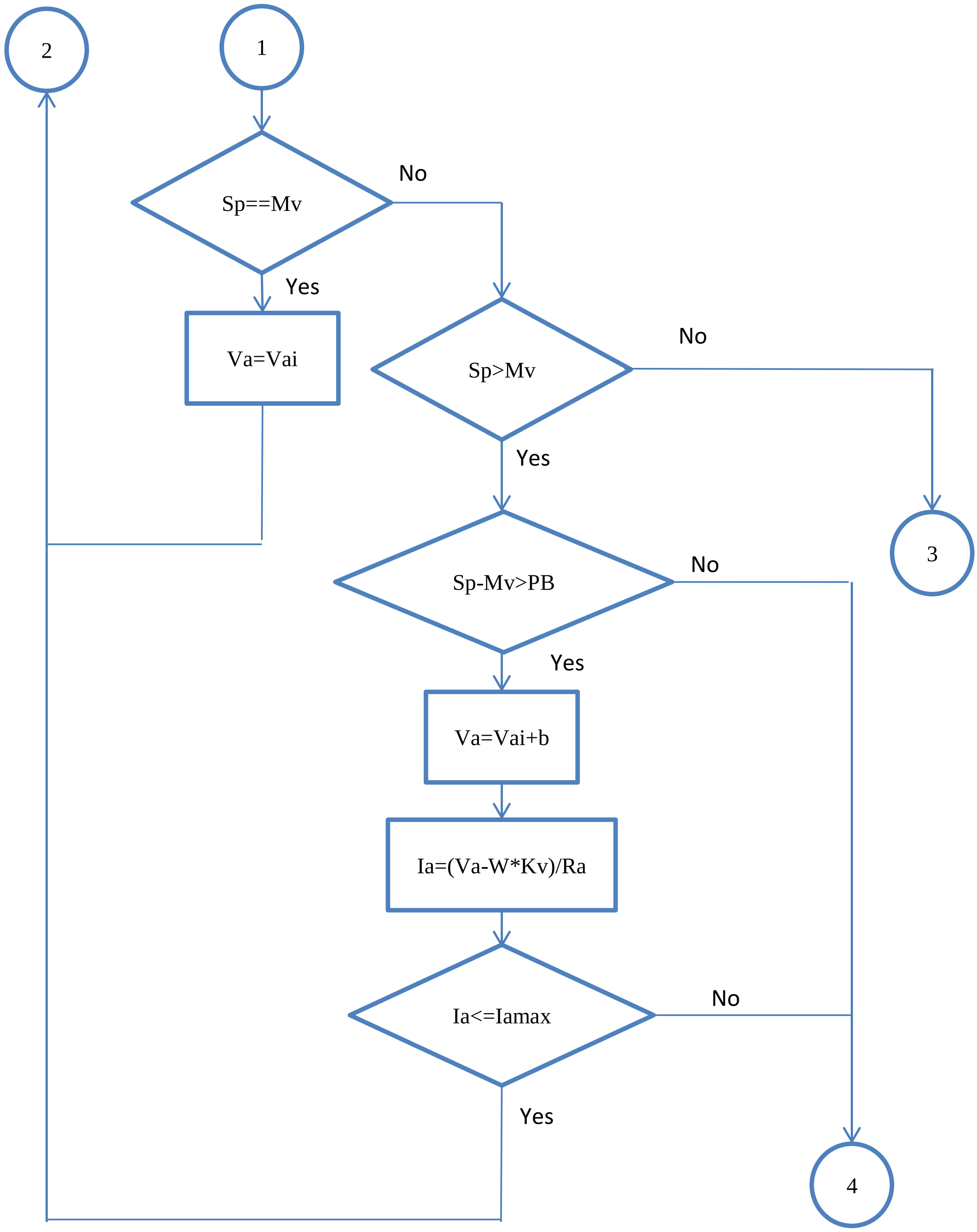
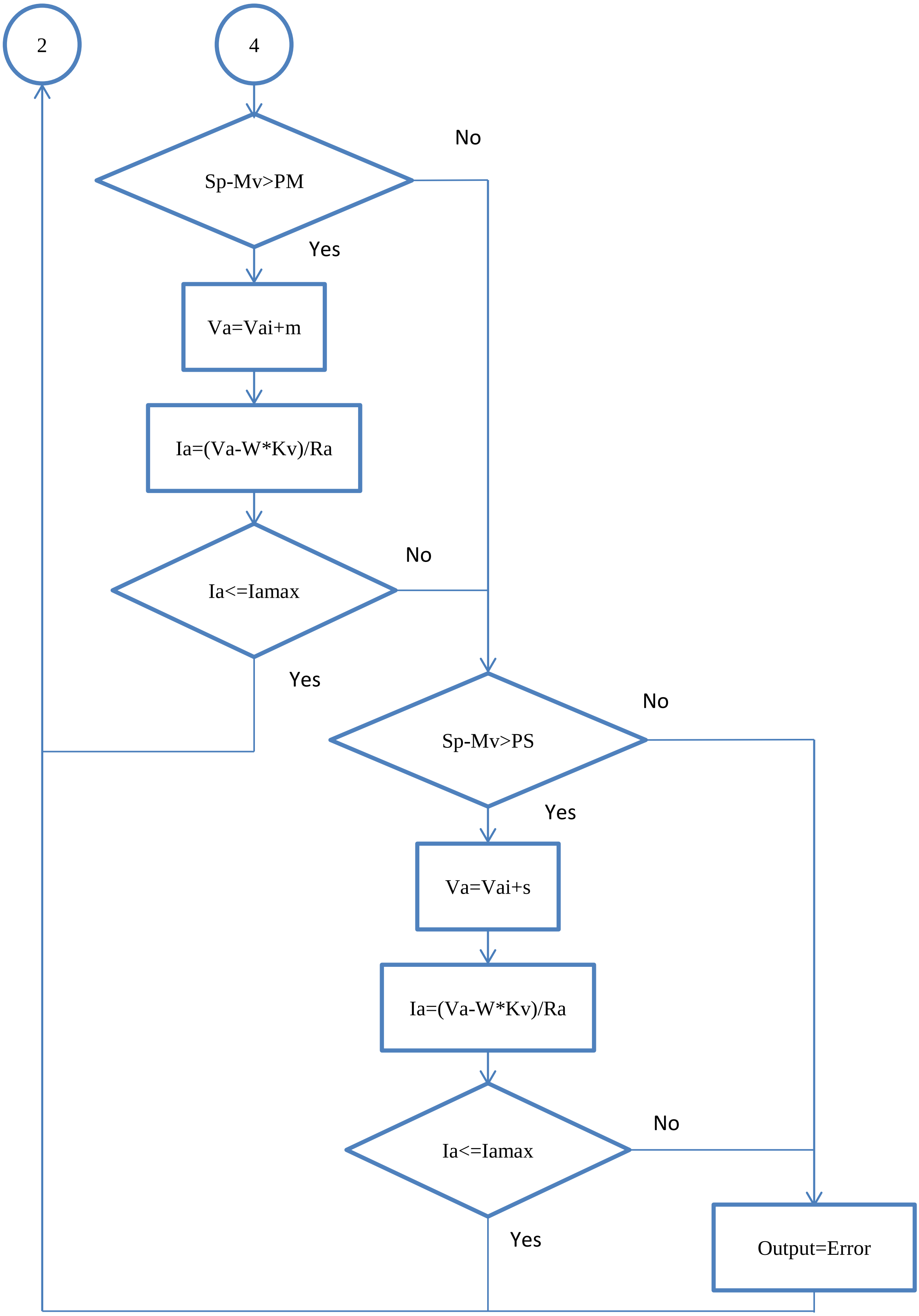
Appendix A: Program Flow Chart



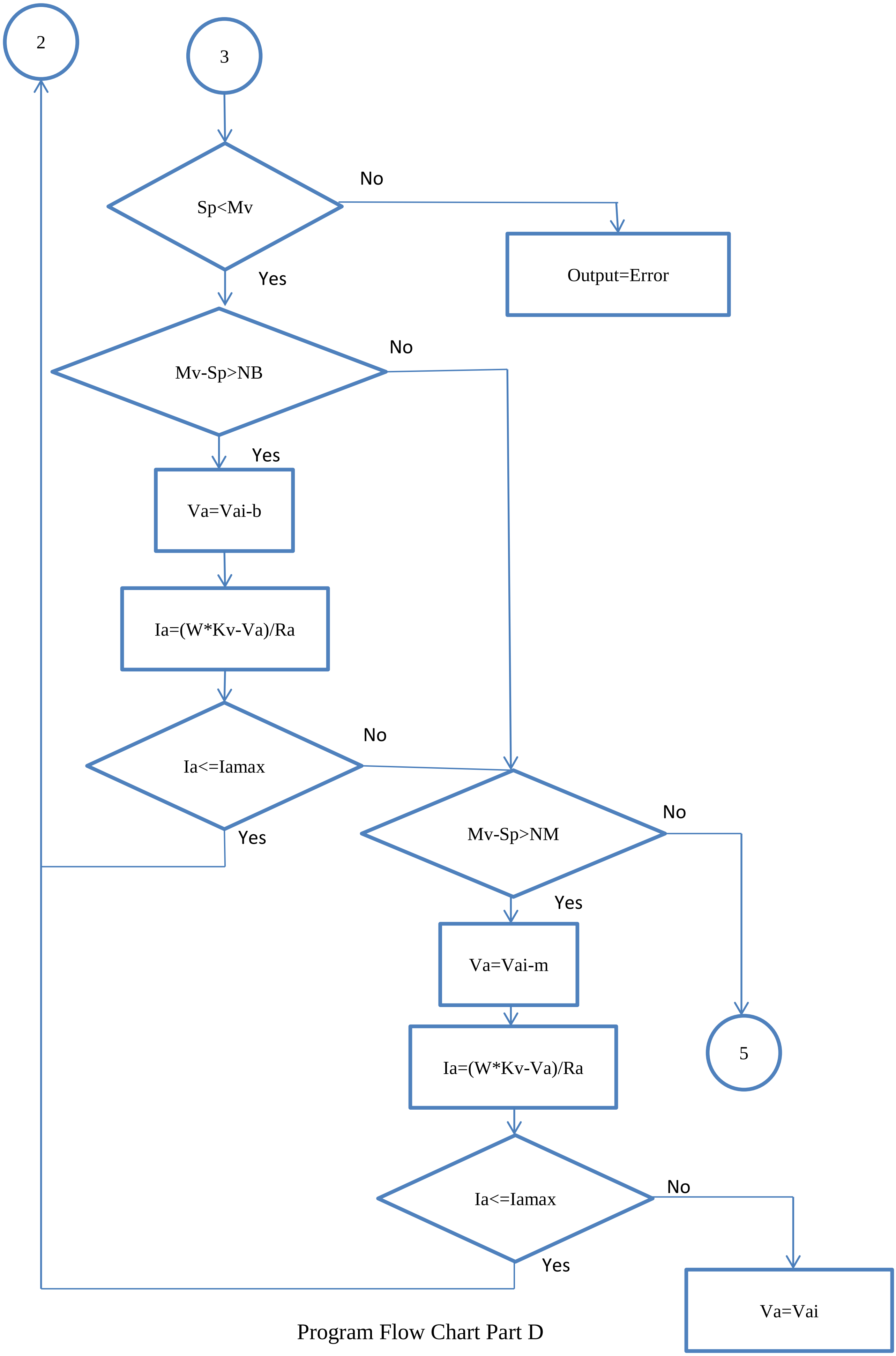
Program Flow Chart Part A



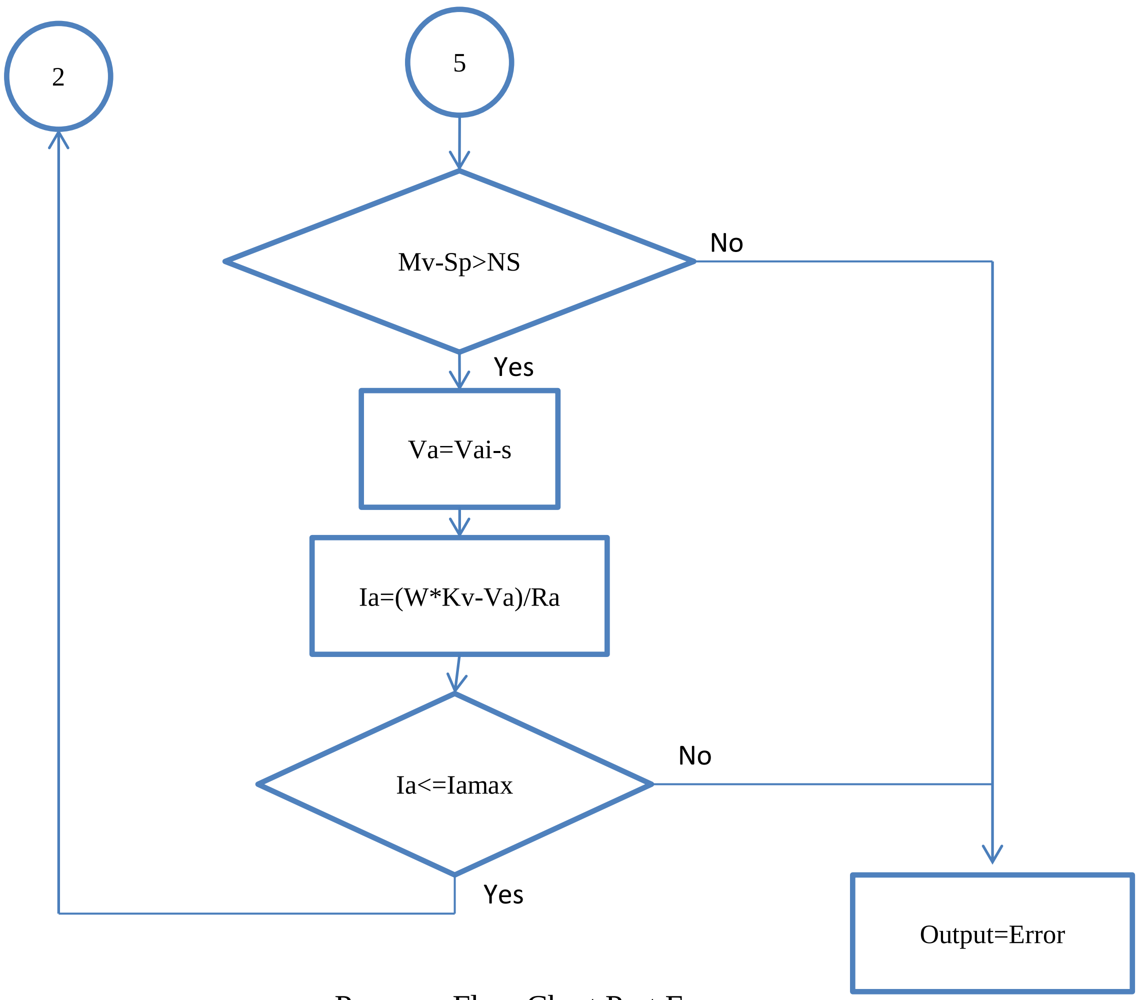
Program Flow Chart Part B



Program Flow Chart Part C



Program Flow Chart Part D



Program Flow Chart Part E

Appendix B: Program Source Code

```
//Project: 2 Quadrant DC Motor Controller
//Programmer: Ahmad Iqbal Fahmi Bin Ahmad Khalil
//PIC: PIC16F877A
//

//Include header
#include "2quadrantcontrollerwithLCD.h"
#include <pic.h>
__CONFIG (0x3F32);


//Define constant
	# define PXL 80
	# define PM 20
	# define PS 0
	# define ZE 0
	# define NS 0
	# define NM 30
	# define NXL 100

	# define xl 20
	# define m 5
	# define ns 0.5
	# define ps 0.5

	#define  Kv 1.77
	#define  Iamax 2.2
	#define  Ra 31

//Define Variable
double Vao, Va;
unsigned long Sp, Mv;
unsigned long w;

double  Ia;


//Main Function
void main(void)
{
	int PLoop=0;
	//int NLoop=0;
	int ON=1;

double SetPointValue=0;

	init_io();					//setting I/O
	setup_adc();				//setting for reading analog value
	setup_pwm();



		//configure lcd
	send_config(0b00000001);		//clear display at lcd
	send_config(0b00000010);		//lcd return to home
	send_config(0b00000110);		//entry mode-cursor increase 1
	send_config(0b00001100);		//display on, cursor off and cursor blink
off
```

```
send_config(0b00111000);                    //function set

Mv=0;
Sp=0;
w=0;

while (1)
{
        init_io();
        LED1=1;

        Vao=0;
        Va=0;

        ON=switch1;

        //display startup message
        lcd_clr();                                              //clear lcd
        lcd_goto(1);                                    //set the lcd cursor to
location 0
        send_string("iController");             //display "iContrller"
        lcd_goto(21);                                   //set the lcd cursor to
location 20
        send_string("by: Iqbal fahmi");                 //display
        delay(50000);

        while(!ON)
        {

                init_io();

                //to read analogue value
                Sp=(read_adc(1)*5.8947);        //
                Mv=(read_adc(2)*9.8127);

                w=((read_adc(2))*1.02266);      //Rad/Sec output =
(5x500x2p)/(2^8x60)

                lcd_clr();                              //clear lcd
                lcd_goto(0);
                //set the lcd cursor to location 0
                send_string("Sp= " );                   //display Sp
                lcd_goto(4);
                //set the lcd cursor to location 4
                dis_num(Sp);                            //display Set Point
                lcd_goto(9);

                send_string("rpm " );
                lcd_goto(20);
                //set the lcd cursor to location 20
                send_string("Mv= ");                    //display Mv
                lcd_goto(24);
                //set the lcd cursor to location 24
                dis_num(Mv);                            //display Speed
                lcd_goto(29);

                send_string("rpm " );
                delay(10000);
```

```
LED2=1;

Vao=Va;            PLoop=0;        //NLoop=0;

SteadyState=0;
AcceleratingState=0;
BrakingState=0;

//set point=output
if(Sp==Mv)
{
        Va=Vao;

        SteadyState=1;

}//end of if loop

//setpoint is bigger than output
else if(Sp>Mv)
{
        if((Sp-Mv)>PXL)
        {

                Va=Vao+xl;
                Ia=(Va-Kv*w)/Ra;

                if( Ia<=Iamax)
                {
                        PLoop=1;
                }//end of 2nd nested if loop
        }//end of nested if loop

        if(((Sp-Mv)>PM)&&PLoop!=1)
        {

                Va=Vao+m;
                Ia=(Va-Kv*w)/Ra;

                if( Ia<=Iamax)
                {
                        PLoop=1;
                }//end of 2nd nested if loop
        }//end of nested if loop

        if(((Sp-Mv)>PS)&&PLoop!=1)
        {

                Va=Vao+ps;
                Ia=(Va-Kv*w)/Ra;

                if( Ia<=Iamax)
                {
                        PLoop=1;
                }//end of 2nd nested if loop
        }//end of nested if loop

        //This loop is to ensure that Ia won't exceed Iamax which happen
because of the delay caused by the field device
        if(PLoop!=1)
        {
```

```
				Va=Vao;

			}//end of nested if loop

		AcceleratingState=1;

		}//end of if loop

		//setpoint is smaller than output
		else if(Sp<Mv)
		{

			if((Mv-Sp)>NXL)
			{

				Va=Vao-xl;
				Ia=(Kv*w-Va)/Ra;

				if( Ia<=Iamax)
				{
					PLoop=1;
				}//end of 2nd nested if loop

			}//end of nested if loop
			if(((Mv-Sp)>NM)&&PLoop!=1)
			{

				Va=Vao-m;
				Ia=(Kv*w-Va)/Ra;

				if( Ia<=Iamax)
				{
					PLoop=1;
				}//end of 2nd nested if loop
			}//end of nested if loop
			if(((Mv-Sp)>NS)&&PLoop!=1)
			{

				Va=Vao-ns;
				Ia=(Kv*w-Va)/Ra;

				if( Ia<=Iamax)
				{
					PLoop=1;
				}//end of 2nd nested if loop

			}//end of nested if loop

			//This loop is to ensure that Ia wont exceed Iamax which happen
because of the delay caused by the field device
			if(PLoop!=1)
			{

				Va=Vao;

			}//end of nested if loop
```

```
				BrakingState=1;
				}//end of else if loop

				else
				{
					int i=5;
					while ( i>0)
					{
						ALARM=1;delay((50000));
						ALARM=0;delay((50000));
						i=i-1;
					}//end of while loop
				}//end of else loop

			pwm1=Va*0.941176;

			init_io();

			if(!switch2)
				ON=1;

			LED2=0;

			}//end of while loop

			LED1=0;

		}//end of while loop
}//end of main function
```

Appendix C: Program Header Code

```
#include <pic.h>

#define Output1                 RA4         //PWM output
#define Output2                 RA5         //

#define switch1                 RB0         //
#define switch2                 RB1         //

#define PushON                  RB3         //
#define PushOFF                 RB4         //

#define ALARM                   RB5
#define LED1                    RB6         //
#define LED2                    RB7         //

#define pwm1                    CCPR1L      //
#define pwm2                    CCPR2L      //

#define  rs                     RC4         //RS pin of the LCD display
#define  e                      RC5         //E pin of the LCD display

#define lcd_data        PORTD //LCD 8-bit data PORT

#define SteadyState                 RE0
#define AcceleratingState  RE1
#define BrakingState            RE2

void init_io ( void ) ;
void init_serial ( void ) ;
void setup_adc ( void ) ;
unsigned char read_adc ( unsigned char channel) ;
void delay (unsigned long i);

void send_config(unsigned char data);
void send_char(unsigned char data);
void e_pulse(void);
void lcd_goto(unsigned char data);
void lcd_clr(void);
void send_string(const char *s);
void dis_num(unsigned long data);

void setup_pwm(void);


// subroutines

void init_io ( void )
{
        TRISA = 0b11001111;
        PORTA = 0b00000000;

        TRISB = 0b00011111;
        PORTB = 0b00011000;

        TRISC = 0b11000000;
        PORTC = 0b00000000;
```

```
	TRISD = 0b00000000;
	PORTD = 0b00000000;

	TRISE = 0b00000000;
	PORTE = 0b00000000;

}

void setup_adc ( void )
{
	ADCON0 = 0b10000000;  //Left justified, RA0, RA1 and RA3 as ADC input
	ADCON1 = 0b01000100;  //Fosc/32, channel 0, ADC not active, ADC off
}
unsigned char read_adc ( unsigned char channel )
{
	switch (channel)
	{
		case 1:
		ADCON0 = 0b10000001;
		break;
		case 2:
		ADCON0 = 0b10001001;
		break;
		case 3:
		ADCON0 = 0b10011001;
		break;
		default:
		ADCON0 = 0b10000000;
	}

	delay(5);				// delay for a while
	ADGO = 1;				// start conversion
	while (ADGO) continue;
	ADON = 0;				// Off ADC module
	return ADRESH;		// return ADC result

}

void delay (unsigned long i)
{
	for (; i>0; i-=1);
}


//==========================================================================
====================================
//	LCD	functions
//==========================================================================
=====================================


void send_config(unsigned char data)			//send lcd configuration
{
	rs=0;
	//set lcd to config mode
	lcd_data=data;							//lcd data
port = data
	delay(400);
	e_pulse();
	//pulse e to confirm the data
```

```
}

void send_char(unsigned char data)                    //send lcd character
{
        rs=1;
        //set lcd to display mode
        lcd_data=data;                                          //lcd data
port = data
        delay(400);
        e_pulse();
        //pulse e to confirm the data
}

void e_pulse(void)                                              //pulse e to
confirm the data
{
        e=1;
        delay(300);
        e=0;
        delay(300);
}

void lcd_goto(unsigned char data)                     //set the location of the lcd cursor
{
        if(data<16)                                                     //if
the given value is (0-15) the
        {
        //cursor will be at the upper line
                send_config(0x80+data);
        }
        else                                                            //if
the given value is (20-35) the
        {
        //cursor will be at the lower line
                data=data-20;                                   //location of
the lcd cursor(2X16):
                send_config(0xc0+data);                 // ----------------------
-----------------------------
        }
        // | |00|01|02|03|04|05|06|07|08|09|10|11|12|13|14|15| |
}
        // | |20|21|22|23|24|25|26|27|28|29|30|31|32|33|34|35| |

        // ----------------------------------------------------

void lcd_clr(void)                                              //clear the
lcd
{
        send_config(0x01);
        delay(350);
}

void send_string(const char *s)                       //send a string to display in the lcd
{
        while (s && *s)send_char (*s++);
}

void dis_num(unsigned long data)
{
//      unsigned char tenthousand;
```

```
	unsigned char thousand;
	unsigned char hundred;
	unsigned char tenth;

//	tenthousand= data / 10000;
//	data = data % 10000;
	thousand = data / 1000;
	data = data % 1000;
	hundred = data / 100;
	data = data % 100;
	tenth = data / 10;
	data = data % 10;

//	send_char(tenthousand + 0x30);
	send_char(thousand + 0x30);
	send_char(hundred + 0x30);
	send_char(tenth + 0x30);
	send_char(data + 0x30);
}


void setup_pwm(void)
{
	PR2 = 255;
	TMR2ON = 1;	//enable timer 2
	pwm1 = 0;
	pwm2 = 0;
	CCP1CON = 0b00111100;
	CCP2CON = 0b00111100;
}
```