"I hereby acknowledge that the scope and quality of this thesis is qualified for the award of the Bachelor Degree of Electrical Engineering (Electronics)"

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Date : 10 NOVEMBER 2008

SPEED CONTROL OF DC MOTOR USING PID CONTROLLER IMPLEMENTATION WITH PLC

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This thesis is submitted as partial fulfillment of the requirements for the award of the Bachelor of Electrical Engineering (Hons.) (Electronics)

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I declare that this thesis entitle "Speed Control of DC Motor Using PID Controller Implementation With PLC" is the result of my own research except as cited in the reference. The thesis is not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Date : 10 NOVEMBER 2008

To my beloved father, Mat Aris B Abdul Ghafar and mother, Fatimah Bt Abdul Hamid,
Who always pray for me and give me courage to finish this thesis.

And also to those people who have guided and inspired me throughout my journey.
Thank you for the supports and advices that have been given.

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ABSTRACT

The idea of motor speed control is to keep the rotation of the motor at the set speed. When used in speed applications, speed feedback control the DC motor's speed or confirms that the motor is rotating at the desired speed. To maintain the speed, it requires the speed feedback at all times. The objective of this project is to use the algorithm of Proportional Integral Derivative (PID) controller to control the speed of the DC motor using Programmable Logic Controller (PLC) implementation. The used of PLC in this project will help to reduce complexity and easy to troubleshoot. The model of PLC which is used in this project is OMRON (CQM1H-CPU51) and the program for this controller system is in ladder diagram (CX programmer). The PID is implemented in the PLC program so that the system has a better response and less error. Finally, analysis of the response is made after the PID is implemented into the system.

ABSTRAK

Idea bagi mengawal kelajuan motor ini adalah untuk mengawal putaran motor pada kelajuan yang diberikan. Apabila aplikasi kelajuan digunakan, suap balik kelajuan akan mengawal kelajuan DC motor atau memastikan bahawa motor berputar pada kelajuan yang dikehendaki. Untuk keseimbangan pada kelajuan motor, suap balik kelajuan diperlukan setiap masa. Tujuan projek ini adalah untuk menggunakan algoritma pengawal 'Proportional Integral Derivative' (PID) untuk mengawal kalajuan DC motor dengan implementasi 'Programmable Logic Controller' (PLC). Penggunaan PLC di dalam projek ini membantu memudahkan sistem dan membuatkan kerja-kerja penyelenggaraan suatu perkara mudah untuk dilakukan. Model PLC yang digunakan di dalam projek ini adalah OMRON (CQM1H-CPU51) dan program yang direka untuk operasi kawalan ini adalah di dalam bentuk 'ladder diagram' (CX programmer). Pengawal PID dimasukkan ke dalam program PLC supaya system memiliki respon yang lebih baik dan kurang kesilapan. Akhir sekali, analisis dilakukan terhadap respon setelah PID dimasukkan ke dalam system.

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LIST OF ABBREVIATIONS

P	-	Proportional
PI	-	Proportional Integral
PID	-	Proportional Integral Derivative
Pulse I/O Board	-	Pulse Input/Output Board
PV	-	Present Value
SP	-	Set Point

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

This project is to design and to control a dc motor of speed control systems using algorithm of Proportional Integral Derivative (PID). This dc motor is controlled by a modern computerized control system, which is programmable logic controller (PLC). A Programmable Logic Controller (PLC) or Programmable Controller is a digital computer used for automation of industrial processes, such as control of machinery on factory assembly lines. PLCs are used in many different industries and machines such as packaging and semiconductor machines. The program is stored in battery-backed memory and/or EEPROMs. It can often control complex sequencing and is often written by engineers. Unlike general-purpose computers, the PLC is designed for multiple inputs and output arrangements, extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. [16].

The main contribution is the algorithm of PID controller. A proportional-integral-derivative controller (PID controller) is a generic control loop feedback mechanism widely used in industrial control systems. The PID controller calculation 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. The PID controller compares a measured value from a process with a reference set point value. The difference (error) is then used to calculate a new value for a manipulatable input to the process that brings the process measured value back to its desired set point. Unlike simpler control algorithms, the PID controller can adjust process outputs based on the history and rate of change of the error signal, which gives more accurate and stable control. PID controllers do not require advanced mathematics to design and can be easily adjusted (tune) to the desired application [17].

The purpose to design this project is to overcome the problem in industry like to avoid machine damages and to avoid slow rise time and high overshoot. This is because when the starting voltage is high, it is not suitable for machine and can make machine damages. So, we use PID controller to overcome this problem.

1.2 Problem Statement

Machines are easily damage without implementation of control methodology in it system. Frequently, the desired performance characteristics of control systems are specified in terms of the transient response. The transient response of a practical control system usually exhibits damped oscillation before reaching steady state. As for machines, having a high overshoot is an undesired condition since the starting current is very high. Thus, control methodology such as PID controller is used to limit the maximum overshoot as well as to reduce the starting current of the machine. Therefore, the power used can be reduced as well as avoid machine from damaged due to bad system performance.

A Dc motor can be control by PLC itself without applying PID controller. However, it is inefficient and having slow response system as desired output is normally hard to achieve. Thus, PID controller is implemented as a control methodology to obtain precise numerical information input, and yet capable of highly adaptive control.

1.3 Objectives of the Project

The objectives of this project are:

i. To develop the PID controller to control the speed of DC motor
ii. To evaluate and analyze the performance of the controller
iii. To implement the controller using Programmable Logic Controller (PLC)

1.4 Project Scope

The scopes of this project are:

i. Design the PID controller in the CX programmer (Ladder Diagram)
ii. Perform simulation by using MATLAB
iii. Compare the performance of propose PID and uncontrolled system
iv. Implement the controller in the PLC

1.5 Organization of the Thesis

This thesis is composed of five chapters covering introduction, literature review, methodology, analysis and result and the last chapter is a conclusion and recommendation in future work.

Chapter 1 explains the background and an overview of a Proportional Integral and Derivatives or as known as PID Controller and Programmable Logic Controller (PLC). It also consists of the problem statement, objectives and also scope of the project.

Chapter 2 discusses recent literature reviews on PID Controller, PLC and DC motor. All the journals and the books that have some attachment to this project are used as a reference to guide and help completing this project. Each of this part is explain based on this finding.

Chapter 3 explains about the methodologies that have been used in order to complete this project. It consists of two parts which are the software and the hardware. The parameters of the PID controller and the tuning concepts were included in this chapter.

Chapter 4 gives a detail result and analysis on the design aspects for the systems, which consists SIMULINK of DC motor and PID Controller using MATLAB® SIMULINK. Meanwhile discusses the design and development of the PID controller on ladder diagram.

Chapter 5 presents the overall conclusion of development of the project. This chapter also discusses for a few suggestion and recommendation for future work or modification.

CHAPTER 2

LITERATURE REVIEW

2.1 Background

This chapter focused on literature review for each component that has been used in this project. All the components are described in details based on the finding during the completion of this project.

2.2 PID Controller

Proportional-Integral-Derivative (PID) controllers are still widely used in industrial systems, despite the significant developments of recent years in control theory and technology. This is because they perform well for a wide class of processes. Also, they give robust performance for a wide range of operating conditions. Furthermore, they are easy and remarkable effectiveness and simplicity to implement using analogue or digital hardware and familiar to engineers [1] [2] [7].

Most of the control techniques implemented in industrial processes employ PID controller. There are two reasons why nowadays it is still the majority in industrial processes. The first reason is that its simple structure and the well-known Ziegler-Nichols tuning algorithms have been developed [5] [6]. The second that is controlled processes in industrial plant almost can be controlled through the PID control. However, the conventional PID controller design usually needs to retune the parameters (proportional gain, integral time constant and derivative time constant) mutually by a skilled operator.

There is renewed interest in proportional-integral-derivative (PID) controllers because of two reasons. First, they are extensively used in applications in all industries second, despite the existence of some results modern optimal control methods are not suitable to deal with fixed structure and fixed order controllers. Thus, there is much that remains to be done to modernize PID design methods [3].

PID (Proportional-integral-derivative) controller is one of the most commonly used controllers because it is simple and robust .Also, it is suitable for use in a control system where the transfer function of the plant has not been completely defined. A continuous-data PID controller can be defined as, with the gain of each block to be set independently [8].

In view of this and robustness enhancement of DC motor control system, we propose an adaptive PID learning controller which consists of a set of learning rules for PID gain tuning and learning of an auxiliary input. The proposed PID learning controller is shown to drive the state of uncertain DC motor system with unknown system parameters and external load torque to the desired one globally asymptotically [2].

An example of the block diagram of the PID speed control system is shown in Figure 2.1. The error signal e represents the difference between the speed command and the speed feedback. The proportional control multiplies the speed error e by a constant K_p, the integral control multiplies the e by a constant K_i, to correct steady state error; the derivative control reduces the overshoot and the rise time or,

$$U(t) = K_p\, e(t) + K_p K_i \int_0 e(t)dt + K_p K_d\, de(t)/dt \qquad (2.1)$$

Where : *U(t) is a control signal*

K_p is a proportional gain

K_i is a an integral gain

K_d is a derivative gain

$e(t)$ is an error term $\int_0 e(t)dt$ *is* a summation of all past error over time and *de(t)/dt* is rate of change of error term. For the basic control system, the controller compares the measured value to a set point or reference voltage to get the error value as expressed in equation above and then the error signal will take the appropriate corrective action. The parameter of PID controller, K_p, K_i, and K_d can be manipulated to produce various response curves from a motor controller [7].For this project, we change voltage to speed .It is because we need to know an error of speed.

$$e(t) = r(t) - y(t) \qquad (2.2)$$

Where; r(t) is a set point (SP) or reference voltage

y(t) is a measured value (Process Variable)

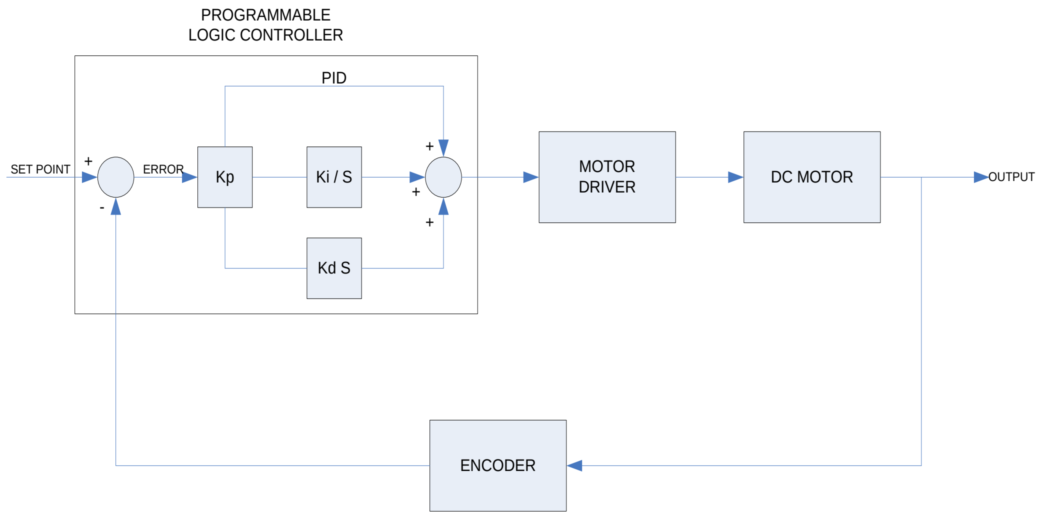

Figure 2.1: A block diagram of speed PID controller

2.3 Programmable logic controller (PLC)

Since 1970's, PLC system began being used in order to ease human activities [5]. It is a control system that is applied to change the behavior of a system. When industrial revolution started, PLC has become common choice for manufacturing controls. In the past, humans are the main methods for controlling a system. Nowadays, PLCs have been gaining popularity in factories sectors because of it advantages which are:

a. Cost effective for controlling complex systems.
b. Flexible and can be reapplied to control other systems quickly and easily.
c. Computational abilities allow more sophisticated control.
d. Trouble shooting aids make programming easier and reduce downtime.
e. Reliable components make these likely to operate for years before failure.

Since technology for motion control of electric drives became available, the use of programmable logic controllers (PLCs) with power electronics in electric machines applications has been introduced in the manufacturing automation [9].

This use offers advantages such as lower voltage drop when turned on and the ability to control motors and other equipment with a virtually unity power factor [10]. Many factories use PLCs in automation processes to diminish production cost and to increase quality and reliability [9]. Other applications include machine tools with improved precision computerized numerical control (CNC) due to the use of PLCs [10].To obtain accurate industrial electric drive systems, it is necessary to use PLCs interfaced with power converters, personal computers, and other electric equipment . Nevertheless, this makes the equipment more sophisticated, complex and expensive [13] [14].

Few papers were published concerning dc machines controlled by PLCs. They report both the implementation of the fuzzy method for speed control of a dc motor/generator set using a PLC to change the armature voltage [11], and the incorporation of an adaptive controller based on the self-tuning regulator technology into an existing industrial PLC [12]. Also, other types of machines were interfaced with PLCs. Thereby; an industrial PLC was used for controlling stepper motors.

PLCs have been gaining popularity on the factory floor and will probably remain predominant for some time to come. Most of this is because of the advantages they offer. There are cost effective for controlling complex systems, flexible and can be reapplied to control other systems quickly and easily. Beside that, computational abilities allow more sophisticated control and Trouble shooting aids make programming easier and reduce downtime. The last of advantages is reliable components make these likely to operate for years before failure.

There are many types of PLC being used in industries according to their needs such as OMRON, SIEMENS and FESTO. [4]The main method of PLC is ladder logic. They can be programmed, controlled and operated by drawing the lines and devices of ladder diagram with a keyboard onto a display screen. [4] The drawing is converted into computer machine language and run as a user program. It is usually use to motor control or a process that involved relays (switch). This technique is based on relay logic wiring schematics. In the past, electrical control based on relays and nowadays it has been used for control whereby these relays allow power to be switched ON or OFF without a mechanical switch. The used of relays is the best decisions especially to make a simple logical control. It can operate any system with discrete or digital as well as analog outputs.

2.7 DC motor

Essentially, a DC motor consists of a stator, a rotor and a commutator. The stator is the housing of the motor and contains magnets, bearing and etc .The rotor is the rotating part of the motor, which contains a coil of wire through which current flows [15].

To understand this topic, we must understand of the operation and mathematical model of DC motor. When current flows through the coil of wire in rotor (armature), a torque is created that causes the rotor spin. The function of torque in DC motor is motor to provide the mechanical output to drive any piece of equipment that is attached to the DC motor [15].

CHAPTER 3

METHODOLOGY

3.1 Introduction

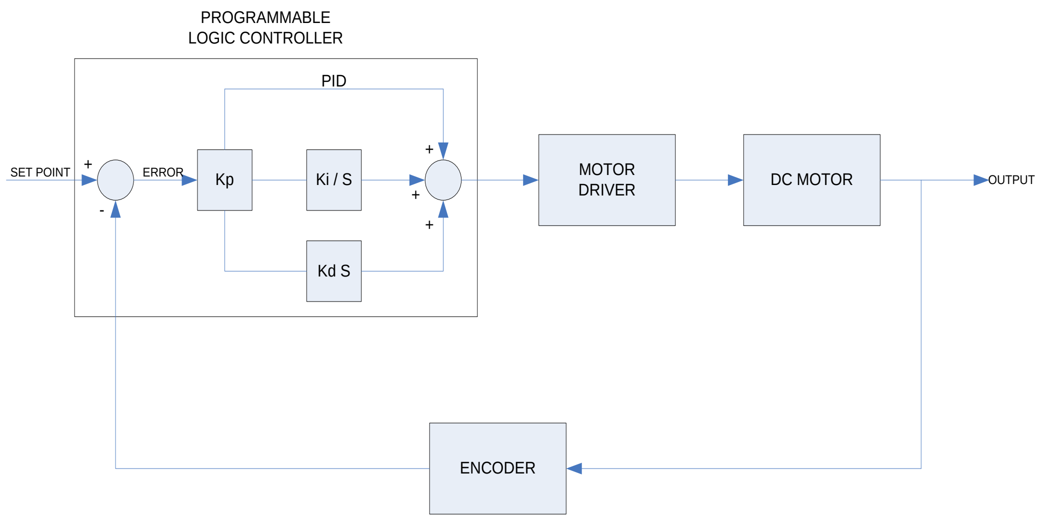

Figure 3.1: Basic block diagram of the project

This project is to design and to control speed of a dc motor using Programmable Logic Controller (PLC). This dc motor is controlled by a modern computerized control system, which is programmable logic controller (PLC) control system. The main contribution is the algorithm of PID controller (P, PI and PID).

Block diagram in Figure 3.1 shows the close loop system of this project. The set point is a voltage equal to the desired speed. This voltage is applied to the PLC, which has the PID controller inside it. Then, the output will be applied to the motor driver. This will make the motor start rotating and the signal from the encoder will then sent to the PLC as a feedback.

3.2 Flowchart Of System

There are two important parts that need to done in this project which is the software development and hardware implementation. This is shown in flowchart at Figure 3.2. For the software development, a simulation using MATLAB has been done. The parameter of PID is founded by using the Ziegler–Nichols Frequency Response Method. After the simulation is finished, the programming of the PID is made in the PLC using the CX Programmer.

In hardware implementation, a wiring of the DC motor and the motor driver have been made. Another part that needs to be wiring is at the Pulse I/O Board since this board will be the important part that will send the output from PLC to the motor driver so that the speed of DC motor can be controlled.

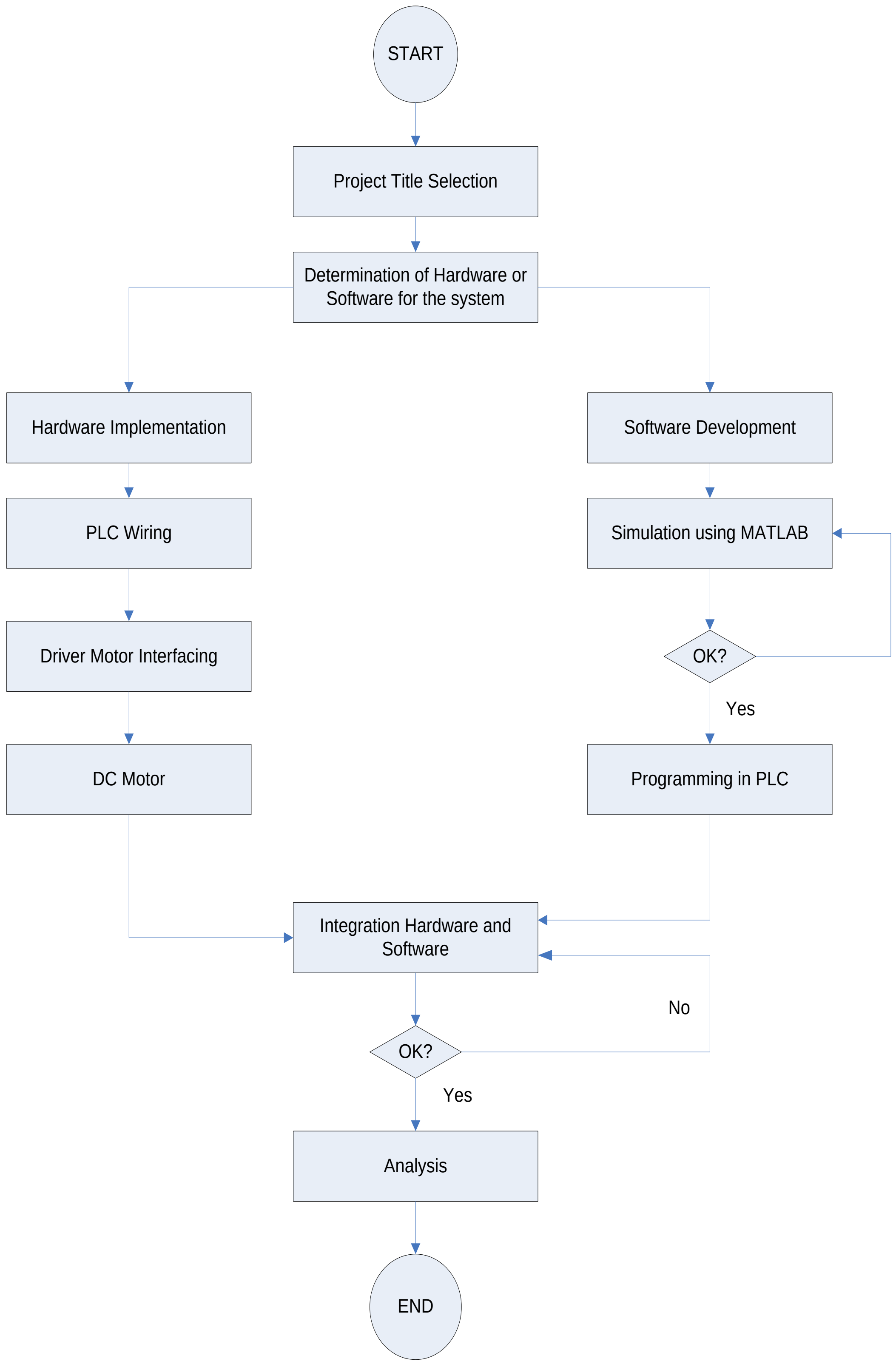

Figure 3.2: Flowchart of system development

3.3 Software Development

3.3.1 DC Motor Modeling

For the DC motor modeling, the value of the physical parameters should be assumed. These parameters values are derive from actual motor which is Clifton Precision Servo Motor JDH-2250-HF-2C-E.

Table 3.1: Physical parameters of DC motor.

Moment of inertia of the rotor (J)	0.0001 kgm2
Damping ratio of mechanical system (Bm)	0.0000093 Nmsrad-1
Electromotive force constant (k)	kW = 0.105 V.srad-1 kT = 0.105 NmA-1 kgear = 0.005
Electric Resistance (R)	2.7Ω
Electric Inductance (L)	0.004H

Applying Newton's Law and Kirchhoff's Law, the state equation is determined (in vector form):

$$\begin{bmatrix} {dia}/{dt} \\ {d\omega r}/{dt} \end{bmatrix} = \begin{bmatrix} {-Ra}/{La} & {-k\omega}/{La} \\ {kT}/{J} & {-Bm}/{J} \end{bmatrix} \cdot \begin{bmatrix} {ia}/{1} \\ {\omega r}/{1} \end{bmatrix} + \begin{bmatrix} {i}/{La} \\ 0 \end{bmatrix} ua \tag{3.1}$$

$$y = \begin{bmatrix} 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} {ia}/{1} \\ {\omega r}/{1} \end{bmatrix} + [0]\, ua \tag{3.2}$$

Substituting the parameters into the vector form:

$$\begin{bmatrix} {dia}/{dt} \\ {d\omega r}/{dt} \end{bmatrix} = \begin{bmatrix} {-2.7}/{0.004} & {-0.105}/{0.004} \\ {0.105}/{0.0001} & {-0.0000093}/{0.0001} \end{bmatrix} \cdot \begin{bmatrix} {ia}/{1} \\ {\omega r}/{1} \end{bmatrix} + \begin{bmatrix} {1}/{0.004} \\ 0 \end{bmatrix} ua$$

$$\begin{bmatrix} {dia}/{dt} \\ {d\omega r}/{dt} \end{bmatrix} = \begin{bmatrix} -675 & -26.25 \\ 1050 & -0.093 \end{bmatrix} \cdot \begin{bmatrix} {ia}/{1} \\ {\omega r}/{1} \end{bmatrix} + \begin{bmatrix} 250 \\ 0 \end{bmatrix} ua$$

$$y = \begin{bmatrix} 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} {ia}/{1} \\ {\omega r}/{1} \end{bmatrix} + [0]\, ua$$

Converting state space to a transfer function:

$$ {Y(s)}/{U(s)} = C(SI - A)^{-1}B + D \tag{3.3}$$

Solving the term $(SI - A)^{-1}$:

$$(SI - A) = \begin{bmatrix} S & 0 \\ 0 & S \end{bmatrix} - \begin{bmatrix} -675 & -26.25 \\ 1050 & -0.093 \end{bmatrix} \tag{3.4}$$

$$= \begin{bmatrix} S + 675 & 26.25 \\ -1050 & S + 0.093 \end{bmatrix}$$

$$(SI - A)^{-1} = \frac{1}{(S+675)(S+0.093) - (26.25)(-1050)} \begin{bmatrix} S + 0.093 & -26.25 \\ 1050 & S + 675 \end{bmatrix} \qquad (3.5)$$

$$= \frac{\begin{bmatrix} S + 0.093 & -26.25 \\ 1050 & S + 675 \end{bmatrix}}{S^2 + 675.093S + 27625.275}$$

Substituting $(SI - A)^{-1}, B, C \ and \ D$ into transfer function equation:

$$Y(s)/U(s) = C(SI - A)^{-1}B + D$$

$$= [0 \quad 1] \frac{\begin{bmatrix} S + 0.093 & -26.25 \\ 1050 & S + 675 \end{bmatrix}}{S^2 + 675.093S + 27625.275} \begin{bmatrix} 250 \\ 0 \end{bmatrix} + [0]$$

$$= \frac{[1050 \quad S + 675]}{S^2 + 675.093S + 27625.275} \begin{bmatrix} 250 \\ 0 \end{bmatrix}$$

$$= \frac{262500}{S^2 + 675.093S + 27625.275}$$

$$\therefore \quad TF, \quad Y(s)/U(s) = \frac{262500}{S^2 + 675.093S + 27625.275}$$

3.3.2 Ziegler-Nichols Frequency Response Method

Ziegler and Nichols proposed rules for determining values of the proportional gain K_p, integral time T_i, and the derivative time T_d based on transient response characteristics of a given plant. For the Ziegler-Nichols Frequency Response Method, the critical gain, K_{cr} and the critical period, P_{cr} have to be determined first by setting the $T_i = \infty$ and $T_d = 0$. Increase the value of K_p from 0 to a critical value, K_{cr} at which the output first exhibits sustained oscillation.

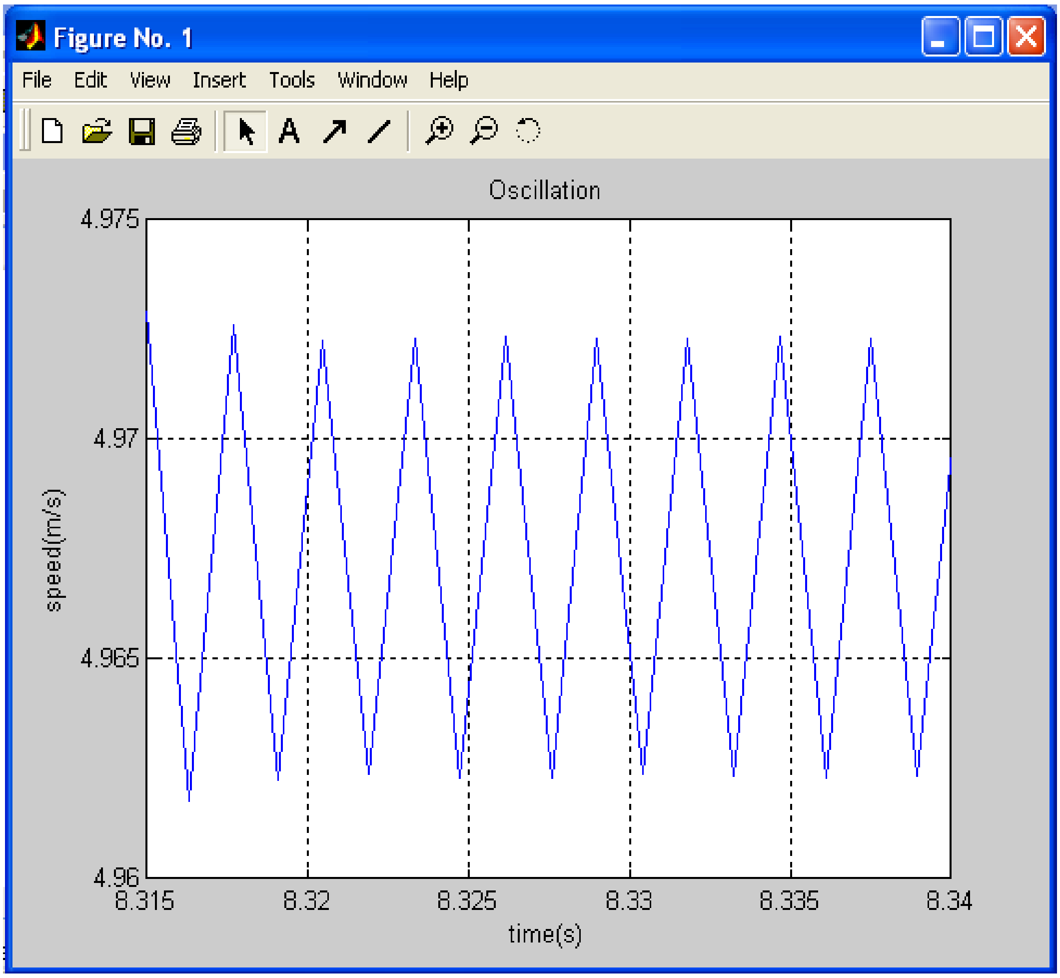

Figure 3.3: Sustained oscillation response

Table 3.2: Ziegler-Nichols tuning rule based on K_{cr} and P_{cr}

Type of Controller	K_p	T_i	T_d
P	$0.5K_{cr}$	∞	0
PI	$0.45K_{cr}$	P_{cr}	0
PID	$0.6K_{cr}$	$0.5P_{cr}$	$0.125P_{cr}$

From the graph in Table 3.2:

$$Kcr = 16$$

$$Pcr = 8.324 - 8.321$$

$$= 0.003$$

Tuning the PID controller:

$$G(s) = Kp\left(1 + \frac{1}{Tis} + Tds\right) \quad (3.6)$$

i. P Mode

$$Kp = 0.5Kcr \quad (3.7)$$

$$= 0.5(16)$$

$$= 8$$

ii. PI Mode

$$Kp = 0.45Kcr \quad (3.8)$$

$$= 0.45(16)$$

$$= 7.2$$

$$Ki = \frac{1}{Ti} \tag{3.9}$$

$$= \frac{1}{(\frac{Pcr}{1.2})}$$

$$= \frac{1}{(\frac{0.003}{1.2})}$$

$$= 400$$

iii. PID Mode

$$Kp = 0.6Kcr \tag{3.10}$$

$$= 0.6(16)$$

$$= 9.6$$

$$Ki = \frac{1}{Ti} \tag{3.11}$$

$$= \frac{1}{0.5Pcr}$$

$$= \frac{1}{0.5(0.003)}$$

$$= 666.67$$

$$Kd = 0.125Pcr \tag{3.12}$$

$$= 0.125(0.003)$$

$$= 0.000375$$

Table 3.3: Tuned PID controller value

Type of Controller	K_p	K_i	K_d
P	8	0	0
PI	7.2	400	0
PID	9.6	666.67	0.000375

3.3.3 Simulation in MATLAB

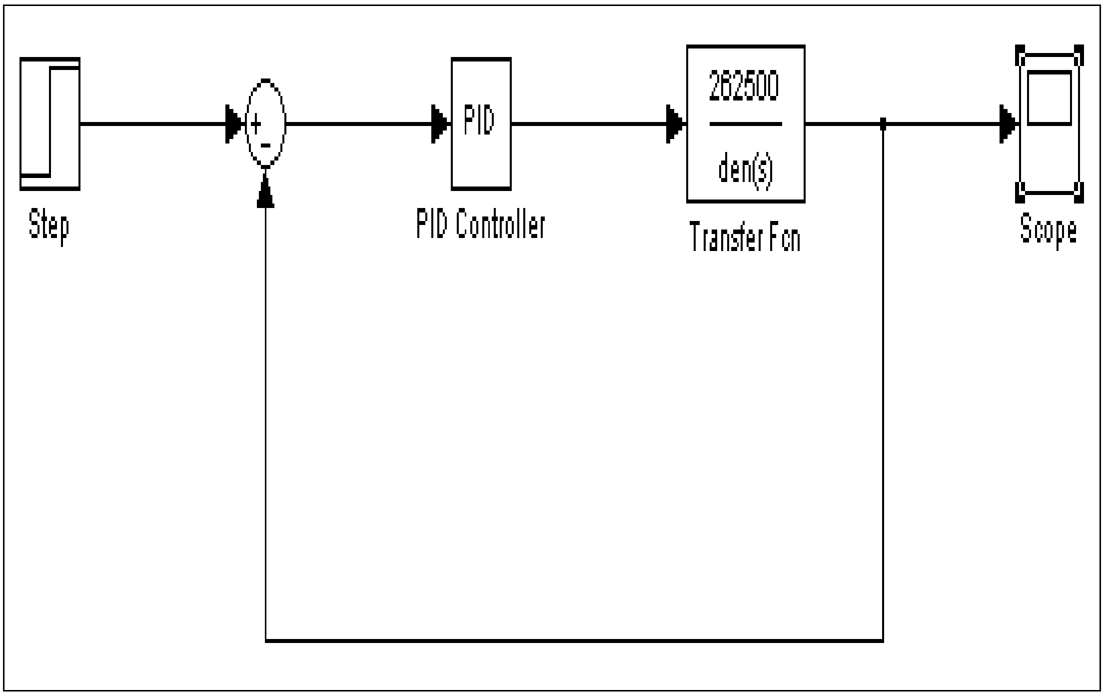

Figure 3.4: Block diagram for simulation in MATLAB

The block diagram from Figure 3.4 can be directly implemented in MATLAB. The transfer function is from the calculation that had been done before this. The PID controller is placed before the DC motor as shown in the block diagram so that it will control the speed of the motor. At the set point the parameter for step time is 3, then for the initial value is 0. The final value and the sample time are 5 and 0.5. The gain for P (Proportional), I (Integral) and D (Derivative) is set by using the tuned value that had been calculated before.

3.3.4 PLC Programming

3.3.4.1 PC Setup

CX-programmer CQMH1-CPU51 type is used in this project. In ladder diagram the block of MOV(21), SUB(31), ADD(30), MUL(32), PWM(18), CMP(20), PID(17) and TIM are used to run this project. Figure 3.5 and Figure 3.6 show that setup of the PLC before running the ladder diagram.

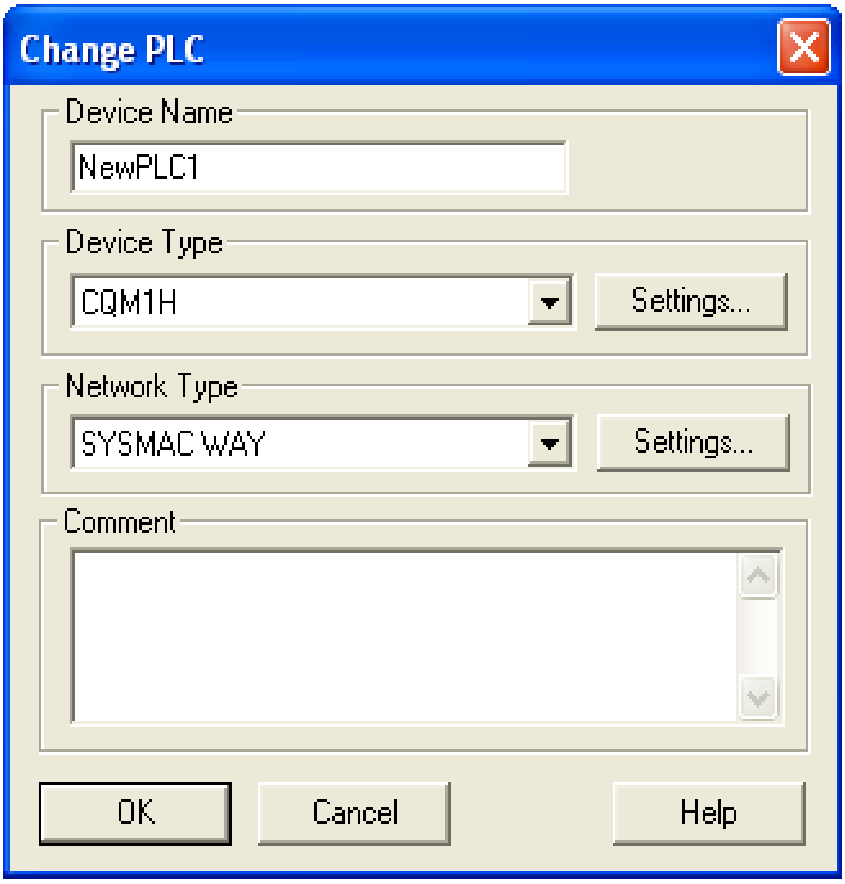

Figure 3.5: Setting for change PLC

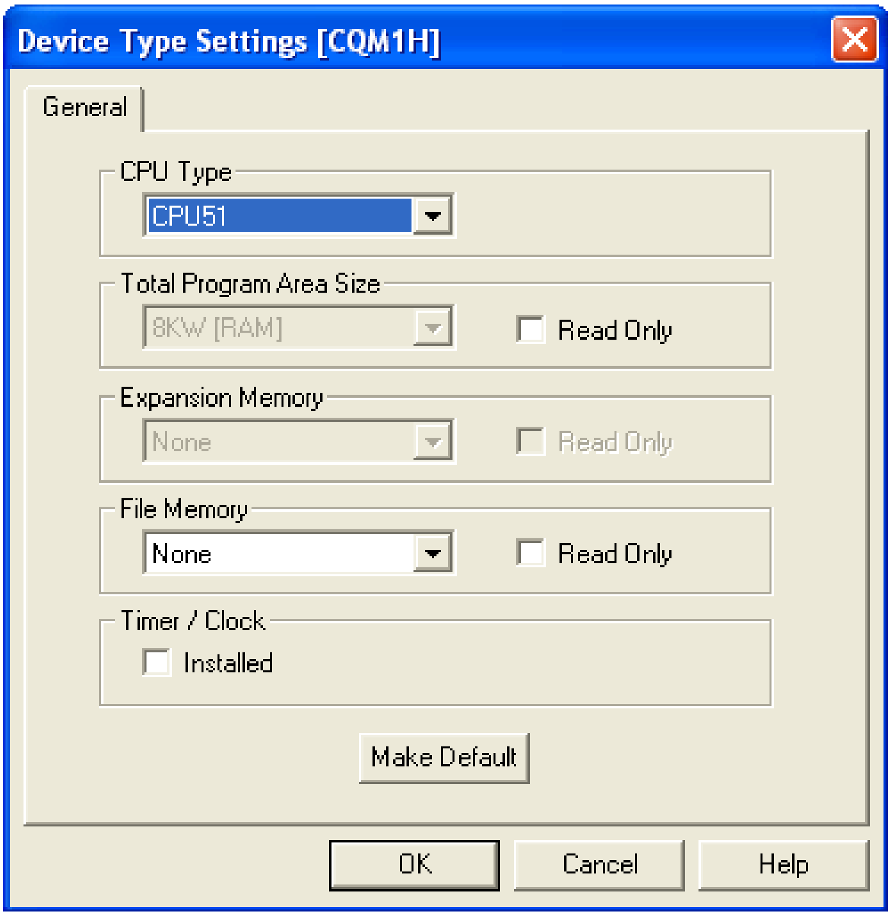

Figure 3.6: Setting for device type of CPU in PLC

In order to use the Pulse I/O Board, some setting had to be done in the PLC memory. Memory of DM6611 had to be set to 0000 to enable the high speed function. To use the function block PWM(18), memory of DM6643 need to be set to 1000. The DM6644 is did not need to be set since we only use Port 1 of the Pulse I/O Board. The setting of the DM6611 and DM6643 are shown in Figure 3.7.

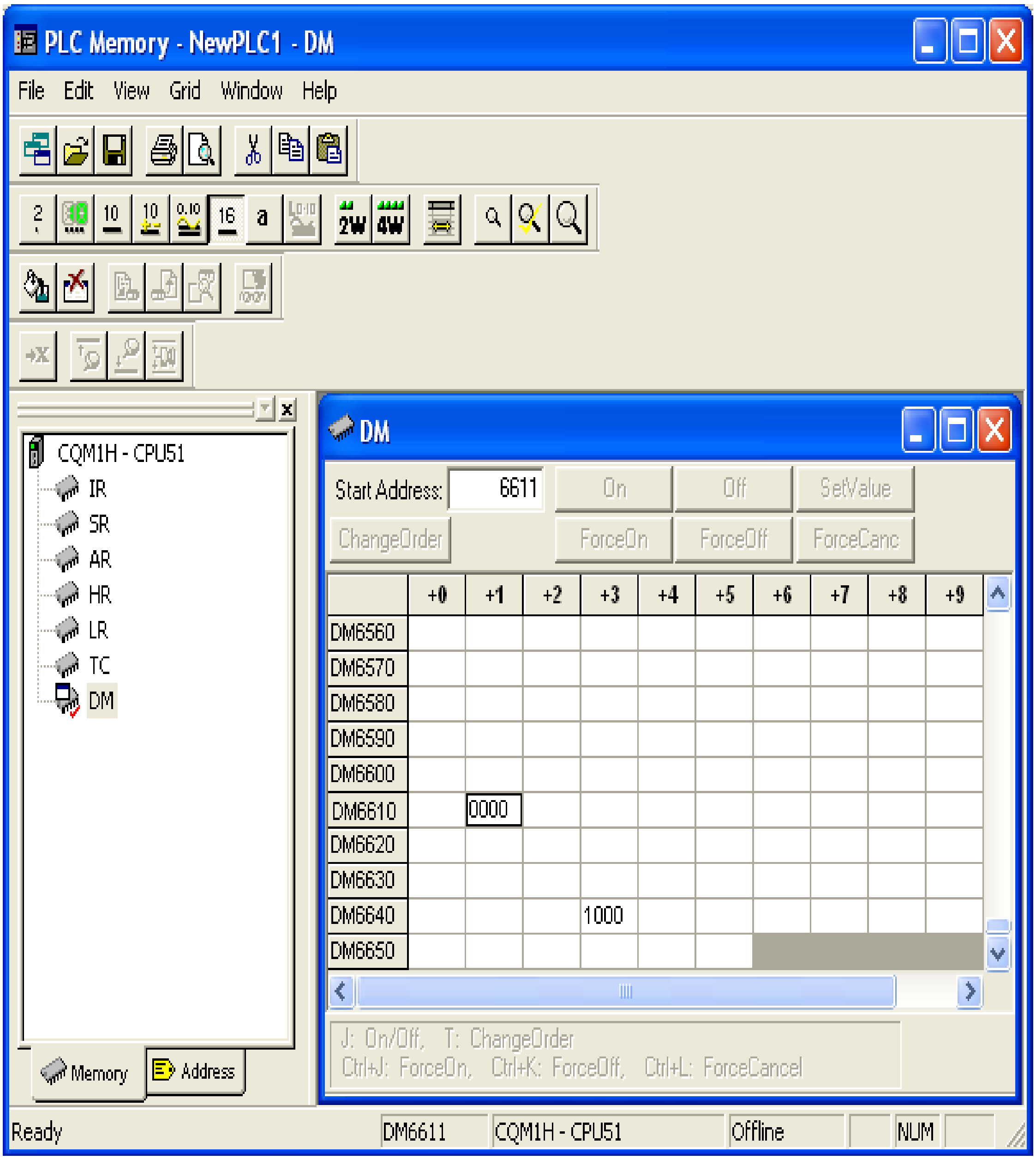

Figure 3.7: Memory setting for Pulse I/O Board