DEVELOPMENT OF PID VOLTAGE CONTROL FOR DC MOTOR USING
ARDUINO

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Praise be to Allah the Almighty (Most Gracious, Most Merciful)
and His Messenger Prophet Muhammad S.A.W.

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ABSTRACT

This project focuses on the design and implementation of PID voltage control for DC motor. DC motor is a machine that widely used due to excellence speed control for acceleration and deceleration with effective and simple torque control. The PID controller is employed to control the output voltage of three phase controlled rectifier to run a DC motor as a load. The function of this PID controller is to correct the error in order to achieve the target value of desired voltage. The modelling, control and simulation of this project has been implemented using MATLAB/Simulink Software version 2013a. The Pulse Width Modulation (PWM) signals generated from MATLAB/Simulink model will be downloaded into Arduino microcontroller. Arduino microcontroller board is an interfacing device between MATLAB/Simulink model and actual hardware. The PWM signals from Arduino will step up using gate driver and then will be sent to power MOSFET gates for triggering rectifier. The output produced from this controlled rectifier is in DC form. The open loop and closed loop simulations analyses for PID control voltage were successfully conducted. Results show that the error of voltage for closed loop is lower compared than open loop. Furthermore, hardware has been setup to verify the MATLAB/Simulink model. From here, the speed of DC motor is increased as the controlled output voltage is increased. This project contributes to the efficiency and robustness of controlling output voltage for DC motor being used in industry based on PID controller rather than using conventional method like rheostat armature control and direct on line (DOL) starter.

ABSTRAK

Projek ini memberi tumpuan kepada rekabentuk dan pelaksanaan PID kawalan voltan bagi motor arus terus (AT). Motor arus terus adalah mesin yang digunakan secara meluas kerana kawalan kelajuan untuk pecutan dan nyahpecutan yang cekap serta kawalan daya kilas yang mudah. Pengawal PID digunakan untuk mengawal voltan keluaran penerus terkawal tiga fasa untuk menjalankan motor DC sebagai beban. Fungsi pengawal PID ini adalah untuk membetulkan kesilapan bagi mencapai nilai sasaran voltan yang dikehendaki. Pemodelan, kawalan dan simulasi projek ini telah dilaksanakan menggunakan Perisian MATLAB / Simulink versi 2013a. Isyarat Pemodulatan Lebar Denyut (PWM) yang dijana daripada model MATLAB / Simulink akan dimasukkan ke dalam mikropengawal Arduino. Papan mikropengawal Arduino adalah satu antara muka antara model MATLAB/Simulink dan perkakasan sebenar. Isyarat PWM dari Arduino akan ditingkatkan menggunakan pemandu get dan kemudian akan dihantar ke get MOSFET kuasa untuk pemicuan penerus.. Keluaran yang dihasilkan dari penerus terkawal ini adalah dalam bentuk arus terus. Analisis simulasi gelung terbuka dan gelung tertutup untuk PID kawalan voltan telah dijalankan dengan jayanya. Keputusan menunjukkan bahawa ralat voltan untuk gelung tertutup adalah lebih rendah berbanding dengan gelung terbuka. Seterusnya, perkakasan dibangunkan untuk mengesahkan model MATLAB/Simulink. Daripada sini, kelajuan motor AT bertambah dengan pertambahan voltan yang dikawaltan. Projek ini menyumbang kepada kecekapan dan keteguhan mengawal voltan keluaran motor AT yang digunakan dalam industri berdasarkan kepada pengawal PID berbanding dengan menggunakan kaedah konvensional seperti reostat kawalan angker dan pemula dalam talian (DOL).

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LIST OF SYMBOLS AND ABBREVIATIONS

PID	-	Proportional Integral Derivative
DC	-	Direct Current
MOSFET	-	Metal Oxide Field Effect Transistor
K_P	-	Proportional Gain
K_I	-	Integral Gain
K_D	-	Derivative Gain
Matlab	-	Matrix Laboratory
PCB	-	Printed Circuit
USB	-	Universal Board Seriel Bus
ICSP	-	In Circuit Seriel Programming
UTHM	-	Universiti Tun Hussein Onn Malaysia

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INTRODUCTION

1.1   Background

From the definition, Direct Current (DC) motor is a machine that converts electrical energy into mechanical energy. It is a mechanically commutated electric motor powered from direct current. Two main parts of DC motor are rotor and stator. Stator is stationary part while rotor is rotating part. The most common types of DC motors are brush, brushless, series connection, shunt connection and compound connection. Nowadays, DC motor plays an important role in research and laboratory experiments because of its simplicity and low cost. Thus, fine speed control is one of the reasons for the strong competitive position of DC motors in the modem industrial applications. The speed of the DC motor can be controlled by changing the voltage applied to the armature (voltage control method) or by changing the field current (flux control method). The introduction of variable resistance in the armature circuit or field circuit allowed speed control. Modern DC motors are often controlled by power electronics systems called DC drives.

A control system is an interconnection of components forming a system that will provide a desired system response. Arduino hardware acts as the interface between the computer and the outside world (controlled DC motor). The user interface was developed in an Arduino environment. There are many types of controller such as P, PI, PD, PID and fuzzy logic controller (FLC) can be used to control the speed of DC motor. The important of control speed of DC motor is to overcome the problem in industry like high overshoot and slow rise time to avoid machine damages. In this project, Proportional Integral Derivative (PID) controller will be developed in Matlab Simulink environment for an application of DC motor speed control to overcome this problem. PID Controller will be created in Matlab Simulink software as a medium for controlling DC motor.

This project is to develop PID voltage control to control the speed of a DC motor. Arduino is a single-board microcontroller to make using electronics in multidisciplinary projects more accessible. The hardware consists of an open-source hardware board designed around an 8-bit Atmel microcontroller, or a 32-bit Atmel. The software consists

of a standard programming language compiler and a boot loader that executes on the microcontroller.

1.2 Problem Statement

DC motor widely used in speed control systems in industry which needs high control requirement in order to achieve good production. One of the most common methods to drive a DC motor is by using PWM signals respect to the motor input voltage. Manual controller using rheostat/variable resistor (VR) is also not practical because it can waste time and cost. By varying the applied voltage with a rheostat, the speed can be varied from zero to the maximum rotation per minute (RPM) of the motor. Making a controller based on computer can reduce cost and time. The low cost electronic devices can be designed to make a speed controller system.

The most issue discusses in speed controller is regarding their efficiency and reliability for DC motor. The efficiency factor is important in order to save cost. The efficiency of speed controller is depending on method of control system which is PID, p-resonant, repetitive, time delay, fuzzy logic control and etc.

1.3 Objectives of the Project

The objectives of this project are
i.   to develop the PID voltage control for DC motor control.
ii.   to design three phase rectifier for DC motor control.
iii.   to design gate driver for three phase rectifier.
iv.   to communicate between Arduino and Matlab Software

1.4 Project Scope

This project is concentrated to control the speed of DC motor using PID controller. Voltage control method will be used to control the speed of DC motor. The PID controller is generated by Matlab Simulink.

Three phase fully controlled rectifier circuit is used to convert 3-ϕ AC input to DC output for supplying DC voltage to DC Motor. The specification/rating of the available DC motor is 220V, 1.8A and 0.3kW. For rectifier rating, the absolute maximum rating for power MOSFET is Drain-Source Voltage, V_{DS}=500V, Gate-Source Voltage, V_{GS}=$\pm$ 20V and Continuous Drain Current, I_{DS}=8A in order to drive the motor. The features of this power MOSFET is fast switching and simple drive requirements. The target of output voltage is ranging from 0 to 220V.

The gate driver that will be developed for rectifier contains six outputs. This is the combination of one input two outputs gate driver. Output pin (PWM) of Arduino Board is connected to the input of gate driver.

The communication between Arduino and Matlab Simulink will be investigated. Matlab Software is a powerful tool that contains Simulink Support Package for Arduino.

CHAPTER 2

LITERATURE REVIEW

2.1   DC Motor

The DC motors have been popular in the industry control area for a long time, because they have many good characteristics, for example: high start torque characteristic, high response performance, easier to be linear control. The combination of proportional, integral and derivative control action is called PID control action. PID controllers are commonly used to regulate the time-domain behavior of many different types of dynamic plants. These controllers are extremely popular because they can usually provide good closed-loop response characteristics [1]. DC motors capable for control capabilities, which means that speed, torque and even direction of rotation can be changed. It is used in speed control applications because of their low cost, excellent drive performance and low maintenance. DC motors also can provide a high starting torque at low speed and it is possible to obtain speed control over a wide range. The equivalent electrical circuit of a DC motor is illustrated in Figure 2.1. It can be represented by a voltage source (V) across the coil of the armature. The induced voltage (E) is generated by the rotation of the electrical coil through the fixed flux lines of the permanent magnets. This voltage is often referred to as the back emf (electromotive force). The following equations are applicable for all DC motors

$$E = K_e \Phi \omega_m \tag{2.1}$$

$$V = E + I_a R_a \tag{2.2}$$

$$T = K_e \Phi I_a \tag{2.3}$$

where Φ= flux per pole ; I_a = armature current; V = armature voltage; R_a = resistance of the armature circuit; ω_m = speed of the motor; T = tork developed by the motor, K_e = motor constant
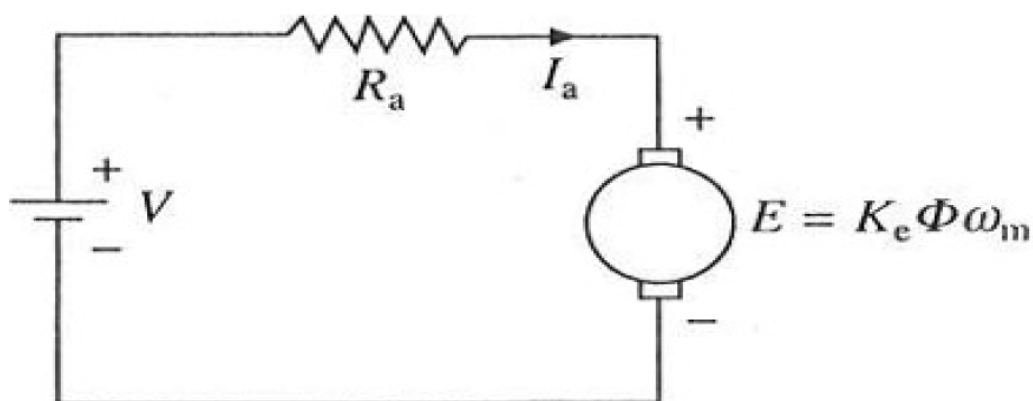
Figure 2.1: Equivalent Circuit of DC Motor
(Source, Gopal K. Dubey, Fundamental of Electric Drives, pg 61)

DC motors are seldom used in ordinary applications because all electric supply companies furnish alternating current. However for special applications such as in steel mills, mines and electric trains, it is advantageous to convert alternating current into direct current in order to use DC motors. The reason is that speed/torque characteristics of DC motors are much more superior to that of AC series-wound, shunt-wound and compound wound. The use of a particular DC motor depends upon the type of mechanical load it has to drive[2].

DC machines are characterized by their versatility. By means of various combinations of shunt, series, and separately-excited field windings they can be designed to display a wide variety of volt-ampere or speed-torque characteristics for both dynamic and steady-state operation. Because of the ease with which they can be controlled systems of DC machines have been frequently used in many applications requiring a wide range of motor speeds and a precise output motor control[3].

Direct current (DC) motors have been widely used in many industrial applications such as electric vehicles, steel rolling mills, electric cranes, and robotic manipulators due to precise, wide, simple, and continuous control characteristics. Traditionally rheostat armature control method was widely used for the speed control of low power dc motors. However the controllability, cheapness, higher efficiency, and higher current carrying capabilities of static power converters brought a major change in the performance of electrical drives. The desired torque-speed characteristics could be achieved by the use of conventional proportional- integral-derivative (PID) controllers. As PID controllers require exact mathematical modeling, the performance of the system is questionable if there is parameter variation[4].

The block diagram of DC motor is represented in the Figure 2.2 as shown below. In a DC motor, the supply voltage, E and current, I is given to the electrical port (input port) and the mechanical output i.e. torque, T and speed, ω from the mechanical port (output).
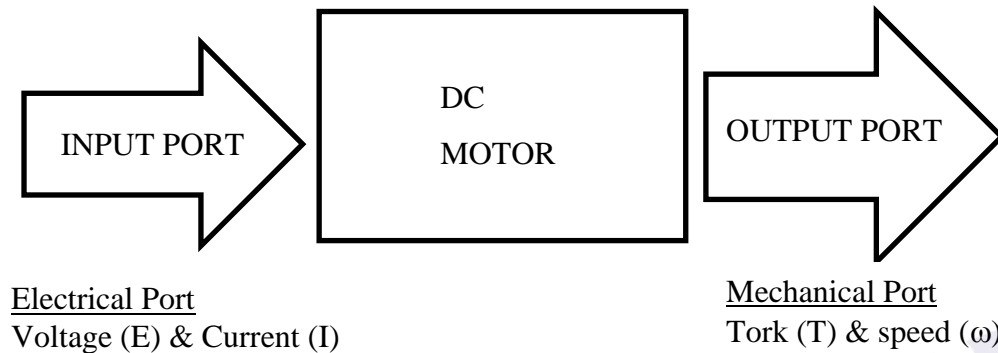
Figure 2.2: Block Diagram of DC Motor

In a DC motor this power is supplied to the armature directly from a DC source, while in an induction motor this power is induced in the rotating device. Motors that operate from DC power sources have many applications where speed control is desirable. The most desirable characteristic of DC motors is their speed-control capability. By varying the applied voltage with a rheostat (variable resistor), speed can be varied from zero to the maximum rpm of the motor[5].

For this project, multi-function DC motor will be used as a load as shown in Figure 2.3. This multi-function DC motor can be used as shunt, series and compound wound machine with commuting. The ability of this motor can handle high peaks in torque and linearity of speed characteristics. For this project, the DC motor is operated via three phase controlled rectifier. The rating operations of this motor are as follows

   i.   Power = 0.3 kW
   ii.   Voltage = 220V
   iii. Current = 1.8A
   iv.   Speed = 2000 rpm
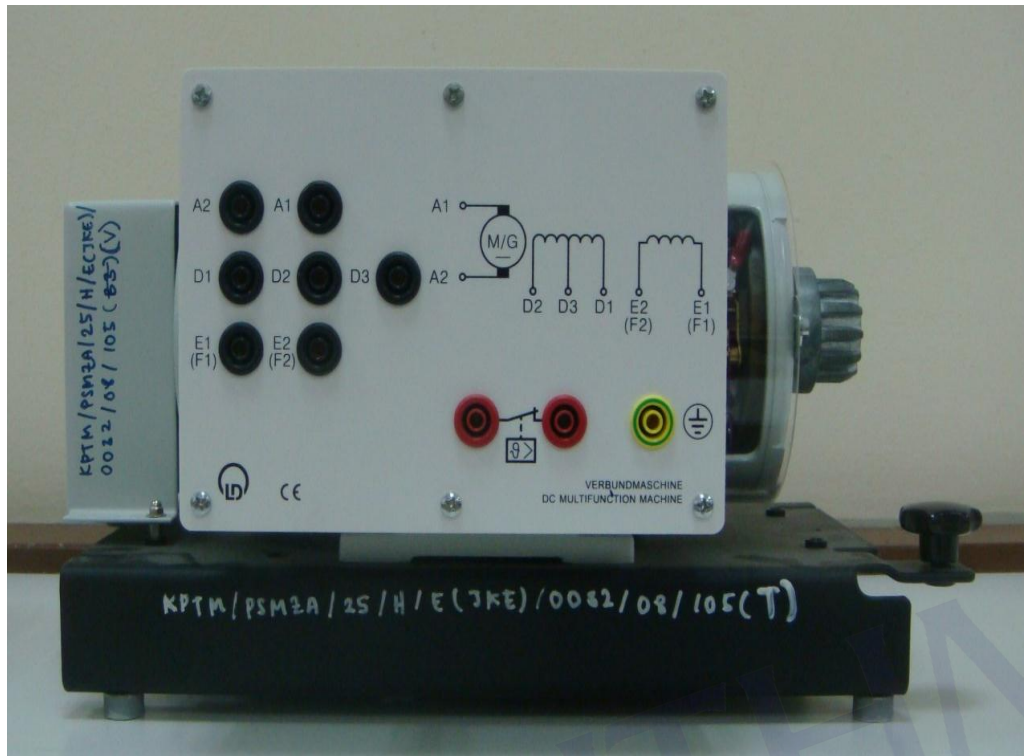
Figure 2.3: Multi-function DC Motor

2.2 Three-phase Controlled Rectifier

Three-phase controlled rectifiers have a wide range of applications, from small rectifiers to large high voltage direct current (HVDC) transmission systems. They are used for electrochemical processes, many kinds of motor drives, traction equipment, controlled power supplies, and many other applications [6].

A three-phase fully-controlled bridge rectifier can be constructed using six metal oxide semiconductor field effect transistors (MOSFETs) or SCRs. Three phase controlled rectifier is used to convert 3-ϕ (415 VAC) AC to DC voltage. The output DC is 415 VDC. This output voltage will be supplied to DC motor. The specification of motor is 220VDC, so the output of rectifier will be step down from 415VDC to 220VDC using voltage divider. Figure 2.4 shows the circuit of three phase controlled rectifier. The three-phase bridge rectifier circuit has three-legs, each phase connected to one of the three phase voltages. Alternatively, it can be seen that the bridge circuit has two halves, the positive half consisting of the MOSFETs Q_1, Q_3 and Q_5 and the negative half consisting of the MOSFET Q_2, Q_4 and Q_6.
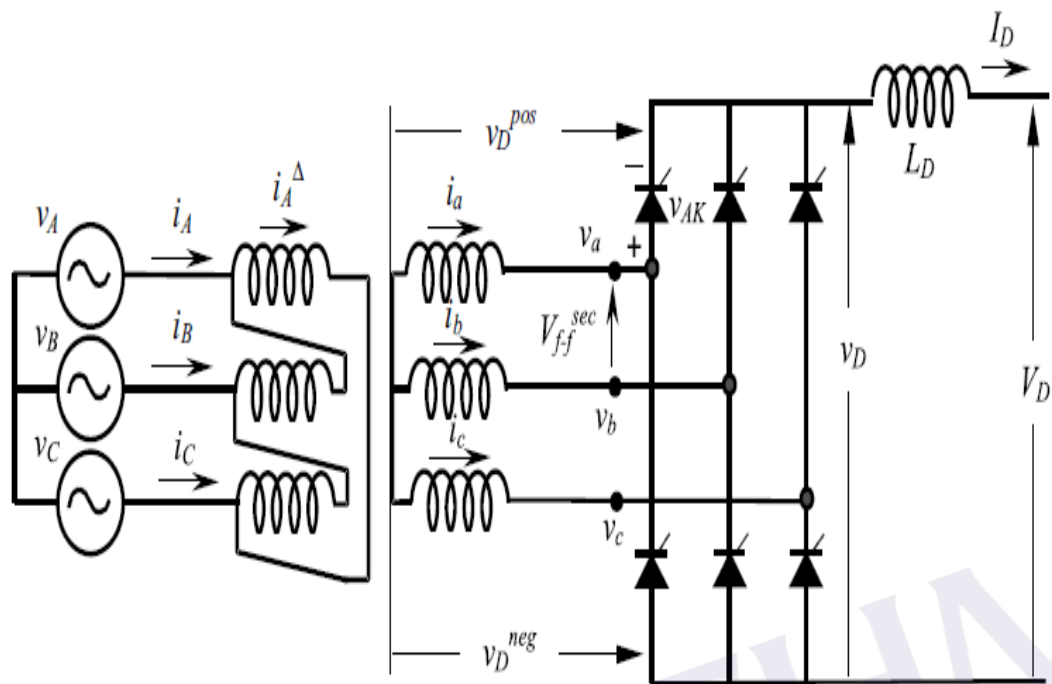
Figure 2.4: Three-phase Controlled Full-wave Rectifier

2.3 Gate Driver

The basic concepts of circuits and technologies for gate drivers in power converters focusing on voltage-controlled devices like power MOSFETs. Global trends towards energy efficiency over the last three decades have facilitated the need for technological advancements in the design and control of power electronic converters for energy processing. Voltage-controlled devices are semiconductors which require a constant voltage drive on the gate control terminal in order to remain in conduction. The input drive requirements of these devices are substantially lower than their current-driven counterparts and are the preferred choice in modern power electronics. Two such devices are the power MOSFET and the IGBT which are forced commutated switching devices being fully controlled at the gate terminal under normal operating conditions. Both MOSFETs and IGBTs require sufficient charge deposited into their gate junctions, whilst maintaining a minimum gate threshold voltage in order to remain in conduction. When designing a gate driver, it is always important to understand both the static and dynamic behavior of the semiconductor devices used as it aids the effectiveness of the design for a given gate

driver system[7]. Figure 2.5 shows the generalized block diagram of power electronic system whic h includes the gate driver circuit in the system.

Figure 2.5: Generalize Layout of a Power Electronic System
Showing the Situation of the Gate Driver Circuit

(Source : Irshad Khan, Gate Driver for Power Converter, Power Electronic Handbook, 2011)

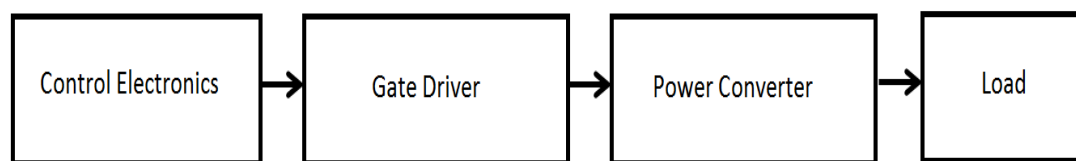One of the main contributions of power MOSFET is that led to the growth of the power electronics field has been the unprecedented advancement in the semiconductor technology, especially with respect to switching speed and power handling capabilities. Unlike the lateral channel MOSFET devices used in many IC technology in which the gate, source, and drain terminals are located in the same surface of the silicon wafer, power MOSFET use vertical channel structure in order to increase the device power rating. The modern power MOSFET has an internal diode called a body diode connected between the source and the drain. Most of the MOSFET devices used in power electronics applications are of the n-channel, enhancement-type. Depending on the applications, the power range processed in power electronic range is very wide, from hundreds of milliwatts to hundreds of megawatts. Therefore, it is very difficult to find a single switching device type to cover all power electronic applications. Today's available power devices have tremendous power and frequency rating range as well as diversity[10].

MOSFET is an acronym for Metal Oxide Semiconductor Field Effect Transistor and it is the key component in high frequency, high efficiency switching applications across the electronics industry. It might be surprising, but FET technology was invented in 1930, some 20 years before the bipolar transistor. The first signal level FET transistors were built in the late 1950's while power MOSFETs have been available from the mid 70's. Today, millions of MOSFET transistors are integrated in modern electronic components, from microprocessors, through "discrete" power transistors. The focus of this topic is the gate drive requirements of the power MOSFET in various switch mode power conversion applications[8].

A gate driver is a power amplifier that accepts a low-power input from a controller and produces a high-current drive input for the gate of a high-power transistor such as power MOSFET. Gate drivers can be provided either on-chip or as a discrete module. For this project, three "one input two output" gate drivers will be used. Three inputs are connected to output port of Arduino board in the form of PWM while 6 outputs are connected to MOSFETs gates of three phase rectifier. The main purpose of gate driver is to drive the rectifier. The output of signal PWM from Arduino is about 5V could not be able to drive power MOSFETs of rectifier. In order to drive power MOSFETs that needs input around 15V to its gate, gate driver will be used.

2.4   Controller

There are many types of controllers had been developed by academician and researchers. A controller is a hardware device or a software program that manages or directs the flow of data between two entities. In computing, controllers may be cards, microchips or separate hardware devices for the control of a peripheral device. In a general sense, a controller can be thought of as something or someone that interfaces between two systems and manages communications between them. There are two types of controllers in power systems which are passive controller and adaptive controller. The examples for passive controllers are relay control, hysteresis and sliding mode control and for adaptive controllers are PID, PI Repetitive, P-Resonance and Fuzzy Logic Controller (FLC).

2.4.1   Fuzzy Logic Controller (FLC)

A fuzzy logic controller system is a control system based on fuzzy logic. Fuzzy means uncertainty, fuzzy computes uncertainty by assigning values between 0 and 1 compared to conventional computation in digital form just only 0 or 1. That means, it deals with reasoning that is approximate rather than fixed and exact. Fuzzy logic involves computing using knowledge base and rule base. In fuzzy logic systems, input variables are assigned with a membership function. Each membership function is assigned with specified values., FIS Inference System and Fuzzy Logic Controller Toolbox is available in Matlab Simulink as shown in Figure 2.6. Fuzzy logic was introduced by Lotfi A. Zadeh of the University of California at Berkely. Today, fuzzy logic becomes the standard technique

for multi variable control. Fuzzy Control System Design is based on empirical methods which approach to trial and error. The general process is as follows:

i.   Document the system's operational specifications and inputs and outputs.

ii.   Document the fuzzy sets for the inputs.

iii.   Document the rule set.

iv.   Determine the defuzzification method.

v.   Run through test suite to validate system, adjust details as required.

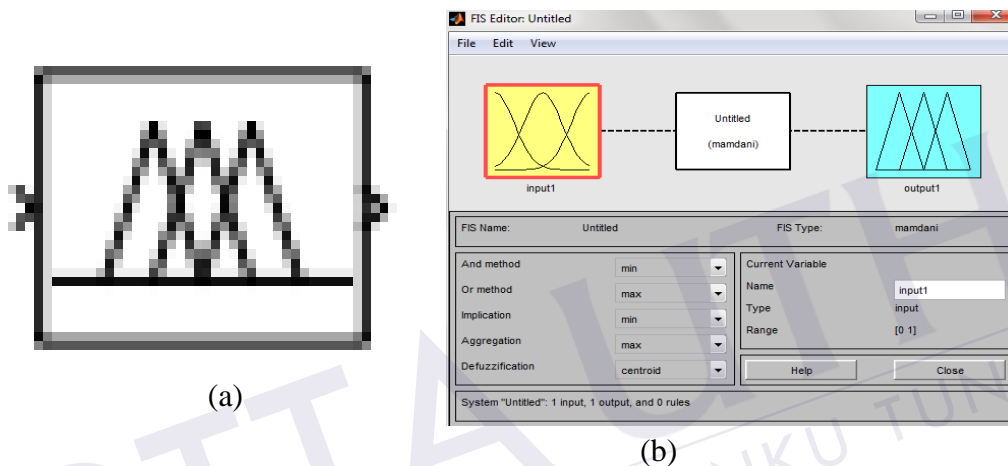vi.   Complete document and release to production.

Figure 2.6: (a) Fuzzy Logic Controller   (b) Fuzzy Inference System

The application of control algorithms based on the fuzzy logic theory has grown in recent years. This control method is one of adaptive control based on a linguistic process which is in turn based on the prior experience and heuristic rules used by human. The implementation of such control consists of translating the input variables to a language, like positive big zero, negative small and to establish control rules so that the decision process can produce the required outputs. If necessary, these linguistic outputs are transformed to numerical values[9].

The advantages of fuzzy logic controller includes

i.   Easy computation. Widely available toolboxes and dedicated integrated circuits.

ii.   Convenience user interface. Easier end-user interpretation when the final user is not a control engineer.

iii.   Combine regulation algorithm and logic reasoning. Allowing for integrated circuit schemes.

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