# THREE PHASE INVERTER FOR INDUCTION MOTOR CONTROL USING FUZZY-PI CONTROLLER WITH ARDUINO

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Allah S.W.T, Muhammad S.A.W,
For my beloved mother, father, wife, sons
Alhamdulillah

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# ABSTRACT

In this project, the main focus is the development of the three phase inverter for induction motor using Fuzzy-PI controller with Arduino. The Fuzzy-PI controller is designed using the Matlab's Simulink program software. The purpose of the controller is to control the current fed to the induction motor during motor operation. Using this Fuzzy-PI control algorithm, the speed of the running motor can be adjust depend on the DC voltage input which also effect the current flow into the induction motor. There are two situations being test in this project, which is open loop and close loop control scheme. Both situations are covered in both simulation and real hardware testing. The result of the open loop testing and the close loop testing are being compared as the performance indicator. The close loop control scheme show a good ability and responsive in current control for induction motor operation as compared to open loop control.

# ABSTRAK

Dalam projek ini, tumpuan utama ialah pembangunan penyongsang tiga fasa bagi motor aruhan menggunakan pengawal Fuzzy-PI dengan Arduino. Pengawal Fuzzy-PI telah direka menggunakan perisian program Simulink pada Matlab. Tujuan pengawal adalah untuk mengawal arus semasa motor aruhan sedang beroperasi. Dengan menggunakan algoritma kawalan Fuzzy-PI, kelajuan motor berpusing boleh dikawal berdasarkan kepada input voltan DC yang juga akan mempengaruhi aliran arus ke dalam motor aruhan. Terdapat dua keadaan yang dijalankan dalam projek ini, gelung terbuka dan gelung tertutup. Kedua-dua keadaan akan dibincangkan dalam bentuk simulasi dan pengujian perkakasan sebenar. Hasil ujian gelung terbuka dan ujian gelung tertutup dibandingkan sebagai petunjuk prestasi. Kawalan gelung tertutup menunjukkan keupayaan yang baik dan responsif dalam kawalan semasa untuk operasi motor aruhan berbanding kawalan gelung terbuka.

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| | |
|---|---|
| *ABS* - | Automatic Brake System |
| *AC* - | Alternating Current |
| *ADC* – | Analogue to Digital |
| *DAC* - | Digital to Analogue |
| *DC* - | Direct Current; |
| *DOL* - | Direct On Line |
| *DTC* - | Direct Torque Control |
| *DSP* - | Digital Signal Processing |
| *FFNN* - | Feed Forward Neural Network |
| *FOC* - | Field Oriented Control |
| *GA* - | Genetic Algorithms |
| *MV* - | Manipulated Variable |
| *PCB* - | Printed Circuit Board |
| *PD* – | Proportional Derivative |
| *PI* - | Proportional Integral |
| *PID* - | Proportional Integral Derivative; |
| *PWM* - | Pulse Width Modulation; |
| *VVVF* - | Variable Voltage Variable Frequency |

# CHAPTER 1

# INTRODUCTION

## 1.1 Project Background

Induction motor also known as asynchronous motor is a popular choice among the other type of motor and can be found easily within our surrounding, cover wide range of applications in both industrial and home appliance, from fan, compressor, pump, washing machine, freezer and many more. The main reason for these phenomena is none other than it advantages such as robustness, reliability, low price, maintenance free operation and no magnetic interference [1].

In terms of usage, it is by far the most important, with something like one third of all the electricity generated being converted back to mechanical energy in induction motors. It will continue to dominate these fixed-speed applications, but thanks to the availability of reliable variable-frequency inverters, it is now also the leader in the controlled-speed arena [2].

A power inverter, or inverter, is an electronic device or circuitry that changes direct current (DC) to alternating current (AC). There are many general applications for inverter that can be found in solar generating power systems to convert DC power from solar panel to AC power for house electrical appliance. The use of Pulse Width Modulation, PWM within the inverter design for the induction motor application. The output of the inverter at the load can be in specific pattern, this is useful for motor controller, which can be used for run the motor at full speed or stop. The pattern, which is the duty cycle of the PWM signal variation, can be created using analog component, microcontroller or any specific PWM integrated circuits.

There are a lot of microcontrollers with the built-in PWM feature, range from 8-bit to 32-bit architecture design. These microcontroller usually are cheap, great resources and easy to obtained. But there are manufacturers that provide more interesting microcontroller based product like Chipkit, Sakura and Arduino. These products were called electronic prototyping platform. It can be used straight out-of the-box, without any additional devices or component [3, 4].

## 1.2 Problem Statement

Three-phase AC induction motors are widely used in industrial and commercial applications. They are classified either as squirrel cage or wound-rotor motors. It produces medium to high degrees of starting torque. The power capabilities and efficiency in these motors range from medium to high. Popular applications pumps, compressors, conveyors, farm equipment and other mechanical duty applications.

AC induction motors are often operated in open loop with no velocity or position feedback. The Volt/freq ratio is maintained constant to provide a constant (maximum) torque over the operating range. This form of control is relatively inexpensive and easy to implement. Feedback from the rotor is not utilized and the rotor is assumed to follow the rotating flux generated in the stator, with a certain amount of slip present depending upon the load.

The disadvantage of open-loop Volt/freq control is that the motor can stall if the speed is ramped up too quickly or the load otherwise changes rapidly. Without some form of feedback, it is impossible to detect whether the motor is turning as expected, or if it is stalled. A stall causes high currents and the motor loses torque. By monitoring current, excessive slip can be detected, and the motor frequency can be adjusted accordingly by using controlled PWM.

The traditional PID controller can be said as one of the most successful controller available today but the parameters are not easy to moderate on-line in complex progress with the parameters changed with time.

## 1.3 Project Objectives

The main objectives for this project are:

i. To design a closed-loop control for a three phase induction motor.

ii. To design a combination of PI-Fuzzy controller to control the speed a three phase induction motor.

iii. To develop the hardware (inverter and gate driver) of the controller to control a three phase induction motor.

iv. To successfully make a communication between computer using Matlab software and Arduino.

## 1.4 Scope Project

The scope of this project is:

i. Design the closed-loop control with current feedback for the 1kWatt three phase induction motor type squirrel cage.

ii. Design the Fuzzy- PI controller using volt/frequency method to control the current of a three phase induction motor.

iii. Build the hardware for this project, which is the inverter using MOSFET as the switching device and the gate-driver for the inverter.

iv. Successfully make a connection between Matlab's Simulink and Arduino Mega 2560.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Induction Motor

The three-phase induction motors are the most widely used electric motors in industry. They run at essentially constant speed from no-load to full-load. However, the speed is frequency dependent and consequently these motors are not easily adapted to speed control. Nevertheless, the 3-phase induction motors are simple, rugged, low-priced, easy to maintain and can be manufactured with characteristics to suit most industrial requirements.

Like any electric motor, a 3-phase induction motor has a stator and a rotor. The stator carries a 3-phase winding (called stator winding) while the rotor carries a short-circuited winding (called rotor winding). Only the stator winding is fed from 3-phase supply. The rotor winding derives its voltage and power from the externally energized stator winding through electromagnetic induction and hence the name. The induction motor may be considered to be a transformer with a rotating secondary and it can, therefore, be described as a “transformer type” AC machine in which electrical energy is converted into mechanical energy.

The squirrel cage type consists of a laminated cylindrical core having parallel slots on its outer periphery. One copper or aluminium bar is placed in each slot. All these bars are joined at each end by metal rings called end rings. This forms a permanently short-circuited winding which is indestructible. The entire construction (bars and end rings) resembles a squirrel cage and hence the name [5].

The wound type consists of a laminated cylindrical core and carries a 3-phase winding, similar to the one on the stator. The rotor winding is uniformly distributed in the slots and is usually star-connected. The open ends of the rotor winding are brought out and joined to three insulated slip rings mounted on the rotor shaft with one brush resting on each slip ring.

Most of 3-phase induction motors use squirrel cage rotor as it has a remarkably simple and robust construction enabling it to operate in the most adverse circumstances. However, it suffers from the disadvantage of a low starting torque. It is because the rotor bars are permanently short-circuited and it is not possible to add any external resistance to the rotor circuit to have a large starting torque [6].

However, the use of induction motors is challenging because of its complex mathematical model, its non-linear behavior during saturation and the electrical parameter oscillation that depends on the physical influence of the temperature.

## 2.2 Three Phase Inverter

Inverter is an electrical power converter that changes direct current (DC) to alternating current (AC). The converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits. Inverters are commonly used to supply AC power from DC sources such as solar panels or batteries.

The word 'inverter' in the context of power-electronics denotes a class of power conversion circuits that operates from a dc voltage source or a dc current source and converts it into ac voltage or current. The 'inverter' does reverse of what ac-to-dc 'converter' does. 'Inverter' is referred as a circuit that operates from a stiff dc source and generates ac output. If the input dc is a voltage source, the inverter is called a voltage source inverter (VSI). One can similarly think of a current source inverter (CSI), where the input to the circuit is a current source. The VSI circuit has direct control over 'output (AC) voltage' whereas the CSI directly controls 'output (AC) current [7].

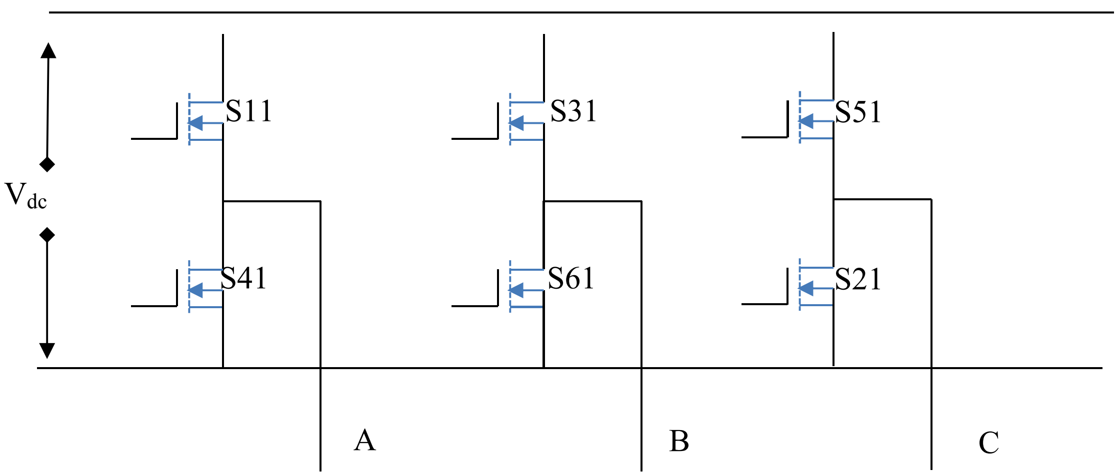


Figure 2.1:Three phase full bridge inverter

As in the single phase voltage source inverters PWM technique can be used in three-phase inverters, in which three sine waves phase shifted by 120° with the frequency of the desired output voltage is compared with a very high frequency carrier triangle, the two signals are mixed in a comparator whose output is high when the sine wave is greater than the triangle and the comparator output is low when the sine wave or typically called the modulation signal is smaller than the triangle. This phenomenon is shown in Figure 2.2. As is explained the output voltage from the inverter is not smooth but is a discrete waveform and so it is more likely than the output wave consists of harmonics, which are not usually desirable since they deteriorate the performance of the load, to which these voltages are applied.

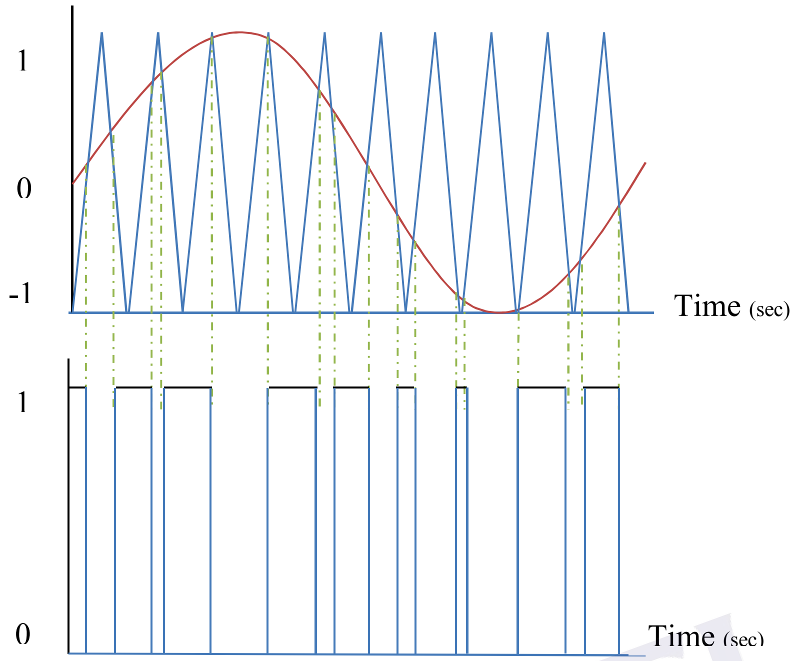


Figure 2.2: PWM illustration by the sine-triangle comparison method (a) sine triangle comparison (b) switching pulses

## 2.3 Controller

Generally there are three type of controller that can be used to control the induction motor. The direct torque control, field oriented control and volts/hertz control. Each controller has pros and cons and the user can choose based on the requirement and application of the motor.

### 2.3.1 Direct Torque Control

Direct Torque Control or DTC, as the name indicates, is the direct control of torque and flux of an electrical motor by the selection, through a look-up table, of the power converter voltage space vectors. The main advantage of DTC is its structure simplicity, since no coordinate transformations, current controllers and modulations are needed.

Moreover the controller does not depend on motor parameters. DTC is considered to be a simple and robust control scheme which achieves quick and precise torque control response. However, torque and flux modulus values and the sector of the flux are needed and more importantly, short sampling period time for the torque and flux control loops are needed in order to keep electromagnetic torque ripple within an acceptable value [8].

There are also a few experiment using this technique for induction motor controller which gave promising result as the controller is capable of controlling the induction motor at any speed like in [9].

### 2.3.2 Field Oriented Control

Field oriented control or FOC methods control the frequency, amplitude and phase of the motor drive voltage. The key to field oriented control is to generate a 3-phase voltage as a phasor to control the 3-phase stator current as a phasor that controls the rotor flux vector and finally the rotor current phasor [10].

The Field Orientated Control consists of controlling the stator currents represented by a vector. This control is based on projections which transform a three-phase time and speed dependent system into a two coordinate (d and q coordinates) time invariant system.

Field orientated controlled machines need two constants as input references, the torque component (aligned with the q coordinate) and the flux component (aligned with d coordinate). As Field Orientated Control is simply based on projections the control structure handles instantaneous electrical quantities. This makes the control accurate in every working operation (steady state and transient) and independent of the limited bandwidth mathematical model [11].

### 2.3.3 Volts/Hertz Control

The constant volts/hertz control methods is the most popular method of scalar control, it controls the magnitude of the variables like frequency, voltage or current [12]. The command and feedback signals are DC quantities and are proportional to the respective variables. The purpose of the volts/hertz control scheme is to maintain the air-gap flux of AC Induction motor constant in order to achieve higher run-time efficiency [13].

The magnitude of stator flux is proportional to the ratio of stator voltage & frequency. If ratio is kept constant the stator flux remains constant & motor torque will only depend upon slip frequency.

When stator frequency fails under a given frequency threshold (boost frequency), the voltage magnitude must be kept at given level called boost voltage to keep rotor flux magnitude constant. Vboost means small voltage is added to dc voltage reference to compensate stator resistance drop at low frequency.

At opposite when frequency becomes higher than rated value, the voltage magnitude is kept at rated value. The stator flux is no more constant & torque decreases. The characteristic is defined by the base point of the motor. Below the base point the motor operates at optimum excitation because of the constant v/f ratio [14].

Above this point the motor operates under-excited because of the DC-bus voltage limit. If speed is changed by maintaining v/f ratio constant, then maximum torque remains same.

### 2.3.4 PID Controller

The Proportional, Integral and Derivative or PID is a control algorithm that tries to compensate for characteristics in your system. There are three primary components to think about in a PID control loop. Each component is prefixed with a gain constant, and when added together, give you the instantaneous control value that you use to drive your system [15].

The ideal version of the PID controller is given by the formula

$$u(t) = k_p e(t) + k_i \int_0^t e(t)dt + k_d \frac{de(t)}{dt} \qquad \text{Eq. 2.1}$$

Where $u$ is the control signal and $e$ is the control error ($e$=r−y). The reference value, r, is also called the set point. The control signal is thus a sum of three terms: a proportional term that is proportional to the error, an integral term that is proportional to the integral of the error, and a derivative term that is proportional to the derivative of the error. The controller parameters are proportional gain,$k_p$, integral gain, $k_i$ and derivative gain, $k_d$.

The proportional term drives a change to the output that is proportional to the current error. This proportional term, $k_p$ is concerned with the current state of the process variable. The integral term, $k_i$ is proportional to both the magnitude of the error and the duration of the error.

It (when added to the proportional term) accelerates the movement of the process towards the set point and often eliminates the residual steady-state error that may occur with a proportional only controller. The rate of change of the process error is calculated by determining the differential slope of the error over time (i.e., its first derivative with respect to time). This rate of change in the error is multiplied by the derivative gain ($k_d$) [16].

The PID controller has been in use for over a century in various forms. It has enjoyed popularity as a purely mechanical device, as a pneumatic device, and as an electronic device. The digital PID controller using a microprocessor has recently come into its own in industry. As you will see, it is a straightforward task to embed a PID controller into your code [17].

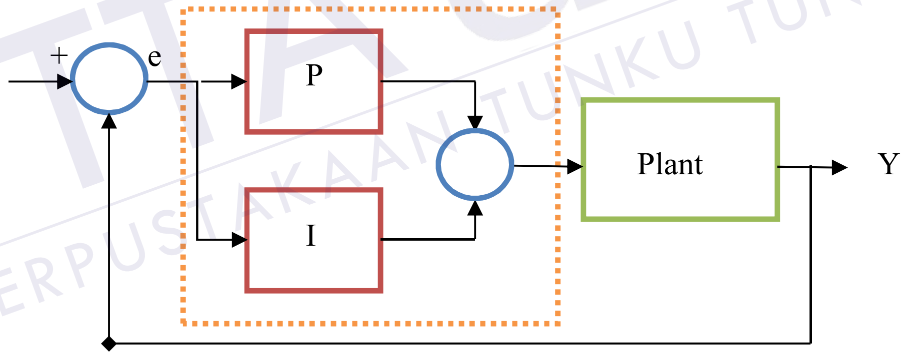


Figure 2.3: PID control logic block diagram

### 2.3.5 Fuzzy Logic Controller

The fuzzy set theory introduced by Zadeh has found many applications in a variety of fields. Among the most successful applications of this theory is fuzzy logic control. A fuzzy logic controller consists of three major process blocks. They are (a) fuzzification, (b) rule evaluation, and (c) defuzzification. The block diagram of a closed-loop fuzzy logic control system is shown in Figure 2.4.

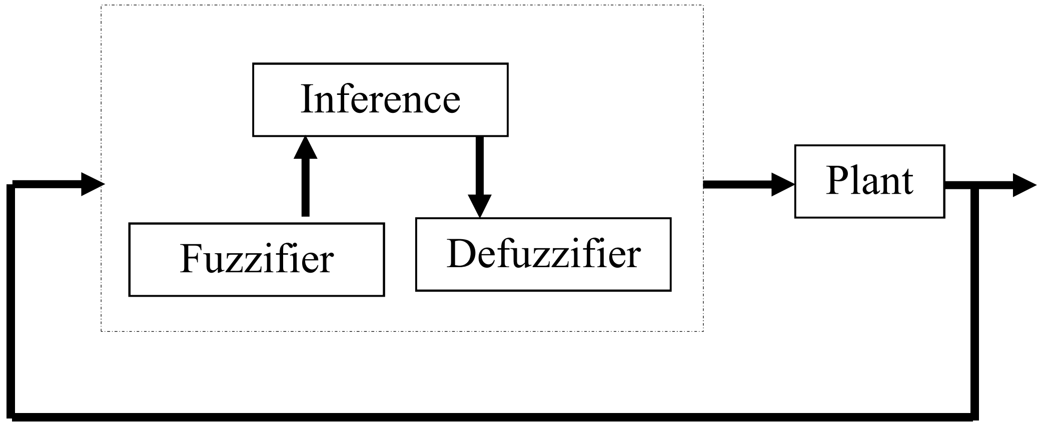


Figure 2.4: Block diagram of typical fuzzy logic controller.

The fuzzification process takes input values and combines them with stored membership function information to produce the grade of membership function. After the grade of membership function is produced, the fuzzy inference will evaluate rules [18].

The truth value for each rule is the minimum of the fuzzy inputs for that rule, and this truth value is stored to each fuzzy output for that rule unless a larger value is already stored in the fuzzy output. When all fuzzy outputs are derived, the defuzzification is performed by combining all fuzzy outputs into a specific composite result to the system.

By contrast, in the technical sense, fuzzy systems are precisely defined systems, and fuzzy control is a precisely defined method of non-linear control. The main goal of fuzzy logic is to mimic and improve on "human-like" reasoning. "Fuzzy systems are knowledge-based or rule-based systems". Specifically, the key components of fuzzy system's knowledge base are a set of IF-THEN rules obtained from human knowledge and expertise [19].

## 2.4 Arduino

Arduino is a single-board microcontroller designed to make the process of using electronics in multidisciplinary projects more accessible. The hardware consists of a simple open source hardware board designed around an 8 bit Atmel AVR microcontroller, though a new model has been designed around a 32-bit Atmel ARM. The software consists of a standard programming language compiler and a boot loader that executes on the microcontroller.

The Arduino project is a fork of the open source Wiring platform and is programmed using a Wiring-based language (syntax and libraries), similar to C++ with some slight simplifications and modifications, and a Processing-based integrated development environment (IDE).

The Arduino integrated development environment (IDE) is a cross-platform application written in Java, and is derived from the IDE for the Processing programming language and the Wiring projects. It is designed to introduce programming to artists and other newcomers unfamiliar with software development [20].

The Arduino is intended as a prototyping platform for electronic project which is good for beginner to actually get the basic idea of embedded system. The ability of the Arduino board totally depend on the micro controller on board used by Arduino, example Arduino Mega 2560 used in this project used micro controller Atmega 2560 by Atmel.

# CHAPTER 3

# METHODOLOGY

All the work process can be dividing into 3 major part, software, firmware and hardware. The software and firmware part includes stage such as designing and simulation, the hardware part involve the implementation and verification process.

## 3.1 Block Diagram of Project

Figure 3.1 shows the block diagram of the project that consists of 4 mains parts which are the DC source, the three phase inverter, the three phase induction motor as a load and the Arduino controller.

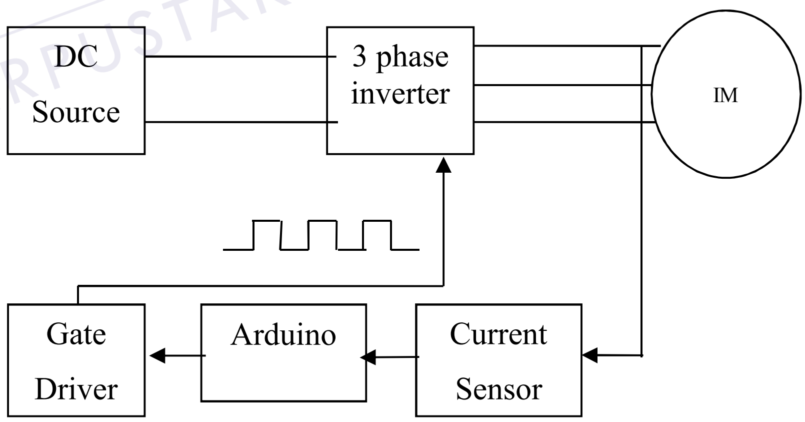


Figure 3.1: Block diagram of the project

The first part of the block diagram is the DC source to give the power for the whole system. The second part is the three phase inverter. The general function of the inverter is to convert the DC voltage to the AC voltage. In this system, the three phase inverter will be used because the load is the three phase induction motor.

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