Modeling and Simulation of Three-Phase Induction Motor for Digital Control

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Abstract

This report basically discusses the development of the project which is Modeling and Simulation of Three Phase Induction Motor for digital control. The purpose of this project is to get better understanding of the various techniques of variable speed control. This report provides a brief overview of the basic operation principles of two types of variable speed which are scalar control and vector control. A comparative study to choose the best techniques will be done in this project. The challenge in this project is the author requires better understanding of the design and the characteristics of the model. The author also requires basic knowledge of computer programming to understand and write MATLAB. Lab testing will be done to stimulate the model. This Final Year Project will includes the selection of the best techniques to be used to stimulate the three phase induction motor as well as practical testing and analysis of the data which will be gathered from the simulation.

Keywords:

Three-phase induction motor, Field Oriented Control, Space Vector Modulation, simulation

Introduction

The ideas of developing induction motor were start by Nicola Tesla during the late 1880s where he gets the ideas in 1888. The induction motor are then recognizable form between 1888 and 1895 and during that period, two and three power sources were developed to produce the rotating magnetic fields within the motor. Then stator winding were develop and the squirrel cage was introduced. By 1896, three-phase induction motors were fully functional and recognizable.

Increasing demand in power electronics for high performance industrial machinery has contributed to rapid developments in motor control. The improvements in induction motor design were lead to improvements in motor operating efficiency and reducing the material cost of the machines. This field study of induction motor has numerous applications in the areas of manufacturing, mining, and transportation. It is also sometimes difficult to determine which techniques are best suited to particular application in the diversity of digital motor control.

The most common motors used in industrial motion control systems and home main power appliances are AC induction motor [1] because of its simplicity and ease of operation. These motor are operates by motor drives which known as power electronic devices. AC induction motor drives consists of two main sections, a controller to set the operating frequency to determine the speed and a three phase inverter to generate the required sinusoidal three phase system from a DC voltage supply [1].

The motor speed of AC induction motor can be changes by vary the frequency and amplitude of the drive voltage using SCR drives. By firing each SCR, it will produce sinusoidal voltage on the motor phase. The SCR drives can produce six ways to produce motor currents however the disadvantages of these type of circuit are it causes high heat dissipation and at low frequencies it give low performance. Due to this problem, SRC drives are now replaced with MOSFET or IGBT devices that will give high performance with minimal power losses. By using Pulse Width Modulation signal, variable drive voltages and currents can be generating continuously.

Problem Statement

Induction motor is the most popular of all electric machines because of its robust construction, low manufacturing cost and easy to control. Compared to DC motor, induction motor only has one excitation connection rather than two excitation connections. For these reasons, induction motor is more durable than a DC motor.

Major improvements in modern industrial processes caused the use of induction motor to increase, which attributed to the advances in variable speed motor drives. In order to be in line with modern technologies, high performance control schemes become essential in application. Various great deal of work has been done such as doing research on the application of sensorless control, three phase voltage source inverter, studies review on techniques application of Field Oriented Control (FOC), Direct Torque Control (DTC) and

Pulse Width Modulation (PWM) and a number of high performance control schemes were evaluated.

The designer's problem, in the light of these standards, is to select which suitable techniques will be using to control the operation of three-phase induction motor. This project requested the student to thoroughly investigate the dynamics and steady state performance of three phase induction motor by using dsPIC Digital Signal Controller. In addition, the outcomes must produced correct simulation by performing and formulating the required interactive computer software, MATLAB programming. Simulink modeling of the chosen controller will be carried out and this simulation also aided in the selection of controller parameter.

Objective & Scope of Study

The objectives of this project are:

1. To do literature review on the design specifications and construction of the Induction motor and to choose the suitable techniques for the control of the motor.

2. To study the principles of Field Oriented Control and Space Vector Pulse Width Modulation

3. To study the basic construction/configuration of dsPIC and its application for the speed control of induction motor.

Basic understanding on theoretical aspect of Induction motor is required in order to design an induction motor using MATLAB. It is essential to understand the operation of the induction motor as the parameters and clarification of the calculation are needs to be done. All parameters of induction motor have to be understood and calculated.

A good knowledge in using MATLAB programming is really important. This is to ensure the output result in the form of simulation can be produced. All calculation is included and tested in computer aided tool, MATLAB. The major part in this project is to formulate MATLAB programming and produced a correct graph output.

This project mainly focused on design study and programming using MATLAB, in which the software is readily available. A lot of self-study, consultation session and researches must be done with the aim getting the job done according to the schedule.

Methodology

- **Phase 1:** Research and literature review

  Theories and concepts relevant to the project's field of study are looked into and analyzed.
- **Phase 2:** Study on the operation of three phase induction motor

  The properties and operating mechanism of a three-phase induction motor is explored.
- **Phase 3:** Choose the suitable techniques for the motor

  Several techniques are compared to find which control technique is more suitable to develop for the motor control
- **Phase 4:** Study the fundamentals of coding and programming of MATLAB

  The basics and relevant commands of MATLAB is learnt and mastered.
- **Phase 5:** Develop coding for the induction motor

  Programs are written in order to enable the induction motor to respond to appropriately.
- **Phase 6:** Further improvement for the project

Tools required for this project is MATLAB. MATLAB is required to execute the simulations for the analysis performed in the design of three-phase induction motor. MATLAB software is used throughout the whole code development process like writing, compiling, debugging, and programming

Control Techniques

Most of the motor in variable-speed drives are AC induction motors. There are various types of speed control tec hniques implemented to the induction motors. Speed control techniques can be classified in three categories:

- Scalar control – Volts per Hertz Control
- Vector control – Field Oriented Control
- Direct Torque Control (DTC)

Volts per Hertz Control Theory

For scalar control the techniques is to vary the voltage and frequency to vary the speed of the motor. One of the techniques is the constant Volts per Hertz (V/f). It is the most common control that used in adjustable speed drives of induction motor. The basic function of V/f is to act as variable frequency generator in order to vary the speed of the motor drives [2]. If the input frequency of the motor is changed, the synchronous speed of the motor is also changes. The changes of the frequency affect the torque profile curve where the curve is depends on the voltage and frequency that are applied to the stator. The torque developed by the induction motor is directly proportional to the ratio of the voltage and frequency. By keeping the ration constant, the torque develop can be kept constant throughout the speed range and the air gap flux at its rated value.

Field Oriented Control

The purpose of FOC is to manage the interrelationship of the fluxes and to squeeze out the most performance from the motor. For FOC there are several blocks that will be used to control the performance of the induction motor. Here Clarke-Park transformation is used where three-phase current vectors are converted to a two-dimensional stationary rotating reference frame (d-q). The d component represents the flux produce by the stator current and q component represents the torque. Figure below shows the basic scheme of torque control with FOC [10].

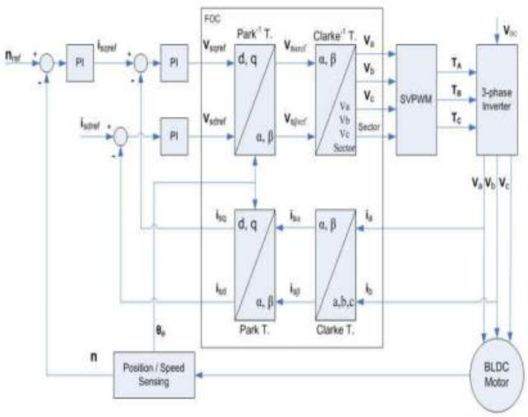

Figure 1 Field Oriented Control Scheme

To implement the basic principle of FOC it is important to control the stator currents that produce stator flux. The Clarke and Park transforms are used to perform a two-step transformation on the stator currents. The first steps is to transform a three-phase to a two phase where the Clarke transform is used to convert the three-axis coordinates into two-axis orthogonal coordinates (i_a and i_b). From the Clarke transform, i_a and i_b are designated to $i_{s\alpha}$ and $i_{s\beta}$. These two components are feed to Park transform where Park transform will convert the fixed coordinates into two-axis rotating coordinates (i_{sd} and i_{sq}).

The i_{sd} and i_{sq} components are compared to the flux reference (i_{sdref}) and torque reference (i_{sqref}). At this point, the control structure can be used to control either synchronous or induction machines by changing the value of flux reference and obtaining rotor flux position. For induction motor, the value of flux reference should not be set at zero because the motor need a rotor flux creation in order to operate [10]. A speed regulator block also known as PI regulator produce a torque command to run the motor at a given speed set point. This speed regulator acts on the set point and the measured speed to produce the torque command. If the motor works below the set speed, the PI regulator commands a larger torque to increase the speed and vice-versa. Here the torque command is i_{sqref}.

The ouput of the current regulators (V_{sdref} and V_{sqref}) will feed to the inverse Park transform. This block is used to convert the controller's reference voltage back onto the stationary α and β axes ($V_{s\alpha ref}$ and $V_{s\beta ref}$) so that the output can be directly feed to SVPWM. The SVPWM block will calculate the switching duty ratios for the PWM unit to generate voltage vector and will give pulses to three-phase inverter to run the motor [10].

Direct Torque Control

The DTC switches the inverter according to the load needs. It can calculate torque without the complex equation of algorithms or mechanical speed sensors. The main model in DTC is its adaptive motor model. The model is based on mathematical expression of basic motor theory [1]. It calculates actual flux and torque of the motor by getting the motor parameters like stator resistance, mutual inductance and saturation coefficiency. The model can get the information without rotating the motor but by rotating the motor helps in the tuning of the model [1].

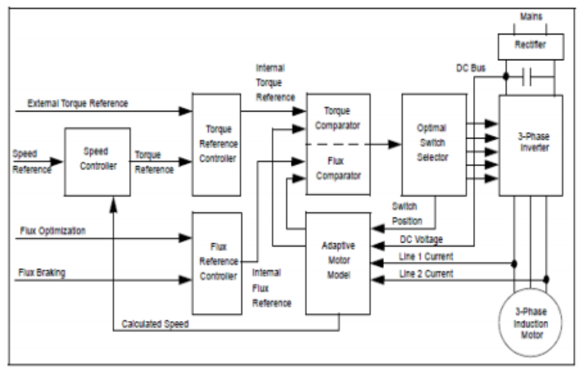

Figure 2 DTC Block Diagram

Results

Field Oriented Control

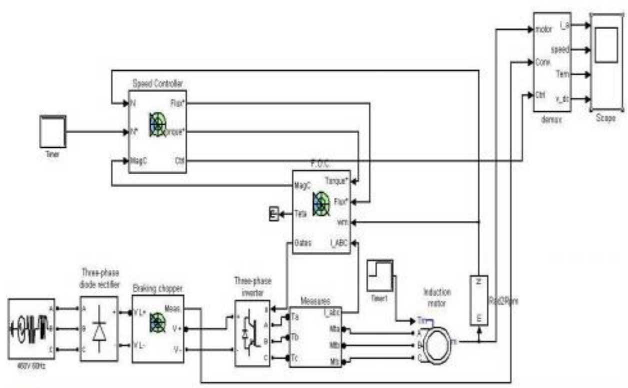

Figure 3 Three Phase Induction Motor with Field Oriented Control

The model blocks or configuration blocks were taken from MATLAB demo. The operating of this block diagram starts with 460V ac supply with frequency 60Hz into three phase diode bridge rectifier. AC supply need to con verted first to DC voltage supply before pump into the inverter by using the three phase diode bridge rectifier. DC voltage is used to generate a variable voltage and variable frequency power supply and breaking chopper is used to absorb the energy produced by motor deceleration. Three phase inverter will convert back dc voltage to ac voltage. The frequency is not change at in ac voltage controller so that the output voltage has the same frequency as the supply voltage.

During simulation, the motor will s end the motor speed to speed controller to compare the value of it speed with speed reference. Author will set constant value of the speed references with time where when t=0s the speed will be 500rpm and at t=1s the speed will be 0rpm. Below in figure 8 shows the result of rotor speed. Field Oriented Control (FOC) will receive the values of flux and motor torque. FOC block diagram is used to control of both frequency and magnitude of the output voltages and it will pump gate pulses into three phase invert\er. FOC is also able to control the magnitude output current of sources inverter. The result below shows the motor stator current, rotor speed, electromagnetic torque and DC bus voltage.

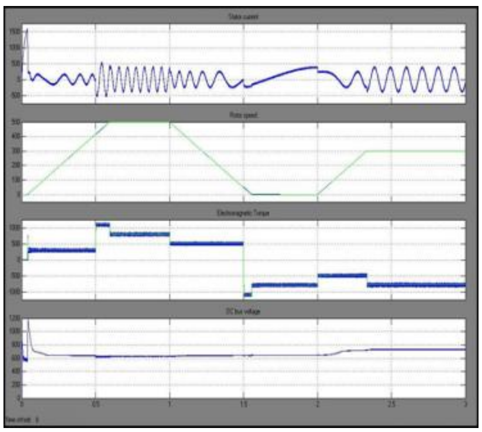

Figure 4 Result of Three-Phase Induction Motor with Field Oriented Control

Space Vector Modulation

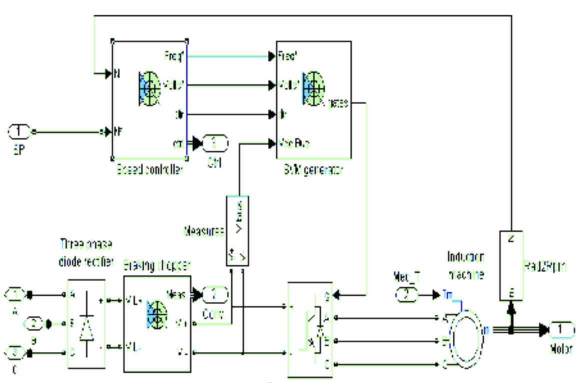

Figure 5 Space Vector PWM VSI Induction Motor Drive

Figure above is the block diagram of space vector PWM VSI induction motor drives. This circuit can be constructed from existing block in the Simulink library or the MATLAB demo. The motor drive starts with 220V ac power supply and input frequency 60Hz. The ac supply will convert to dc link by three-phase diode rectifier. DC voltage is used to generate a variable voltage and variable frequency power supply and breaking chopper is used to absorb the energy produced by motor deceleration.

The block diagram starts with the speed regulator (PI regulator). Where the speed regulator at block no.1 produces a slip compensation and feed to the rotor speed in order to derive the commanded stator voltage frequency. In this block diagram, V/f is also applied to the motor. During simulation, the speed of the block diagram is set 1000 rpm at time t = 0 s, the speed follows precisely the acceleration ramp. Then at time t = 1 s, the speed set point is changed to 1500 rpm and the electromagnetic torque reaches again a high value so that the speed ramps precisely at 1800 rpm/s up to 1500 rpm under full load and at time t = 1.5 s, the mechanical load passed from 11 N.m to -11 N.m, which causes the electromagnetic torque to stabilize at approximately at -11 N.m shortly after. Figure below show the result of the motor stator current, the rotor speed, the electromagnetic torque and the DC bus voltage on the scope. The speed set point and the torque set point are also shown.

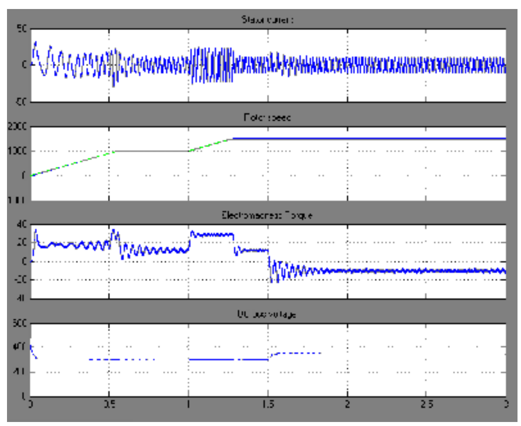

Figure 6 Result of Space Vector PWM VSI Induction Motor Drive

Discussion

Vector control principles are based on the control of both the magnitude and the phase of each phase current and voltage. Here vector control is represented to control the capability performance of motor drive and achieving higher power conversion efficiency. Most of the motor operations are in variable speed drives. This is because variable speed drives help to save energy and optimize system. Th ere are various induction motor control techniques in practice today and the popular control techniques are the V/f and FOC.

The principle of Field Oriented Control is to control the stator currents represented by a vector. The control is based on projection where three-phase current vectors are converted to a two-dimensional stationary rotating reference frame (d-q). To control the motor drive, FOC need two constant as input reference which are the torque component (aligned with the q co-ordinate) and the flux component (aligned with d co-ordinate). The strategy of this control is to manage the interrelationship of the fluxes where FOC allow torque and flux to be decoupled and controlled independently. This makes the control accurate in every working operation (steady state and transient) and independent of the limited bandwidth mathematical model.

For Space Vector Modulation (SVM), the technique is similar to the concept of FOC. Transformation from three-phase to two-phase is required. The purpose of S VM is to generate the respective output signal based on the given input. A techniques which exploits space vectors to synthesize the command or reference voltage within a sampling period by selecting the two adjacent voltage vectors and zero voltage vectors. The switching frequency of the VSI utilizing SVM is constant, depending on the sampling period.

Conclusion

The project has been done in parallel with the objectives and time line established in the project. All the studies of the performance, the characteristics and the techniques of the induction motor were done and understood. For variable speed techniques, it is proven that field oriented control is the best techniques to drive the induction motor. The principle of FOC is easily to understand and de velop using MATLAB.

Rapid development of DSP helps to save energy, less cost and maintain the good performance of induction motor. DSP helps to reduce the complexity of the operation of induction motor where now only writing assemble code are need to run the motor. Bit only the problem is the challenging in writing the assemble code.

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