Simulation of Three Phase Induction Motor on Stationary Reference Frame

by

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LIST OF ABBREVIATIONS

IM	Induction motor
AC	Alternating Current
DC	Direct Current
RMS	Root Means Square
d	Direct axis
q	Quadrature axis
Hp	Horse Power
MATLAB	Mathematical Laboratory
EMTP	Electromagnetic Transient Program
IEC	International Electrotechnical Commission
JEC	Japan Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
PWM	Pulse Width Modulation
f	System frequency
P	Number of poles
Emf	Electromagnetic Field
S	Slip
RPM	Revolution per Minute
Pf	Power Factor
MMF	Magnetomotive Force

LIST OF SYMBOLS

Ø	Phase
Ψ	Flux Linkage
ψ^{s}_{ds}	Stator Flux Linkage on d-axis in Stationary Reference Frame
ψ^{s}_{qs}	Stator Flux Linkage on q-axis in Stationary Reference Frame
ψ'^{s}_{dr}	Rotor Flux Linkage on d-axis in Stationary Reference Frame
ψ'^{s}_{qr}	Rotor Flux Linkage on q-axis in Stationary Reference Frame
ψ^{s}_{md}	Mutual Flux Linkage on d-axis in Stationary Reference Frame
ψ^{s}_{mq}	Mutual Flux Linkage on q-axis in Stationary Reference Frame
ω	Unspecific Speed in Arbitrary Reference Frame
ω_r	Speed in Rotor Reference Frame
ω_e	Speed in Synchronous Rotating Reference Frame
ω_m	Mechanical Speed
ω_b	Base Speed (Rated Speed)
θ_r	Rotor Angle
E_a	Integrated voltage
f	Frequency Oscillation in Hz
f_{abc}	Stator or Rotor Variables in Three Phase Induction Motor
f_{qd0}	Stator or Rotor Variables in Stationary Reference Frame
f_{test}	Test Frequency
f_{rated}	Rated Frequency
i_{as}	Stator Current phase-a

i_{bs}	Stator Current phase-b
i_{cs}	Stator Current phase-c
i_{ar}	Rotor Current phase-a
i_{br}	Rotor Current phase-b
i_{cr}	Rotor Current phase-c
i_{qs}	Stator Current in q-axis
i_{ds}	Stator Current in d-axis
i_{qr}	Rotor Current in q-axis
i_{dr}	Rotor Current in d-axis
i^{s}_{qs}	Stator Current Variables on q-axis in Stationary Reference Frame
i^{s}_{ds}	Stator Current Variables on d-axis in Stationary Reference Frame
i_{0s}	Stator Current Variables on Zero-axis in Stationary Reference Frame
I	Current
$I_{n.l}$	No-Load Current
I_{br}	Block Rotor Current
I_{DC}	DC Current
I_{rated}	Rated Current
I'^{r}_{qr}	Rotor Current Variables on q-axis in Stationary Reference Frame
I'^{r}_{qr}	Rotor Current Variables on d-axis in Stationary Reference Frame
I'_{0r}	Rotor Current Variables on Zero-axis in Stationary Reference Frame
J	Inertia of Motor
L_{sg}	Inductance between the two neutral points
L_{ss}	Self Stator Inductance

L_{rr} Self Rotor Inductance

L_{ls} Stator Leakage Inductance

L_{rs} Rotor Leakage Inductance

L_{sm} Stator Mutual Inductance

L_{rm} Rotor Mutual Inductance

L_{sr}^{abc} Stator Mutual Inductance

n_s Synchronous speed

n_m Mechanical speed

N_1 Windings in Primary of Transformer

N_2 Windings in Secondary of Transformer

P_{br} Block Rotor Input Power

r_1, R_1, R_s Stator Resistor

r_2, R_2, R_r Rotor Resistor

R_c Core losses

R_{sg} Resistance between the two neutral points

R_{br} Block Rotor Resistance

T_{mech} Mechanical Torque

T_{damp} Damping Torque

T_{em} Electromagnetic Torque

T_{qd0} Associated Torque

V Voltage

V_{ph} Phase Voltage

V_{as} Voltage Stator Phase-a

V_{bs} Voltage Stator Phase-b

V_{cs} Voltage Stator Phase-c

V_{ar} Voltage Rotor Phase-a

V_{br} Voltage Rotor Phase-b

V_{cr} Voltage Rotor Phase-c

$V_{n.l}$ No-Load Voltage

V_{rated} Rated Voltage

V_{abc} Ordinary Voltage

V_{dq0} Variables Voltage in Stationary Reference Frame

V_{DC} DC Voltage

V_{sg} Phase Voltages into Neutral Connection

V_{ag}, V_{bg}, V_{cg} Input Voltages for the given Neutral Connections

V_{qs}^{s} Stator Voltage Variables on q-axis in Stationary Reference Frame

V_{ds}^{s} Stator Voltage Variables on d-axis in Stationary Reference Frame

V_{0s} Stator Voltage Variables on Zero-axis in Stationary Reference Frame

$V_{qr}^{\prime r}$ Rotor Voltage Variables on q-axis in Stationary Reference Frame

$V_{dr}^{\prime r}$ Rotor Voltage Variables on d-axis in Stationary Reference Frame

V'_{0r} Rotor Voltage Variables on Zero-axis in Stationary Reference Frame

V'_{rn} Voltage between Point's r and n, and the primes indicate voltages referred to the Stator Side

V_{br} Block Rotor Voltage

$X_{br,test}$ Block Rotor Reactance at Test Frequency

X_1, X_{ls} Stator Leakage Reactance

X_2	Rotor Leakage Reactance
X_m	Magnetizing Reactance
X_{br}	Block Rotor Reactance
$Z_{n.l}$	No-Load Impedance
Z_{br}	Block Rotor Impedance

Simulasi Prestasi Motor Aruhan Tiga Fasa pada Kerangka Rujukan Pegun

ABSTRAK

Tesis ini menerangkan tentang model paksi qd0 untuk menganalisa prestasi fana motor aruhan tiga fasa dengan spesifikasi seperti berikut 0.5Hp, 420V, 50Hz dan 4 kutub dengan menggunakan kerangka rujukan pegun. Dalam bidang kejuruteraan elektrik, transformasi qd0 ini digunakan untuk memudahkan analisis litar tiga fasa dan kegunaannya adalah untuk mengurangkan tiga kuantiti AC kepada dua kuantiti DC. Kajian ini bermula dengan penemuan parameter mesin yang digunakan. Terdapat tiga kaedah utama yang digunakan iaitu ujian pengukuran DC pemegun untuk mencari nilai rintangan pemegun, r_1, ujian tanpa beban untuk mencari nilai regangan kemagnetan, $X_m$dan ujian pemutar disekat untuk nilai-nilai rintangan pemutar, r_2, pemegun regangan bocor dan pemutar regangan bocor, X_1dan X_2. Semua data yang dikumpul dan direkodkan dalam jadual. Kaedah-kaedah ini telah dilakukan di dalam bilik makmal. Pakej Matlab Simulink digunakan untuk analisis tingkah laku fana motor aruhan tiga fasa dan jangka masa yang mencukupi termasuk untuk mengkaji ciri-ciri motor ini. Keputusan analisis menunjukkan magnitud fasa voltan (V_{ph}) kepada neutral, arus fasa pemegun, kelajuan dan kilas enjin. Magnitud voltan fasa pemegun (V_{ph}) ke titik neutral motor aruhan tiga fasa adalah 342.9V. Analisis voltan fasa juga menunjukkan bahawa voltan fasa-b kepada neutral adalah voltan ekoran kepada voltan fasa-a kepada neutral dan fasa-c kepada neutral mendulu kepada Voltan fasa-a kepada neutral. Setiap ekoran dan mendulu adalah $\frac{2}{3}\pi$ atau 120^0. Untuk arus fasa pemegun adalah dibincangkan tentang fasa-a, fasa-b dan fasa-c dari segi magnitud yg semakin menurun dari arus rempuh masuk yang tinggi pada motor sehingga mencapai keadaan mantap. Bagi arus-arus fasa tersebut, nilai magnitud adalah 1.89A dan masa yang diambil adalah 0.8 saat apabila mencapai keadaan keadaan mantap. Bagi kelajuan pemutar, ia bermula dari 0pu dan masa juga 0 saat dan meningkat secara seiring terhadap masa sehingga mencapai nilai keadaan mantap. Kelajuan mencapai nilai keadaan stabil pada 1.16pu dan masa yang yang diambil 0.8956 saat. Magnitud tertinggi yang dicatatkan bagi kilas permulaan adalah 22.92Nm dan nilai ini sentiasa berubah sehingga mencapai nilai keadaan mantap. Nilai keadaan mantap untuk kilas motor ini adalah 2.37Nm dan masa yang 0.9653 saat.

Simulation of Three Phase Induction Motor Performance on Stationary Reference Frame

ABSTRACT

This thesis presents the qd0 axis based modeling is proposed to analyze the transient performance of three phase induction motor with the specifications as 0.5Hp, 420V, 50Hz and 4 poles using stationary reference frame. In electrical engineering field, this qd0 transformation is used to simplify the analysis of three phase circuit and its application is to reduce the three AC quantities to two DC quantities. This research started with the findings of the parameters of the machines used. There are three main methods are used which are stator DC measurement test to find the value of stator resistance, r_1, no-load test to find the value of the magnetizing reactance, X_m and blocked rotor test for the values of rotor resistance, r_2, stator and rotor leakage reactance, X_1 and X_2. All data collected and recorded in a table. These methods have been done in the laboratory room. Matlab Simulink package is used to analysis the transient behavior of the three phase induction motor and the sufficient time span is included to study the complete motor's characteristics. The analysis results show the magnitude of phase voltage (V_{ph}) to neutral, phase currents of stator, speed and torque of the machine. The magnitude of V_{ph} to neutral point of the three phase induction motor is 342.9V. The analysis of the phase voltage also show that phase-b voltage to neutral is lagging phase-a voltage to neutral and the phase-c voltage to neutral is leading the phase-c voltage to neutral. Each lagging and leading is $\frac{2}{3}\pi$ or 120^0. For phase stator currents are discussed about the phase-a, phase-b and phase-c in terms of the magnitudes reduce from the high inrush current during the starting up motor until reaching the steady state condition. The magnitude values of the phases current are 1.89A and the time taken is 0.8 seconds when reached the steady state condition. As for the speed of the rotor, it is starting from 0pu and time also 0 and increase linearly to the time until reach the steady state value. The speed reach the steady state value at 1.16 pu and the time is 0.8956 seconds. The highest magnitude recorded for the starting torque is 22.92Nm and this value keeps changing until it reaches the steady state value. The steady state value for this torque is 2.37Nm and the time is 0.9653 seconds.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Nowadays, Induction Machine (IM) still has its own popularity and relevant to be used in industrial applications not only because of less in costing but also due to its simple of construction, robust and easy to maintain. This IM are made and used in largest numbers because of it can operates in various modes either under steady or dynamic states (Batol & Ahmad, 2013).

A three phase IM can be modeled with quadrature-direct-zero (qd0) axis theory. Basically, an analysis of the three phase circuit can be simplify by using the qd0 axis transformation which is used the mathematical transformation. In the case of balanced three phase circuits, this application of qd0 axis transformation function to reduce the three AC variables to two DC variables. This model will control the motor parameters such as voltages, currents, flux linkage and motor torque (Shah et al., 2012).

The transient behavior studies of the IM by using the mathematical modeling in stationary reference frame are easier because of its superiority in eliminating certain parts from the voltage equations. In order to eliminate the time-varying inductances, the equations are firstly needed to be transformed into qd0 variables in the arbitrary reference frame (Noor et al., 2013). Furthermore, Jain et al. (2014) had found that the equations of the machine in the stationary reference frame can simply be obtained by taking the speed of the arbitrary reference frame, ω, is zero. Variables in the stationary will be identified by an additional superscript of 's'.

This research will use the Simulink software of Mathematical Laboratory (MATLAB) to simulate the modeling of the IM on the stationary reference frame. The modeling is based on the qd0 theory of revolving frame transformation. The main advantage of the MATLAB/Simulink package compared to other simulations programming is this simulation model is built up systematically by basic function blocks. This is a sophisticated way due to the compilation of program code for the machines. As to perform the differential equations of the machine, basically a set of the equations will be applied by interconnection to the suitable function blocks which are performing specific mathematical operation.

1.2 Problem Statement

Basically, start up of IM always produced large currents, voltage dips and oscillatory torque. Therefore, to overcome these issues, it is very important to model an IM on preferred reference frame such as stationary reference frame, rotor reference frame and synchronous reference frame in order to analyze the situation. Mathematical modeling of the three phase IM on stationary reference frame will be apply in this project in order to obtain the behavior of the machine. According to the advance in development of software, MATLAB Simullink is the most practically suitable and easy to use in order to predict the behavior of an IM.

This project will make an observation and analysis of the simulated results in term of the phase voltages stator, phase currents stator, speed of the rotor and torque base on the proposed model.

1.3 Objective

The main objectives of this research project are:

a) To model a mathematical modeling of three phase induction motor on stationary reference frame.
b) To obtain the parameters of the three phase induction motor based on the stator DC resistance measurement, no-load test and blocked rotor test.
c) To analyze the transients behavior of the three phase induction motor base on the mathematical modeling on stationary reference frame using Matlab Simulink.

1.4 Research Scopes

This research will be limited to the following scopes:

- Implement three phase induction motor modeling using qd0 transformation to simplify the analysis of the three phase circuit.
- Develop a modeling of three phase induction motor on stationary reference frame using Matlab/Simulink software.

1.5 Thesis Organization

This thesis has been organized systematically by five separates chapter which is briefly explained, discussed and concluded the overall process of completing the research. All chapters will begin with an overview or introduction as to describe the points included in each chapter.

Chapter one is described about the research background which is contained the introduction of three phase induction motor as worldwide used in applications and the tools that had been used to simulate the performance of the machine on stationary reference frame based on mathematical modeling. It also included the problem statement, objectives and scopes of the research.

The overviews for the chapter two is described the literature reviews according to the previous researchers. It discusses more on the review papers base on the methods used, findings and results of their researches. This chapter also provided some theories about this project such as constructions, operation principles and the equivalent circuit of IM, mathematical modeling of IM on stationary reference frame and the type of references frame including the reference frames transformation that will be applied to this project.

Chapter three is covered about the methodology process of this research. This chapter also briefly explained about the conducted test system in laboratory and measurement process in order to determine the parameters of the machine used in this research. Thus, the steps of develop and simulation process of the circuits by using Matlab/Simulink.

Chapter four will elaborates and discuss about the results getting from the research. The simulation results of the three phase machine performance on preferred reference frame will be shown by graphical of voltages, currents, speed and torque by using the Matlab Simulink software. Then, these results are analyzed and evaluated.

Finally, chapter five provides the conclusion about the overall process, results and findings obtained from this research. This chapter also discussed the future work for this research field.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This research has reviewed various journals and papers that have been done by previous researchers in order to investigate the performances of an IM on stationary reference frame. An IM has the similarity to transformer in action to produce voltages and currents in its field circuit. In fact, an IM is basically known as a rotating transformer. The equivalent circuit of IM is considered similar to that of transformer except for the effects of varying speed. IM reacts as an alternating current motor which has working principle is based on the electromagnetic induction.

Basically, there are so many numbers and rich with the complexity of equations involved in various electrical systems. Therefore, the reference frame transformations are very useful medium in order to reduce them so that the analysis for the three phase IM can be done easily. So that, the reference frame is considered as an important path in order to investigate and analyze the performances of the three phase IM.

Stationary reference frame act since the quadrature-direct-zero (qd0) axis remains static which means no rotate. This frame is usually been used for the condition of the voltages in the stator are unbalanced while the voltage in rotor are in balanced condition. Thus, the stator of q-axis and the stator phase-a axis coincides with each other and produced the speed of magnetomotive force (mmf) wave in this frame. Thus, the voltage supplied to the stator q-axis is equal as the voltage in the phase-a and this will cause the current of the stator q-axis also similar to the stator phase-a current.

2.2 Literature Review of Previous Researches

There are many researches that have been done to investigate the performance of IM using various reference frames such as stationary reference frame, rotor reference frame and synchronous reference frame. According to Lee et al. (1984), in their case studies had investigate the used of various reference frames such as stationary reference frame, rotor reference frame and synchronous rotating reference frame in order to investigate the performance of IM. From the comparison that had been made by them, synchronous rotating reference frame is more useful compared to others. This reference frame is used to stabilize the controller design where the motor equations must be linearized about the operating point since the steady state variables are constant and do not vary sinusoidal with time in this reference frame (Lee et al., 1984).

Another research to investigate the performance of IM was conducted by Kutkut et al. (1995). According to the research, they used back to back thyristors for each phase of the machine for speed control of the IM. The main objective of this paper is wanted to obtain the steady state condition with the new approach which was voltage control and it was applied on rotating reference frame. Steady state of the system becomes more difficult to be analyzed due to the voltage adjustment is obtained by sequentially open circuiting of the stator phase. To overcome this issue, it was predicted with a new analytical approach.

As a result, there were only 3 out of 7 circuit modes need to be determined. The steady state solution is simply a linear combination of these modes (Kutkut et al., 1995).

A new mathematic modeling for a dual three phase IM has been proposed by Lai et al. (2008). The mathematical model is applied to the dual three phase IM on stationary reference frame and the results was determined by comparing the tested and simulated result. The simulation was done by using the MATLAB simulink as well. The novel mathematical model is considered acceptable when the percentage errors between the tested and simulation is ± 2% (Lai et al., 2008). It was proved by the data in Table 2.1. Because of the percentage errors between them is lower than 2%, it could be neglected.

Table 2.1: Simulation of Percentage Error (Lai et al., 2008).

T_2(Nm)	N(rpm)	e1(%)	I_{A1}	e2(%)
1.82	1482.4	-0.263	1.447	1.106
3.62	1465.3	-0.580	1.694	-0.177
5.48	1446.0	-0.947	2.077	-0.385
7.32	1424.1	-1.341	2.552	-0.823

Table 2.1 shows that the column 1 is represented the torque of the machine in Newton Meter, column 2 shows the motor speed in rpm, column 3 is represented the percentage errors between the tested speed and simulations, column 4 is noted the phase-A