THE ANALYSIS OF 3 PHASE SQUIRREL-CAGE INDUCTION MACHINE USING SIMULINK

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”I hereby declared that this report is a result of my own work except for the exerpts that have been cited clearly in the references.”

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Date : 23 MAY 2008

"I hereby declared that I have read through this report and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)"

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Date : 060508

TO MY FAMILY AND FRIENDS...

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Last but not least, I take this opportunity to dedicate this thesis for all electrical engineering students. All suggestions for further improvement of this thesis are welcome and will be gratefully acknowledged.

ABSTRACT

This project is about the Simulink implementation of a three-phase induction machine model. The implementation is done in a step-by-step approach. All of the machine parameters will be accessible for control and verification purposes. After the implementation, the model will be used in simulation to produce curves of torque-speed characteristic and dynamic current (stator and rotor). There is three different conditions to be simulated, that is stationary reference frame, rotor reference frame and synchronous reference frame. Finally, the simulation result will be used for the analysis of torque-speed characteristic and the dynamic behavior of a three-phase induction machine.

ABSTRAK

Projek ini adalah berkenaan dengan perwakilan sesebuah model motor induksi tiga fasa ke dalam blok Simulink. Penggantian ini akan dilaksanakan secara berperingkat. Semua parameter pada mesin tersebut boleh diakses untuk kawalan dan untuk kegunaan verifikasi. Selepas proses penggantian dilaksanakan, simulasi akan diadakan untuk menghasilkan graf yang berkaitan ciri dan prestasi sesebuah motor ininduksi tiga fasa seperti, tork dan kelajuan serta arus pada stator dan rotor. Terdapat tiga keadaan motor yang akan di simulasikan iaitu, rujukan stator, rujukan rotor dan rujukan serentak. Akhir sekali, keputusan daripada simulasi akan digunakan untuk analisis kriteria tork dan kelajuan serta dinamik sesebuah motor induksi tiga-fasa.

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Introduction

1.1 Project Background

The parameters of equivalent circuit of Induction Machines are crucial when considering advanced control techniques. Accidentally there are also uncertain parameters when the machine is released from production. Parameter determination of an equivalent circuit for a squirrel cage induction motor is a complex problem, because no reliable theory exists and no methods of direct measurements in a rotor circuit are available. The skin effect in the rotor winding and the iron core saturation effect lead to complications in the modeling process of a squirrel cage motor. Therefore indirect measurement methods and calculations must be used for the parameter determination from the data given by reference or by experimentally measured torque-speed characteristics.

1.2 Project Objectives

There are two main objectives of this project which are :

i) To build a model of induction machine in Simulink blocks diagram.

- The induction machine *qdo* axis mathematical model derived by Sergey E. Lyschevski will be the background equations of the project. The equations for stationary, rotor and synchronous reference frame will be used to build the simulink model.

ii) To get the torque-speed characteristic of a machine from the simulink model.

- The characteristic of an induction machine will be studied from the curves obtains from the Simulink squirrel-cage induction machine model simulation. The simulation will be carried out in stationary, rotor and synchronous reference frame and the effect of load torque applied to the induction machine also will be studied.

1.3 Problem Statement

Usually, when an electrical machine is simulated in circuit simulators like PSpice, its steady state model is used, but for electrical drive studies, the transient behavior is also important. One advantage of Simulink over circuit simulators is the ease in modeling the transients of electrical machines and drives and to include drive controls in the simulation.

As long as the equations are known, any drive or control algorithm can be modeled in Simulink. However, the equations by themselves are not always enough; some experience with differential equation solving is required.

It is important to study the transient behavior because for the high-performance electric machine it needed the detailed transient dynamic analysis and performance.

1.4 Scope of Project

There are many kinds of methods that can be used to develop this system but for this project, the scopes can be described as follow:

i) Implementation of *qd0* motor model equations into Simulink blocks. (mathematical model derived by Sergey E. Lyshevski)

ii) The torque-speed characteristic and, stator and rotor current can be studied from the model.

Chapter 2

Literature Review

2.1 Motor Conventional Modeling

The parameters of the induction motor model vary as operating conditions change. Accurate knowledge of these parameters and their dependency on operating conditions is critical for optimal field oriented control.

The testing method that will be used for modeling is off site method that is to test the motor separately from its application site (laboratory experiment). The motor will be tested individually, and the tests that will be conducted are no-load test and blocked-rotor test to extract the parameters needed for the characteristic study.

2.1.2 Locked-Rotor Test

The locked-rotor test, like short circuit test on a transformer, provides the information about leakage impedances and rotor resistance, R_r. Rotor is at the stand still, while low voltage is applied to stator windings to circulate rated current. Measure the voltage and power to the phase. Since there is no rotation slip, s=0 the equivalent circuit will be as following. R_r will be ignored as it value is much less than core losses R_c.

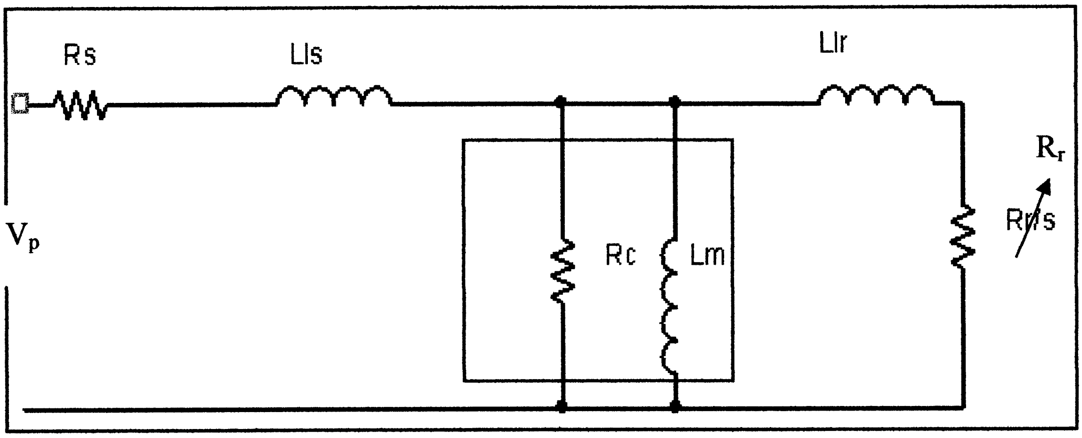

Figure 2.2 : Equivalent Circuit for Locked Rotor Test

2.1.1 No-Load Test

The no-load test is like the open circuit test of the transformer and it gives information about exciting current and rotational loses. The test is performed by applying balanced rated voltage on the stator windings at the rated frequency. The small power provided to the machine is due to core loses, friction and winding loses. Machine will rotate at almost synchronous speed which makes slip nearly to zero.

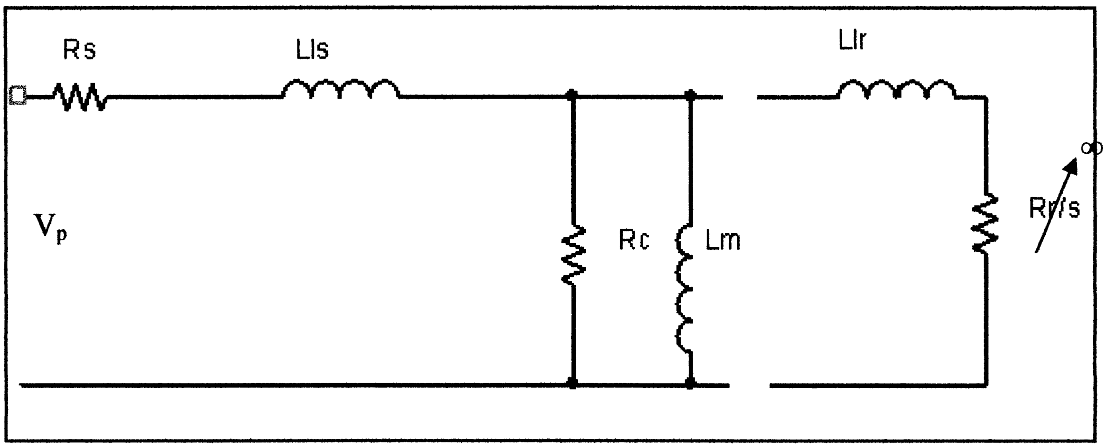

Figure 2.1 : Equivalent Circuit For No-Load Test

2.2 Motor Dynamic Modeling

Steady state models of induction machines are useful for studying the performance of the machine in steady state. This means that all electrical transients are neglected during load changes and stator frequency variations. Such variations arise in applications involving variable speed drives.

The variable speed drives are converter fed from finite sources, unlike the utility sources, due to the limitation of the switch ratings and filter sizes. This results in their incapability to supply large transient power. Consequently, there is a need to evaluate the dynamics of converter-fed variable-speed drives to assess the adequacy of the converter switches and the converter for a given motor and their interaction to determine the excursions of current and torque in the converter and motor.

To find a set of differential equation to map the dynamics of an induction machine and in order to perform a throughout analysis of the transient behavior and steady-state performance, the equations of motion is used by referring to the figure of three-phase symmetrical induction motor (figure2.3).

Equations of motion in the machine variables.

The stator and rotor current; $i_{abcs} = \begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \end{bmatrix}, i_{abcr} = \begin{bmatrix} i_{ar} \\ i_{br} \\ i_{cr} \end{bmatrix}$;

The flux linkages; $\psi_{abcs} = \begin{bmatrix} \psi_{as} \\ \psi_{bs} \\ \psi_{cs} \end{bmatrix}, i_{abcr} = \begin{bmatrix} \psi_{ar} \\ \psi_{br} \\ \psi_{cr} \end{bmatrix}$;

Electric angular velocity ω_r and displacement θ_r ;

The applied voltages $u_{abcs} = \begin{bmatrix} u_{as} \\ u_{bs} \\ u_{cs} \end{bmatrix}$, $u_{abcr} = \begin{bmatrix} u_{ar} \\ u_{br} \\ u_{cr} \end{bmatrix}$.

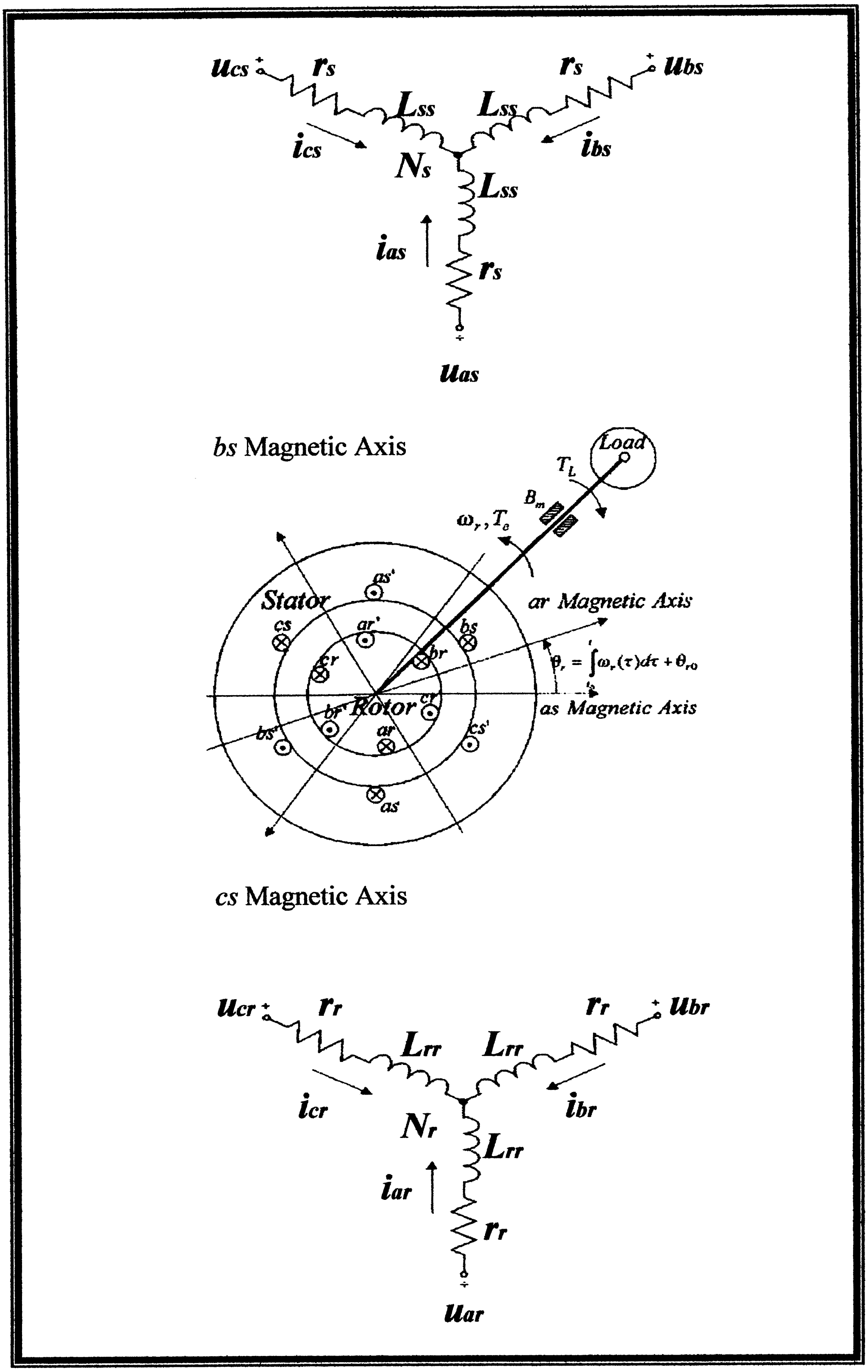

Figure 2.3 : Three-Phase Symmetrical Induction Motor

The circuitry model by using Kirchoff's voltage law;

$$u_{abcs} = r_s i_{abcs} + \frac{d\psi_{abcs}}{dt}, \qquad u_{abcr} = r_r i_{abcr} + \frac{d\psi_{abcr}}{dt},$$

$$\begin{bmatrix} \psi_{abcs} \\ \psi_{abcr} \end{bmatrix} = \begin{bmatrix} L_s & L_{sr} \\ L_{sr}^T & L_r \end{bmatrix} \begin{bmatrix} i_{abcs} \\ i_{abcr} \end{bmatrix},$$

Where $r_s = \begin{bmatrix} r_s & 0 & 0 \\ 0 & r_s & 0 \\ 0 & 0 & r_s \end{bmatrix}, \quad r_r = \begin{bmatrix} r_r & 0 & 0 \\ 0 & r_r & 0 \\ 0 & 0 & r_r \end{bmatrix},$

$$L_s = \begin{bmatrix} L_{ls} + L_{ms} & -\frac{1}{2}L_{ms} & -\frac{1}{2}L_{ms} \\ -\frac{1}{2}L_{ms} & L_{ls} + L_{ms} & -\frac{1}{2}L_{ms} \\ -\frac{1}{2}L_{ms} & -\frac{1}{2}L_{ms} & L_{ls} + L_{ms} \end{bmatrix},$$

$$L_r = \begin{bmatrix} L_{lr} + L_{mr} & -\frac{1}{2}L_{ms} & -\frac{1}{2}L_{ms} \\ -\frac{1}{2}L_{ms} & L_{lr} + L_{mr} & -\frac{1}{2}L_{ms} \\ -\frac{1}{2}L_{ms} & -\frac{1}{2}L_{ms} & L_{lr} + L_{mr} \end{bmatrix},$$

$$L_{sr} = L_{sr} \begin{bmatrix} \cos\theta_r & \cos\left(\theta_r + \frac{2}{3}\pi\right) & \cos\left(\theta_r - \frac{2}{3}\pi\right) \\ \cos\left(\theta_r - \frac{2}{3}\pi\right) & \cos\theta_r & \cos\left(\theta_r + \frac{2}{3}\pi\right) \\ \cos\left(\theta_r + \frac{2}{3}\pi\right) & \cos\left(\theta_r - \frac{2}{3}\pi\right) & \cos\theta_r \end{bmatrix}$$

Where;

r_s and r_r - stator and rotor resistance

$L_{ls}, L_{lr}, L_{ms}, L_{mr}$ - stator and rotor leakage and magnetizing inductance

The differential equations in the state-space form of the circuitry model;

$$\frac{di_{as}}{dt} = \frac{1}{L'_{lr}(3L_{ms}+L'_{lr})}\Big[\big(-r_sL_{ms}(2i_{as}+i_{bs}+i_{cs})\big)+\Big(r_rL_{ms}\Big(i_{ar}\cos\theta_r+i_{br}\cos\Big(\theta_r+\frac{2}{3}\pi\Big)+ i_{cr}\cos\Big(\theta_r-\frac{2}{3}\pi\Big)\Big)\Big)+\Big(1.3L_{ms}^2\omega_r(i_{bs}-i_{cs})+\Big(\frac{3}{2}L_{ms}^2+L_{ms}L'_{lr}\Big)\Big(i_{ar}\sin\theta_r+ i_{br}\sin\Big(\theta_r+\frac{2}{3}\pi\Big)+i_{cr}\sin\Big(\theta_r-\frac{2}{3}\pi\Big)\Big)\Big)+\Big(u_{as}(2L_{ms}+L'_{lr})+\frac{1}{2}L_{ms}u_{bs}+\frac{1}{2}L_{ms}u_{cs}- (u_{ar})L_{ms}\cos\theta_r-(u_{br})L_{ms}\cos\Big(\theta_r+\frac{2}{3}\pi\Big)-(u_{cr})L_{ms}\cos\Big(\theta_r-\frac{2}{3}\pi\Big)\Big)\Big]$$

$$\frac{di_{bs}}{dt} = \frac{1}{L'_{lr}(3L_{ms}+L'_{lr})}\Big[\big(-r_sL_{ms}(i_{as}+2i_{bs}+i_{cs})\big)+\Big(r_rL_{ms}\Big(i_{ar}\cos\Big(\theta_r-\frac{2}{3}\pi\Big)+i_{br}\cos\theta_r+ i_{cr}\cos\Big(\theta_r+\frac{2}{3}\pi\Big)\Big)\Big)+\Big(1.3L_{ms}^2\omega_r(-i_{as}+i_{cs})+\Big(\frac{3}{2}L_{ms}^2+L_{ms}L'_{lr}\Big)\Big(i_{ar}\sin\Big(\theta_r-\frac{2}{3}\pi\Big)+ i_{br}\sin\theta_r+i_{cr}\sin\Big(\theta_r+\frac{2}{3}\pi\Big)\Big)\Big)+\Big(u_{as}\frac{1}{2}L_{ms}+(2L_{ms}+L'_{lr})u_{bs}+\frac{1}{2}L_{ms}u_{cs}- (u_{ar})L_{ms}\cos\Big(\theta_r-\frac{2}{3}\pi\Big)-(u_{br})L_{ms}\cos\theta_r-(u_{cr})L_{ms}\cos\Big(\theta_r+\frac{2}{3}\pi\Big)\Big)\Big]$$

$$\frac{di_{cs}}{dt} = \frac{1}{L'_{lr}(3L_{ms}+L'_{lr})}\Big[\big(-r_sL_{ms}(i_{as}+i_{bs}+2i_{cs})\big)+\Big(r_rL_{ms}\Big(i_{ar}\cos\Big(\theta_r+\frac{2}{3}\pi\Big)+i_{br}\cos\Big(\theta_r- \frac{2}{3}\pi\Big)+i_{cr}\cos\theta_r\Big)\Big)+\Big(1.3L_{ms}^2\omega_r(-i_{as}+i_{cs})+\Big(\frac{3}{2}L_{ms}^2+L_{ms}L'_{lr}\Big)\Big(i_{ar}\sin\Big(\theta_r-\frac{2}{3}\pi\Big)+ i_{br}\sin\theta_r+i_{cr}\sin\Big(\theta_r+\frac{2}{3}\pi\Big)\Big)\Big)+\Big(u_{as}\frac{1}{2}L_{ms}+(2L_{ms}+L'_{lr})u_{bs}+\frac{1}{2}L_{ms}u_{cs}- (u_{ar})L_{ms}\cos\Big(\theta_r+\frac{2}{3}\pi\Big)-(u_{br})L_{ms}\cos\Big(\theta_r-\frac{2}{3}\pi\Big)-(u_{cr})L_{ms}\cos\theta_r\Big)\Big]$$

$$\frac{di_{ar}}{dt} = \frac{1}{L'_{lr}(3L_{ms}+L'_{lr})}\Big[\big(r_sL_{ms}(2i_{ar}+i_{br}+i_{cr})\big)+\Big(r_rL_{ms}\Big(i_{as}\cos\theta_r+i_{bs}\cos\Big(\theta_r+\frac{2}{3}\pi\Big)+ i_{cs}\cos\Big(\theta_r-\frac{2}{3}\pi\Big)\Big)\Big)+\Big(1.3L_{ms}^2\omega_r(i_{br}-i_{cr})+\Big(\frac{3}{2}L_{ms}^2+L_{ms}L'_{lr}\Big)\Big(i_{as}\sin\theta_r+ i_{bs}\sin\Big(\theta_r+\frac{2}{3}\pi\Big)+i_{cs}\sin\Big(\theta_r-\frac{2}{3}\pi\Big)\Big)\Big)+\Big(u_{ar}(2L_{ms}+L'_{lr})+\frac{1}{2}L_{ms}u_{br}+\frac{1}{2}L_{ms}u_{cr}- (u_{as})L_{ms}\cos\theta_r-(u_{bs})L_{ms}\cos\Big(\theta_r-\frac{2}{3}\pi\Big)-(u_{cs})L_{ms}\cos\Big(\theta_r+\frac{2}{3}\pi\Big)\Big)\Big]$$

$$\frac{di_{br}}{dt} = \frac{1}{L'_{lr}(3L_{ms}+L'_{lr})}\Big[\big(-r_sL_{ms}(i_{ar}+2i_{br}+i_{cr})\big)+\Big(r_rL_{ms}\Big(i_{as}\cos\Big(\theta_r+\frac{2}{3}\pi\Big)+i_{bs}\,cos\theta_r+ i_{cs}\cos\Big(\theta_r-\frac{2}{3}\pi\Big)\Big)\Big)+\Big(1.3L_{ms}^2\omega_r(-i_{ar}+i_{cr})+\Big(\frac{3}{2}L_{ms}^2+L_{ms}L'_{lr}\Big)\Big(i_{ar}\sin\Big(\theta_r-\frac{2}{3}\pi\Big)+ i_{bs}\sin\theta_r+i_{cs}\sin\Big(\theta_r+\frac{2}{3}\pi\Big)\Big)\Big)+\Big(u_{ar}\frac{1}{2}L_{ms}+(2L_{ms}+L'_{lr})u_{br}+\frac{1}{2}L_{ms}u_{cr}- (u_{as})L_{ms}\cos\Big(\theta_r+\frac{2}{3}\pi\Big)-(u_{bs})L_{ms}\cos\theta_r-(u_{cr})L_{ms}\cos\Big(\theta_r-\frac{2}{3}\pi\Big)\Big)\Big]$$

$$\frac{di_{cr}}{dt} = \frac{1}{L'_{lr}(3L_{ms}+L'_{lr})}\Big[\big(-r_sL_{ms}(i_{ar}+i_{br}+2i_{cr})\big)+\Big(r_rL_{ms}\Big(i_{as}\cos\Big(\theta_r-\frac{2}{3}\pi\Big)+i_{bs}\,cos\Big(\theta_r+ \frac{2}{3}\pi\Big)+i_{cs}\cos\theta_r\Big)\Big)+\Big(1.3L_{ms}^2\omega_r(i_{ar}-i_{br})+\Big(\frac{3}{2}L_{ms}^2+L_{ms}L'_{lr}\Big)\Big(i_{as}\sin\Big(\theta_r+\frac{2}{3}\pi\Big)+ i_{bs}\sin\Big(\theta_r-\frac{2}{3}\pi\Big)+i_{cs}\sin\theta_r\Big)\Big)+\Big(u_{ar}\frac{1}{2}L_{ms}+(2L_{ms}+L'_{lr})u_{br}+\frac{1}{2}L_{ms}u_{csr}- (u_{as})L_{ms}\cos\Big(\theta_r-\frac{2}{3}\pi\Big)-(u_{bs})L_{ms}\cos\Big(\theta_r+\frac{2}{3}\pi\Big)-(u_{cs})L_{ms}\cos\theta_r\Big)\Big]$$

The torsional-mechanical dynamics of the model by Newton's second law

$$\frac{d\omega_r}{dt} = -\frac{P^2L_{ms}}{4J}\Big[\Big(i_{as}\Big(i_{ar}-\frac{1}{2}i_{br}-\frac{1}{2}i_{cr}\Big)-i_{bs}\Big(\frac{1}{2}i_{ar}-i_{br}+\frac{1}{2}i_{cr}\Big)-i_{cs}\Big(\frac{1}{2}i_{ar}+\frac{1}{2}i_{br}- i_{cr}\Big)\Big)sin\theta_r+\frac{\sqrt{3}}{2}\big(i_{as}(i_{br}-i_{cr})-i_{bs}(i_{ar}-i_{cr})+i_{cs}(i_{ar}-i_{br})\big)cos\theta_r\Big]-\frac{B_m}{J}\omega_r-\frac{P}{2J}T_L$$

[Mathematical Model derived by Sergey E. Lyschevski]

2.3 Commonly Used Induction-Motor Models

Three commonly used reference frames models that are specific cases of the generalised reference frame model are:

- Stationary reference frames model;
- Rotor reference frames model;
- Synchronously rotating reference frames model.

For the stationary reference frames model, the speed of the reference frame is that of the stator which is zero, i.e., $\omega=0$; for the rotor reference frames model, $\omega=$ rotor speed, ω_r; and for the synchronously rotating reference frames model, $\omega=$ synchronous speed, ω_e.