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Review of Modeling and Dynamic Analysis of Three Phase Induction Motor Using MATLAB Simulink

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***Abstract*—The theory of reference frames has been effectively used as an efficient approach to analyses the performance of the induction electrical machines. This paper presents a step by step simulink implementation of an induction machine using stator and rotor equation in the stator reference frame equations. For this purpose, the relevant equations are started at the beginning, and then a generalized model of a three-phase induction motor is developed and implemented in an easy to follow way. The main objective of this paper is to simulate the induction motor model in MATLAB/ Simulink and study the effect of speed, torque, stator and rotor currents on three phase induction motor performance characteristics.**

***Index Terms*— Induction motor, modeling and simulation, stationary reference frame.**

NOMENCLATURES

V_{as}, V_{bs}, V_{cs}	Stator Voltages for phase a, b and c respectively.
V_{ar}, V_{br}, V_{cr}	Rotor Voltages for phase a, b and c respectively.
L_{ms}	Stator magnetising inductance.
L_{ls}	Stator leakage inductance.
L_{lr}	Rotor leakage inductance.
Ψ_{ias}, Ψ_{ibs}, Ψ_{ics}	Stator flux linkage.
Ψ_{iar}, Ψ_{ibr}, Ψ_{icr}	Rotor flux linkage.
T_{em}, T_l	Electromagnetic and Load Torque.
i_{as}, i_{bs}, i_{cs}	Stator current for phase a, b and c respectively.
i_{ar}, i_{br}, i_{cr}	Rotor current for phase a, b and c respectively.
N_r, N_s	Rotational and Synchronous speed.
ω_r	Rotor electrical angular velocity.
r_s	Stator resistance.
r_r	Rotor resistance.
B	Frictional co-efficient.
P	Number of Poles.
J	Moment of Inertia.

I. INTRODUCTION

The voltage and torque equations that describe the dynamic behavior of an induction motor are time-varying. It is successfully used to solve such simple equations such as stator equations in terms of rotor equations and rotor equation in terms of stator equations in order to overcome the complexity of differential equations in the arbitrary reference equation.

The simulink based dynamic induction motor models are available in many books [1] – [5] and research paper [6] – [8] but they describe the models as black-box with no internal connection detail. Some of them recommend s-functions for accessing the model variable but they are not use the full power of simulink. However, the s-function run faster than discrete simulink blocks, but simulink models can be made faster using accelerator function [13] or state space model [14].

The dynamic model of induction motor, which is frequently used in motor dynamic studies like motor control, drive specifications, motor protection, starting high inertia loads, fast and large load changing, successive starting, locked rotor, etc is expressed by the six different equations of three- phase instantaneous torque, speed, voltage and current equations.

The provided machine model is simulated in a way that makes it easy for the reader to follow and understand the implementation process since it gives full details about simulink structure of each of the model equations.

The main goal of this paper is to simulate the mathematical model of three phase induction motor in MATLAB/Simulink and study the effect of stator and rotor currents, speed and torque on motor performance characteristics.

II. INDUCTION MOTOR MODEL

The stator equations are framed in terms of rotor equation and the rotor equations are framed in terms of stator equations. The torque and speed are framed in terms of both stator and rotor equations. Here the rotor voltages (V_{ar}, V_{br}, V_{cr}) are stationary (i.e., zero) and so it terms as stator reference frsme.

The stator currents i_{as}, i_{bs}, i_{cs} is given by,

$$\Psi_{ias} = \frac{1}{(L_{ls}+L_{ms})} \{[V_{as} - (r_s * i_{as})] + [(\frac{Lms}{2}) * (\Psi_{ibs} + \Psi_{ics})] - [L_{ms} * (\frac{Nr}{Ns}) * \{[(\Psi_{iar} * \cos\theta_r) - (i_{ar} * \omega_r * \sin\theta_r)] + [(\Psi_{ibr} * \cos(\theta_r + \frac{2\pi}{3}) - (i_{br} * \omega_r * \sin(\theta_r + \frac{2\pi}{3})] +$$

$$[(\Psi_{ibr} * \cos(\theta_r - \frac{2\pi}{3}) - (i_{ar}*\omega_r*\sin(\theta_r - \frac{2\pi}{3})]\}]\}$$

$$i_{as} = \int \Psi_{ias} \quad (1)$$

$$\Psi_{ibs} = \frac{1}{(L_{ls}+L_{ms})} \{[V_{bs} - (r_s * i_{bs})] + [(\frac{Lms}{2}) * (\Psi_{ias} + \Psi_{ics})] - [L_{ms} * (\frac{Nr}{Ns}) * \{[(\Psi_{ibr} * \cos\theta_r) - (i_{br}*\omega_r*\sin\theta_r)] + [(\Psi_{icr} * \cos(\theta_r + \frac{2\pi}{3}) - (i_{cr}*\omega_r*\sin(\theta_r + \frac{2\pi}{3})] + [(\Psi_{iar} * \cos(\theta_r - \frac{2\pi}{3}) - (i_{ar}*\omega_r*\sin(\theta_r - \frac{2\pi}{3})]\}]\}$$

$$i_{bs} = \int \Psi_{ibs} \quad (2)$$

$$\Psi_{ics} = \frac{1}{(L_{ls}+L_{ms})} \{[V_{cs} - (r_s * i_{cs})] + [(\frac{Lms}{2}) * (\Psi_{ibs} + \Psi_{ics})] - [L_{ms} * (\frac{Nr}{Ns}) * \{[(\Psi_{icr} * \cos\theta_r) - (i_{cr}*\omega_r*\sin\theta_r)] + [(\Psi_{iar} * \cos(\theta_r + \frac{2\pi}{3}) - (i_{ar}*\omega_r*\sin(\theta_r + \frac{2\pi}{3})] + [(\Psi_{ibr} * \cos(\theta_r - \frac{2\pi}{3}) - (i_{br}*\omega_r*\sin(\theta_r - \frac{2\pi}{3})]\}]\}$$

$$i_{cs} = \int \Psi_{ics} \quad (3)$$

The rotor current i_{ar}, i_{br}, i_{cr} is given by,

$$\Psi_{iar} = \frac{1}{[(L_{lr}+(N_r/N_s)^2 * L_{ms})]} \{[V_{ar} - (r_r * i_{ar})] + [(N_r/N_s)^2 * (\frac{Lms}{2}) * (\Psi_{ibr} + \Psi_{icr})] - [L_{ms} * (\frac{Nr}{Ns}) * \{[(\Psi_{ias} * \cos\theta_r) - (i_{as}*\omega_r*\sin\theta_r)] + [(\Psi_{ics} * \cos(\theta_r + \frac{2\pi}{3}) - (i_{cs}*\omega_r*\sin(\theta_r + \frac{2\pi}{3})] + [(\Psi_{ibs} * \cos(\theta_r - \frac{2\pi}{3}) - (i_{bs}*\omega_r*\sin(\theta_r - \frac{2\pi}{3})]\}]\}$$

$$i_{ar} = \int \Psi_{iar} \quad (4)$$

$$\Psi_{ibr} = \frac{1}{[(L_{lr}+(N_r/N_s)^2 * L_{ms})]} \{[V_{br} - (r_r * i_{br})] + [(N_r/N_s)^2 * (\frac{Lms}{2}) * (\Psi_{iar} + \Psi_{icr})] - [L_{ms} * (\frac{Nr}{Ns}) * \{[(\Psi_{ibs} * \cos\theta_r) - (i_{bs}*\omega_r*\sin\theta_r)] + [(\Psi_{ias} * \cos(\theta_r + \frac{2\pi}{3}) - (i_{as}*\omega_r*\sin(\theta_r + \frac{2\pi}{3})] + [(\Psi_{ics} * \cos(\theta_r - \frac{2\pi}{3}) - (i_{cs}*\omega_r* \Psi_{ics} * \sin(\theta_r - \frac{2\pi}{3})]\}]\}$$

$$i_{br} = \int \Psi_{ibr} \quad (5)$$

$$\Psi_{icr} = \frac{1}{[(L_{lr}+(N_r/N_s)^2 * L_{ms})]} \{[V_{cr} - (r_r * i_{cr})] + [(N_r/N_s)^2 * (\frac{Lms}{2}) * (\Psi_{ibs} + \Psi_{ics})] - [L_{ms} * (\frac{Nr}{Ns}) * \{[(\Psi_{ics} * \cos\theta_r) - (i_{cs}*\omega_r*\sin\theta_r)] + [(\Psi_{ibs} * \cos(\theta_r + \frac{2\pi}{3}) - (i_{bs}*\omega_r*\sin(\theta_r + \frac{2\pi}{3})] + [(\Psi_{ias} * \cos(\theta_r - \frac{2\pi}{3}) - (i_{as}*\omega_r*\sin(\theta_r - \frac{2\pi}{3})]\}]\}$$

$$i_{cr} = \int \Psi_{icr} \quad (6)$$

The equations (1) – (3) are a stator current equation which denotes that the integral of stator flux linkages and the equations are framed in terms of rotor equations. The equations (4) – (6) are a rotor current equation which denotes that the integral of rotor flux linkages and the equations are framed in terms of stator equations.

The electromagnetic torque is given by,

$$T_{em} = L_{ms} *(-P/2) * \{[((i_{as}*(i_{ar}-(i_{br}/2)-(i_{cr}/2)) + (i_{bs}*(i_{br}-(i_{ar}/2)-(i_{cr}/2))) + (i_{cs}*(i_{cr}-(i_{ar}/2)-(i_{br}/2)))) *\sin\theta_r] + [((i_{as}*((i_{br}/2)-(i_{cr}/2))) + (i_{bs}*((i_{cr}/2)-(i_{ar}/2))) + (i_{cs}*((i_{ar}/2)-(i_{br}/2)))) * \cos\theta_r * (\sqrt{3}/2)] \quad (7)$$

The angular velocity is given by,

$$\omega_r = \int\{[(P/2*J) * (T_{em}-T_L)] - [(B/J) * \omega_r]\} \quad (8)$$

$$\theta_r = \int\omega_r \quad (9)$$

$$N_r = [(60/2\pi) * 0.5] \quad (10)$$

III. MATLAB/SIMULINK IMPLEMENTATION

In this section, the three phase induction machine model is simulated by using the MATLAB/Simulink. The model is implemented using the same set of equations provided above in equation II.

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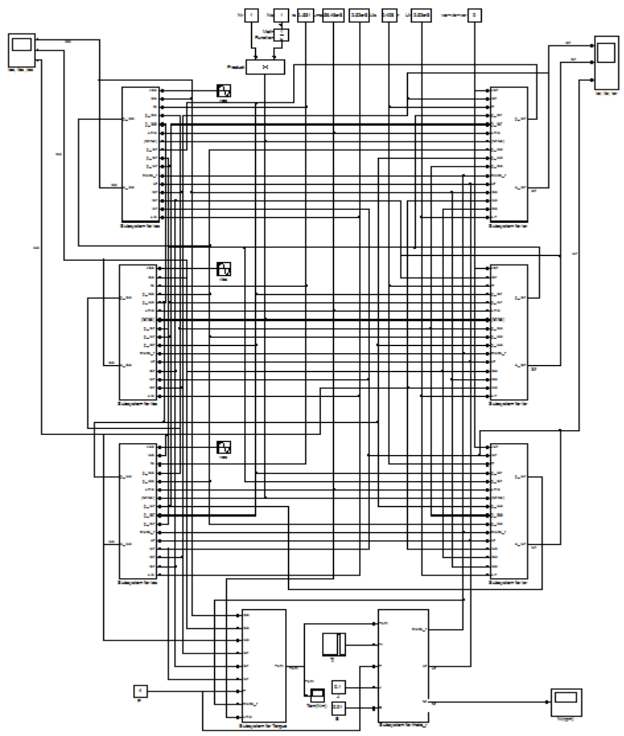

Figure 1 MATLAB Simulink model of Proposed System

In figure 1 depicts the complete simulink scheme of the described induction machine model. In this system the equations are framed with separate sub-systems. There are totally eight sub-system, the left side of the viewer consists of three sub-system for stator currents (i_{as}, i_{bs}, i_{cs}), the right side of the viewer consists of three sub-system for rotor currents (i_{ar}, i_{br}, i_{cr}) and at the bottom it consists of two sub-systems. First is for electromagnetic torque and second is for angular velocity. As for example, sub-system for stator current i_{as} is shown in figure 2.

There are 16 inputs such as V_{as}, i_{as}, r_s, Ψ_{ibs}, Ψ_{ics}, L_{ms}, (N_r/N_s), Ψ_{iar}, Ψ_{ibr}, Ψ_{icr}, theta_r, w_r, i_{ar}, i_{br}, i_{cr}, L_{ls} and two output such as Ψ_{ics} and i_{as} is shown in figure 2. It is designed from the equation (1), is denoted below.

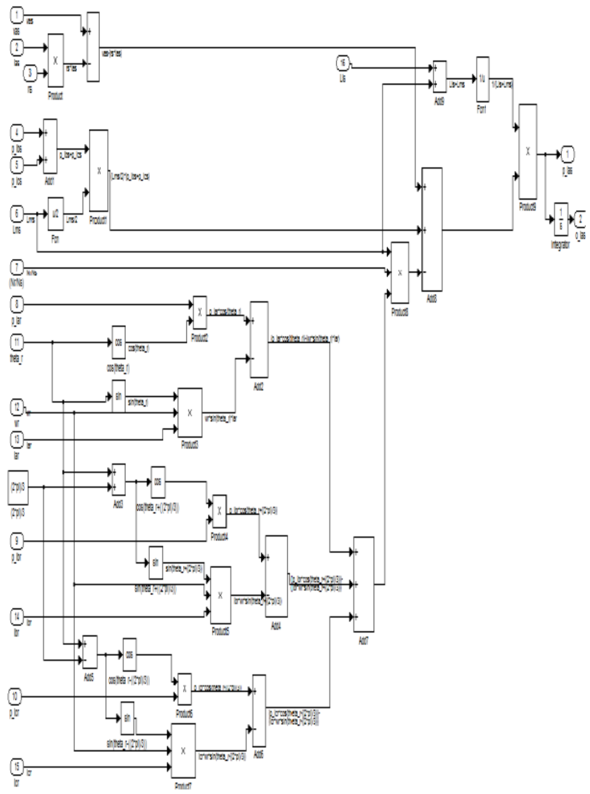

Figure 2 Sub-system of stator current i_{as}

The stator flux linkage Ψ_{ias} is given by,

$$\Psi_{ias} = \frac{1}{(L_{ls}+L_{ms})} \{[V_{as} - (r_s * i_{as})] + [(\frac{Lms}{2}) * (\Psi_{ibs} + \Psi_{ics})] - [L_{ms} * (\frac{Nr}{Ns}) * \{[(\Psi_{iar} * \cos\theta_r) - (i_{ar}*\omega_r*\sin\theta_r)] + [(\Psi_{ibr} * \cos(\theta_r + \frac{2\pi}{3}) - (i_{br}*\omega_r*\sin(\theta_r + \frac{2\pi}{3})] + [(\Psi_{ibr} * \cos(\theta_r - \frac{2\pi}{3}) - (i_{ar}*\omega_r*\sin(\theta_r - \frac{2\pi}{3}))]\}\} .$$

The stator current i_{as} is given by,

$$i_{as} = \int \Psi_{ias} .$$

IV. RESULTS AND DISCUSSION

In figure 1, it shows that the some of the values are given in constant block which is estimated below,

R_s=0.531 ohms, R_r=0.408 ohms, L_{ms}=56.4e-3H, L_{ls}=2.5e-3H, L_{lr}=2.52e-3H, Var=V_{br}=V_{cr}=0, J=0.1 Kgm^2, B=0.01.

The stator voltage for all the phases is given as sinusoidal input with different phase shift values and the load torque as timer input. The result which discusses about the stator current, rotor currents, torque and speed variations is shown below.

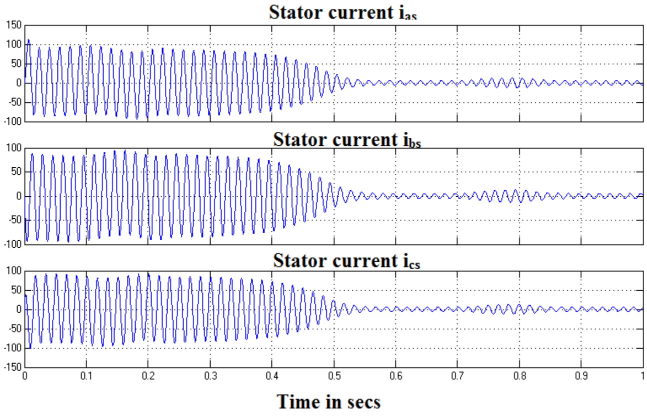

Figure 3 Stator Currents variations

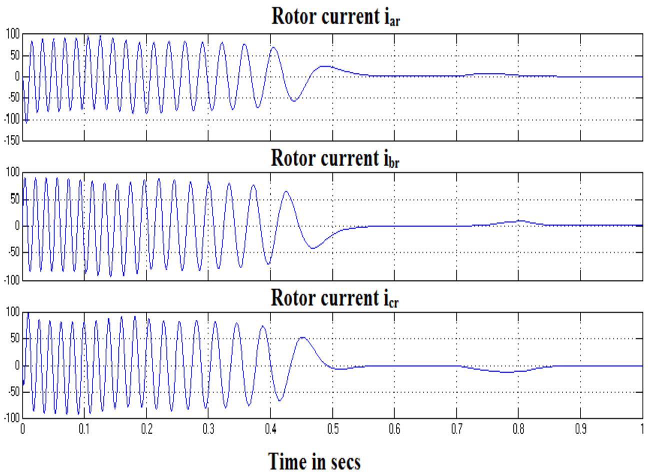

Figure 4 Rotor current variations

In figure 3 which shows that the stator current which has the variations with no limited values whereas in fig 4 shows that the rotor current which has the constant variation after certain limit.

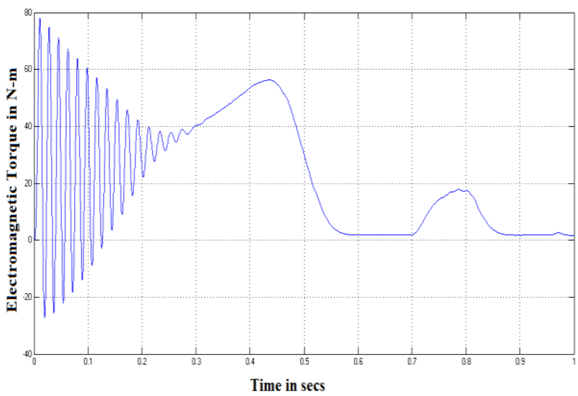

Figure 5 Electromagnetic Torque variation

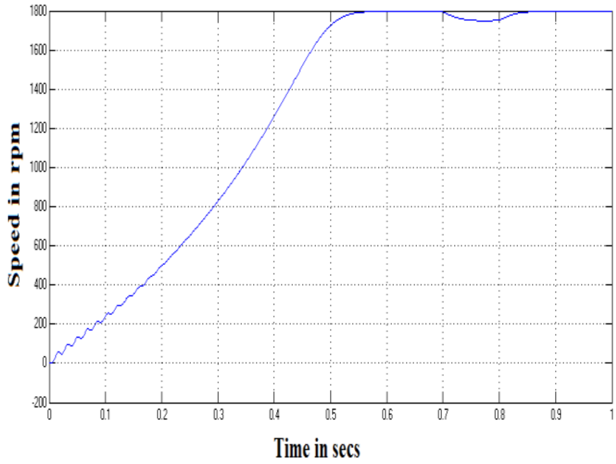

Figure 6 Speed Variation

The figure 5 and 6 represents the torque variation and speed variation. At normal three phase voltage the torque reaches upto 80 Nm whereas the speed reaches upto 1800 rpm.

V. CONCLUSION

In this paper, an implementation and dynamic modeling of a three-phase induction motor using MATLAB/Simulink are presented in step-by-step manner. The simulated result has given a satisfactory response in terms of the torque, speed characteristics. Further work will be on the simulation of induction motor model by taking the effect of saturation of flux and effect of harmonics at supply side.

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