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 analyse 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.
\[ \Psi_{as}, \Psi_{bs}, \Psi_{cs} \] Stator flux linkage.
\[ \Psi_{ar}, \Psi_{br}, \Psi_{cr} \] Rotor flux linkage.
\[ T_{em}, T_s \] 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.
\[ \omega_r \] 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 \( V_{as}, V_{br}, V_{bs} \) are stationary (i.e., zero) and so it terms as stator reference frame.

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

\[
\Psi_{las} = \frac{1}{(i_{as}+i_{ms})} [(V_{as} - (r_s \cdot i_{as})) + \frac{1}{(L_{ms})} (\Psi_{bs} + \Psi_{cs})] - (i_{as} \cdot \omega_r \cdot \sin(\delta_r)) + \frac{1}{(L_{ms})} [((\Psi_{las} - \cos(\delta_r) - (i_{as} \cdot \omega_r \cdot \sin(\delta_r)) + (\Psi_{br} \cdot \cos(\delta_r) + \frac{2\pi}{2} - (i_{bs} \cdot \omega_r \cdot \sin(\delta_r) + \frac{2\pi}{2}))]
\]
The rotor current \( i_r \) is given by,

\[
i_r = \int \Psi_{i_r}
\]

\[
\Psi_{i_r} = \frac{1}{(I_{i_r} + I_{i_m})} \left( \left[ V_{br} \right] - \left[ \left( I_{i_r} + I_{i_m} \right) \right] \right) - \frac{1}{N_r} \frac{L_n}{N_s} \left[ \left( \Psi_{br} \right) - \left( \left( I_{i_r} + I_{i_m} \right) \right) \right]
\]

\[
\Psi_{i_r} = \cos(\theta_r - \frac{2\pi}{2}) - (i_r \cdot \omega_1 \cdot \sin(\theta_r - \frac{2\pi}{2}))
\]

The electromagnetic torque is given by,

\[
T_{em} = L_m \cdot N_r \cdot \left( \left[ \left( \Psi_{i_r} \right) \cdot \left( \left( I_{i_r} + I_{i_m} \right) \right) \right] \right) + \frac{(i_r \cdot \omega_1 \cdot \sin(\theta_r - \frac{2\pi}{2}))}{2}
\]

\[
= \frac{(i_r \cdot \omega_1 \cdot \sin(\theta_r - \frac{2\pi}{2}))}{2}
\]

The angular velocity is given by,

\[
\omega_2 = \left( \left[ \left( \Psi_{i_r} \right) \right] \right) - \left( \left( \left( I_{i_r} + I_{i_m} \right) \right) \right)
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\]
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 $V_{as}$, $i_{as}$, $r_s$, $\Psi_{ibs}$, $\Psi_{ics}$, $L_{ms}$, ($N_r/N_s$), $\Psi_{iar}$, $\Psi_{ibr}$, $\Psi_{icr}$, theta_r, $w_r$, $i_{ar}$, $i_{br}$, $i_{cr}$, $L_{ls}$ and two output such as $\Psi_{ics}$ and $i_{as}$ is shown in figure 2. It is designed from the equation (1), is denoted below.

The stator flux linkage $\Psi_{las}$ is given by,

$$\Psi_{las} = \frac{1}{(L_{ms}+L_{ms})} \left\{ \left( V_{as} - (r_s * i_{as}) \right) + \left[ \frac{i_{ms}}{2} \right] \right.\
\left. \left( \Psi_{ibs} + \Psi_{ics} \right) - \frac{L_{ms}}{N_s} * \left\{ \left[ (\Psi_{iar} * \cos \theta_r) - \\ (i_{ar} * \omega_r * \sin \theta_r) \right) + \\ \left[ (\Psi_{ibr} * \cos \left( \theta_r + \frac{\pi}{2} \right)) - (i_{br} * \omega_r * \sin \left( \theta_r + \frac{\pi}{2} \right)) \right) + \\ \left( i_{ar} * \omega_r * \sin \left( \theta_r - \frac{\pi}{2} \right) \right) \right\} \right\}.$$

The stator current $i_{as}$ is given by,

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

IV. RESULTS AND DISCUSSION

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

$$R_s=0.531 \text{ ohms}, \quad R_r=0.408 \text{ ohms}, \quad L_{ms}=56.6e^{-3} \text{H}, \quad L_{la}=2.5e^{-3} \text{H}, \quad L_{lb}=2.52e^{-3} \text{H}, \quad \varphi_r=V_{br}=V_{cr}=0, \quad J=0.1 \text{ Kgm}^2, \quad B=0.01.$$

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 3 shows the stator currents with variations and no limited values. Figure 4 shows the rotor currents with a constant variation after a certain limit.

Figure 4 Rotor Current variations

In figure 3, the stator current variations are depicted, showing no limited values. Figure 4 illustrates the rotor current variations, which remain constant after a specific limit.

Figure 5 Electromagnetic Torque variation

Figure 5 represents the electromagnetic torque variation over time. The torque reaches up to 80 Nm at normal three-phase voltage.

Figure 6 Speed Variation

The speed variation is shown in figure 6, reaching up to 1800 rpm at normal three-phase voltage.

V. CONCLUSION

In this paper, the implementation and dynamic modeling of a three-phase induction motor using MATLAB/Simulink are presented in a step-by-step manner. The simulated results have shown satisfactory responses in terms of torque and speed characteristics. Further studies will focus on simulating the induction motor model by considering saturation of flux and the effect of harmonics at the supply side.

REFERENCES


