Modeling and Simulation of Induction Motor and Its Steady State Response

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Abstract

With advancement in technologies, industrializations there has been tremendous increase in utilization of motors and electronics devices. Therefore it has become utmost important to make them work efficiently and control efficiently to avoid wastage of electrical power there by resulting in it saving. To bring this into realization, constant innovations and improvement are must in these devices, which in turn opens the gate of research on such devices, which can only be achieved through modeling and simulation of such devices and their analysis on the computers. This paper in turn present the basics set of equations for modeling of Induction motor and its implementation in Matlab software, also taking into consideration its behavior analysis, steady state response of the model has been displayed graphically.

Keywords: Induction Motor, Reference Frame, Software modeling, Steady state response, Transformations.

I. INTRODUCTION

Induction motors are one of the widely used motors in industries as well as residential applications owing to its robust and easy availability economically. Thus researches inclined toward induction motors design and performance improvement must be concentrate more on. Operation and behavior of each and every electrical devices, equipment or system in general can be defined by some of the basic set of mathematical equations. They may be in form of Linear equations, Non linear, Differential equations of various orders. These equations in turn define the complete steady state and dynamic behavior of the system. Part II of the paper explain the basic set of electrical and mechanical equation of Induction motor. Part III deals with the implementation in MATLAB Software and Part IV gives the steady state behavior of the Model without load (i.e. on no load) and with load (i.e. on load).

II. MATHEMATICAL MODELING OF INDUCTION MOTOR

Any electrical machine consists of electrical circuits, magnetic circuits which together define the electromechanical and dynamics of the machine. The basic electrical equations (1) which energize the stator are obtained by applying Kirchhoff's voltage law to the three phases of the stator and to rotor (2). The electromagnetic flux linkage equations for machine are given by (3). The point to note is all the equations are represented in arbitrary reference frame obtained by applying change of variable or theory of reference frame transformation. Owing to wide advantages like reduced equations complexities, reduced no of equations, less memory consumption, speed of obtaining solution on computers, and last but not the least decoupled control of system can be achieved using reference frame transformations. Such transformation studies are more involving and a separate subject on its own. So taking into consideration the length of the paper, the method of obtaining the above referred equations has not be considered only the final derived equations and transformation matrix to obtain these equations has been given directly [1], [3],[4],[5].

Stator equations:

\[ V_{qs} = i_{qs}r_s + p\lambda_{qs} + \omega\lambda_{dr} \]
\[ V_{ds} = i_{ds}r_s + p\lambda_{ds} + \omega\lambda_{qr} \]
\[ V_{0s} = i_{0s}r_{0s} + p\lambda_{0s} \]

Rotor equations:

\[ V'_{qr} = i'_{qr}r'_r + p\lambda'_{qr} + (\omega - \omega_r) \lambda'_dr \]
\[ V'_{dr} = i'_{dr}r'_r + p\lambda'_dr + (\omega - \omega_r) \lambda'_qr \]
\[ V'_{0s} = i'_{0} r'_{r} + p \lambda'_{0s} \]

Flux linkage equations:
\[ \lambda_{qs} = i_{qs} L_{ts} + (i'_{qr} + i_{qs}) L_{M} \]
\[ \lambda_{ds} = i_{ds} L_{ts} + (i'_{dr} + i_{ds}) L_{M} \]
\[ \lambda_{0s} = i_{0r} L_{lr} \]

\[ K_s = \frac{2}{3} \begin{bmatrix} \cos \theta & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ \sin \theta & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \]

\[ \theta = \int_{0}^{t} \omega(t) dt + \theta(0). \]  

- \( \theta \) = position of the reference Frame w.r.t to the reference axis
- \( \omega \) = speed of reference frame considered for study
- \( \omega = 0 \): Stationary reference frame (Clark transformation, or Stanley Transformation).
- \( \omega = \omega_r \): Synchronously rotating reference frame (Kron’s Transformation).
- \( \omega = \omega_q \): Rotor reference frame (i.e. the reference frame is fixed on the rotor) (Park’s Transformation).
- \( \omega_r \) = Speed of rotor in electrical rad/sec
- \( V_{qdos} \) = Stator voltages in reference frame
- \( I_{qdos} \) = Stator currents in reference frame
- \( \lambda_{qdos} \) = Stator flux linkages in reference frames
- \( V'_{qdo} \) = Rotor voltages in reference frame as referred to primary
- \( I'_{qdo} \) = Rotor currents in reference frame as referred to primary
- \( \lambda'_{qdo} \) = Rotor flux linkages in reference frames as referred to primary.
- \( L_s \) = Stator winding leakage inductance H
- \( L_r \) = Rotor winding leakage inductance H
- \( L_m \) = Magnetizing inductance of the machine H.
- \( T_e \) = Electromagnetic Torque N-m
- \( T_L \) = Applied load torque
- \( J \) = Moment of inertia in Kg/m^3

### III. Mathematical Modeling of Induction Motor in Matlab

Using the equation sets discussed in Part II of the paper, the basic block diagram of induction motor can be obtained as shown in Fig[1], which can be finally implemented in Matlab software as shown in Fig [2]. As shown in block diagram when stator is excited by 3 phase voltages, synchronously rotating magnetic field gets linked with the flux linkage system which in turn gets transferred to rotor. The flux and the current so produced interact to produce electromagnetic torque \( T_e \).
IV. **FREE RUNNING AND STEADY STATE RESPONSE OF THE MODELED INDUCTION MOTOR IN MATLAB**

- **No load operation**: Fig [3] to Fig [8] below depicts the behavior of motor on no load. Induction motor being an inductive load draws a very high magnetizing current at starting, when 3 phase sinusoidal rated voltage is applied at time t=0, as shown in Fig [3]. The starting torque transients are very high as the motor needs to startup from stand still owing to its inertia Fig [7]. As no external load is connected to the shaft the motor speeds up almost near to synchronous speed, reaching the final steady state condition with electromagnetic torque reaching to zero and magnitude of current drawn by stator at time t=0.4 becoming negligible as shown in Fig [7] and Fig [8]. This current is sufficient enough to drive its own weight. Fig [4] shows the appearance of stator voltage, stator current and rotor current in synchronous reference frames. It can been clearly seen that the these parameters almost remains frequency independent and are constant which lead to an important concept of application of synchronous reference frame transformation when there is unbalance or disturbances created in supply system. Fig [5] depicts the machine variable in rotor reference frame, the parameters vary at very low frequencies near to slip frequency, which indicates it importance when studying or analyzing rotor circuit. Similarly the stator frame has its own advantages based on its application.

- **On load operation**: Fig [9] to Fig [13] shows the behavior of the motor and corresponding parameters with load torque of 10N-m applied on the motor shaft.
Fig. 4: Machine parameters as viewed in Synchronous Reference Frame.

Fig. 5: Machine parameters as viewed in Rotor Reference Frame.
Fig. 6: Machine parameters as viewed in Stationary Reference Frame

Fig. 7: Torque and Speed of the machine with respect to time

Fig. 8: Torque Speed characteristic of the machine
Fig. 9: Machine parameters in original machine variable with 10 N-m load Torques on the shaft.

Fig. 10: Machine parameters in Rotor Reference Frame with 10 N-m load Torque on the shaft.

Fig. 11: Machine parameters in Synchronous Reference Frame with 10 N-m load Torque on the shaft.
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Fig. 12: Torque and Speed of the machine with respect to time with 10 N-m load connected on the shaft

Fig. 13: Torque Speed characteristic of the machine with 10 N-m load torque on the shaft.

Table-1
Parameters of Induction Motor under study

<table>
<thead>
<tr>
<th>Induction Motor Parameters For simulation</th>
<th></th>
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<tbody>
<tr>
<td>H.P</td>
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<tr>
<td>Voltage</td>
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<tr>
<td>Speed</td>
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<td>Break down Torque</td>
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<td>Rs</td>
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<td>J</td>
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<td>frequency</td>
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</table>
REFERENCES

[1] Paul C Krause, “Reference Frame Theory”, Analysis of electric Machinery and Drive System