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Dynamic Model Analysis of Three Phase Induction Motor Using Matlab/Simulink

Pratyusha Biswas Deb, Sudhangshu Sarkar

Abstract— This paper reproduce the dynamic model of three phase induction motor derived from detailed mathematical equation in MATLAB/Simulink and study the transient performance as well as steady state response of machine including the constant moment of inertia and load torque for the external system. Dynamics generalized approach [1] of digital computer simulation of three phase induction machine is universally applicable method to propose for simulating a dynamic behavior of a large, non linear, time varying physical system. The model can account for unbalanced on both sides of the air gap provided the structure of winding remains unaltered. The simulation in the three-phase Induction motor is with variations in moment of inertia [2]. Transient performance of any electrical machine is greatly affected by sudden changes in its supply system operating speed, shaft load including any variation of moment of inertia due to gear arrangement application. Rotor reference frame is used for the simulation study of this machine. MALTLAB/ Simulink based model is adopted to compare a transient performance of induction machine including main flux saturation with and without the moment of inertia. Simulated results have been compared and verified with experimental results on a test machine setup. During the development of dynamic models of induction motors, most of the researchers neglected the effect of magnetic saturation and assumed inductances to be constant [2]. The computer simulation for these various modes of operation is conveniently obtained from the equations which describe the symmetrical induction machine in an arbitrary reference frame.

Index Terms— d-q axis, Dynamic model, Leakage inductance, Magnetic saturation, Reference frame, Transient analysis,

1 Introduction

Three phase squirrel cage type Induction Motors (IM) are commonly utilized in the industries from the capacity of several kilowatts to thousands of kilowatts as the driving units for the fans, pumps and compressors [1]. The motor favours because of its good self starting capability, simple and rugged structure, low cost and reliability etc. Usually, the motors are maintained periodically. However, when the ground fault occurs at the motor terminal, a serious damage may be brought to the motor [3]. Also it has been known that re-switching the supply onto a squirrel cage IM can result in the production of large negative torque transients. Therefore it is significant to understand the transient phenomenon under abnormal conditions for the optimal design of the IM. The traditional methods of modeling of IMs have been applied by several authors. In this method of analysis it is assumed that the effect of saturation is negligible.

In order to investigate the problems like large currents, voltage dips, oscillatory torques and harmonics in power systems during severe transient operations and introduce, the dq-axis model has been found to be well tested and proven describes the basic concept of transient modeling of the machine [2].

Dynamic behavior of the machine may be analyzed using rotor reference frame and stationary reference frame, recommends exact tests to estimate the machine parameters to proceed with transient modeling [10]. The effect of considering the main flux saturation is investigated. It has been shown that the main magnetizing field contributes significantly to the inequality between the induction machines computer simulation results and the experimentally derived results [15]. As a result, the effect of saturation in induction machines can be included through variation of main flux inductance while assuming the leakage inductances to be constant. Transient performance of any electrical machine is greatly affected by sudden changes in its supply system, operating speed, shaft load including any variation of moment of inertia.

MATLAB / SIMULINK, which has been found to be a very useful tool for modeling electrical machine and it is used to predict the dynamic behavior of the machines [10]. In this paper, MATLAB / SIMULINK based model using rotor reference frame and including saturation effect is proposed for simulation purpose. Simulated results as obtained have been compared and verified with experimental results on a test machine setup. During simulation sufficient time span is included to predict the complete behavior of the machine. A close agreement between the simulated results proves the validity of proposed mode. Apart from this it can be stated that another objective is to gain experience and understanding the problem associated with an implementation of Induction Motor Model. The transformation to the arbitrary reference frame is modified to accommodate rotating circuits. Once this ground work has been laid, the machine voltage equations are written in the stationary reference frame, directly without a laborious exercise in trigonometry with which one is faced when starting from the substitution of the equations of transformations into the voltage equation expressed in machine variables. The equation may then be expressed in any reference frame by appropriate assignment of the reference frame speed in the stationary reference frame voltage equation rather than performing each transformation individually as in the past. Alt-

- *Pratyusha Biswas Deb is currently working as Assistant Professor in electrical engineering department in Narula Institute of Technology, India PH-+919748941162. E-mail: pratyushabiswas85@gmail.com*
- *Sudhangshu Sarkar is currently working as Assistant Professor in electric engineering department in Narula Institute of Technology, India PH-+919830054232. E-mail: sarkar.sudhangshu@gmail.com*

hough the stationary reference frame, the reference frame fixed in the rotor and the synchronously rotating reference frame are most frequently used, the arbitrary reference frame offers a direct means of obtaining the voltage equations in these and all other reference frames. Computer solutions are used to illustrate the dynamic performance of typical induction motor and to depict the variables in various reference frames during free acceleration.

2 Mathematical Equation of Induction Motor

The mathematical description of an ideal symmetrical squirrel cage type induction motor in rotor reference frame is given by as follows. The stator windings are identical, sinusoidal distributed windings, displaced 120˚, with Ns equivalent turns and resistance r_s and the rotor windings will also be considered as three identical sinusoidal distributed windings, displaced 120˚, with N_r equivalent turns and resistance r_r. The positive direction of the magnetic axis of each winding is shown. It is important to note that the positive direction of the magnetic axes of the stator windings coincides with the direction of f_{as}, f_{bs}, and, f_{cs} as specified by the equations of the transformation.

The voltage equations in machine variables may be expressed as

$$V_{abcs} = r_s i_{abcs} + p\lambda_{abcs}$$
$$V_{abcr} = r_r i_{abcr} + p\lambda_{abcr} \quad (1)$$

For a magnetically linear system, the flux linkages may be expressed as

$$\begin{bmatrix} \lambda_{abcs} \\ \lambda_{abcr} \end{bmatrix} = \begin{bmatrix} L_s & L_{sr} \\ (L_{sr})^T & L_r \end{bmatrix} \begin{bmatrix} i_{abcs} \\ i_{abcr} \end{bmatrix} \quad (2)$$

The voltage equations expressed in terms of machine variables referred to the stator windings may be written as

$$\begin{bmatrix} V_{qs} \\ V_{ds} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_s + L_s p & \omega_r L_s & L_m p & \omega_r L_m \\ -\omega_r L_s & R_s + L_s p & -\omega_r L_m & L_m p \\ L_m p & 0 & R_r + L_r p & 0 \\ 0 & L_m p & 0 & R_r + L_r p \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix} \quad (3)$$

The torque and rotor speed are related by

$$T_e = J(\frac{2}{P}) p\omega_r + T_L \quad (4)$$

In the analysis of the induction machines it is also desirable to transform the variables associated with the symmetrical rotor windings to the arbitrary reference frame.

A change of variables which formulates a transformation of the 3-phase variables of the rotor circuits to the arbitrary reference frame is: $f'_{qd0r} = K_r f'_{abcr}$ (5)

3 Dynamic Model of Induction Motor

In this paper, stationary reference frame is used for the simulation study of three phase Induction motor. Matlab / Simulink based modeling is adopted to compare the transient performance of three phase induction motor including main flux saturation of the system attached to the motor.

The induction machine d-q or dynamic equivalent circuit is shown in fig 3.1.

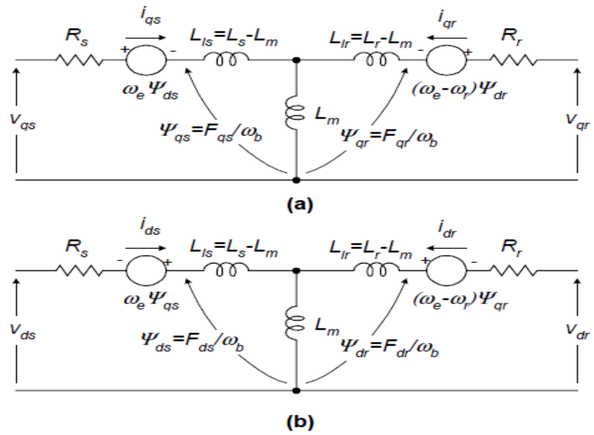

Fig 3.1 d-q equivalent circuit of an Induction Machine

According to this model the modeling equation in flux linkage form are as follows:

$$\frac{dF_{qs}}{dt} = \omega_b [v_{qs} - \frac{\omega_e}{\omega_b} F_{ds} + \frac{R_s}{X_{ls}} (F_{mq} + F_{qs})] \quad (6)$$

$$\frac{dF_{ds}}{dt} = \omega_b [v_{ds} + \frac{\omega_e}{\omega_b} F_{qs} + \frac{R_s}{X_{ls}} (F_{md} + F_{ds})] \quad (7)$$

$$\frac{dF_{dr}}{dt} = \omega_b [v_{dr} + \frac{(\omega_e - \omega_r)}{\omega_b} F_{qr} + \frac{R_r}{X_{lr}} (F_{md} - F_{dr})] \quad (8)$$

$$\frac{dF_{qr}}{dt} = \omega_b [v_{qr} - \frac{(\omega_e - \omega_r)}{\omega_b} F_{dr} + \frac{R_r}{X_{lr}} (F_{mq} - F_{qr})] \quad (9)$$

For a Squirrel Cage Induction Machine as in the case of this paper, V_{qr} and V_{dr} are set to zero. The modeling equations of a Squirrel cage Induction motor in state space become:

$$\frac{dF_{qs}}{dt} = \omega_b [v_{qs} - \frac{\omega_e}{\omega_b} F_{ds} + \frac{R_s}{X_{ls}} (\frac{X^*_{ml}}{X_{lr}} F_{qr} + (\frac{X_{ml}^*}{X_{ls}} - 1) F_{qs})] \quad (10)$$

$$\frac{dF_{ds}}{dt} = \omega_b [v_{ds} + \frac{\omega_e}{\omega_b} F_{qs} + \frac{R_s}{X_{ls}} (\frac{X^*_{ml}}{X_{lr}} F_{dr} + (\frac{X_{ml}^*}{X_{ls}} - 1) F_{ds})] \quad (11)$$

$$\frac{dF_{qr}}{dt} = \omega_b [-\frac{(\omega_e - \omega_r)}{\omega_b} F_{dr} + \frac{R_r}{X_{lr}} (\frac{X^*_{ml}}{X_{ls}} F_{qs} + (\frac{X_{ml}^*}{X_{lr}} - 1) F_{qr})] \quad (12)$$

$$\frac{dF_{dr}}{dt} = \omega_b [\frac{(\omega_e - \omega_r)}{\omega_b} F_{qr} + \frac{R_r}{X_{lr}} (\frac{X^*_{ml}}{X_{ls}} F_{ds} + (\frac{X_{ml}^*}{X_{lr}} - 1) F_{dr})] \quad (13)$$

$$\frac{d\omega_r}{dt} = (T_e - T_l)(\frac{p}{2J}) \quad (14)$$

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4 Simulink Model Implementation

Using SIMULINK, the simulation model can be built up systematically starting from simple sub-models. The main advantage of SIMULINK over other programming software is that, instead of compilation of program code, the simulation model is built up systematically by means of basic function blocks. The induction motor model developed may be used this software, it can be incorporated in an advanced motor drive system [2]. A set of machine differential equations can thus be modeled by interconnection of appropriate function blocks, each of which performing a specific mathematical operation. Programming efforts are drastically reduced and the debugging of errors is easy.

Since SIMULINK is a model operation programmer, the simulation model can be easily developed by addition of new sub-models to create for various control functions. As a sub-model the induction motor could be incorporated in a complete electric motor drive system [3–5]. This complete simulink model which depend on mathematical d-q model equation is given below.

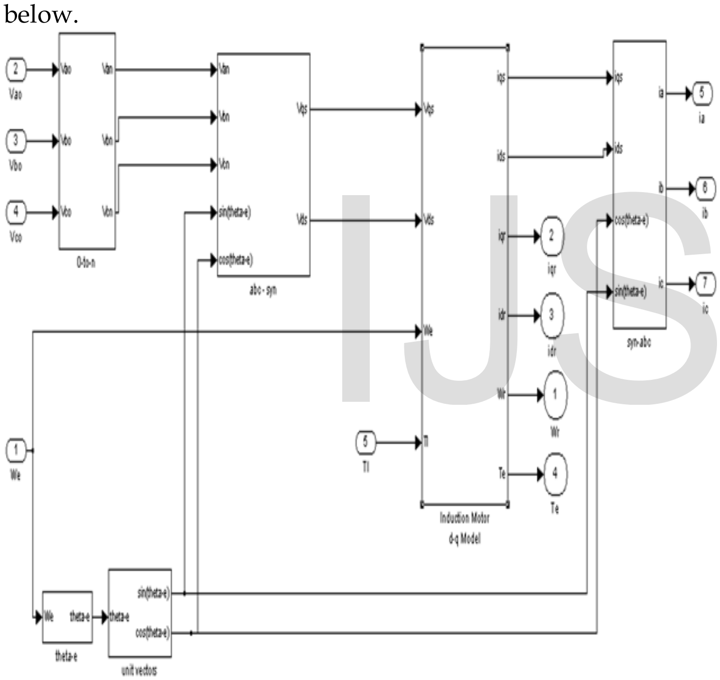

Fig. 4.1 MATLAB Simulink model of Induction Motor

A generalized dynamic model of the induction motor consists of an electrical portion to implement the three-phase to two-axis (3/2) transformation of stator vsoltage and current calculation, a torque sub-model to calculate the developed electromagnetic torque and a mechanical sub-model to yield the rotor angular speed. In electrical engineering, dq_0 transformation is a mathematical transformation used to simplify the analysis of three phase circuit. In this case of balanced three phase circuits, applications of dq_0 transform reduce the three ac quantities to 2 dc quantities. Simplified can then be carried out on this imaginary dc quantities before performing the inverse transform to recover the actual three phase ac results.

5 Performance Analysis

In this paper, the performance analysis of three phases IM is discussed in details. The behavior of stator output current per phase, d-q axis stator current, d-q axis rotor current, speed and torque characteristics are also briefly explained with respect to time. The detail implemented MATLAB/Simulink model of IM is used for performance analysis. Performance analysis simulation is done using ode23tb (stiff/TR-BDF2) solver, for a total time of 0.2 sec. and relative tolerance is 1e-3.

From all curves, the nature of the implemented IM is explained in transient as well as steady state condition.

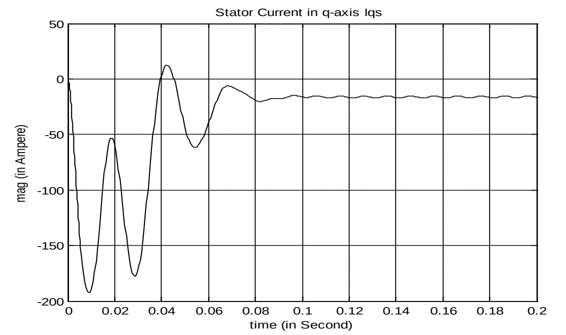

Fig.5.1 Stator Current in q- axis versus time curves (iqs vs. time)

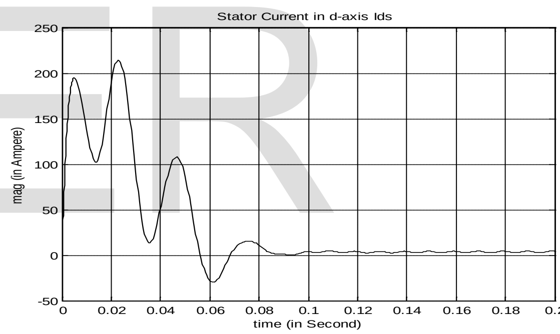

Fig.5.2 Stator Current in d- axis versus time curves (ids vs. time)

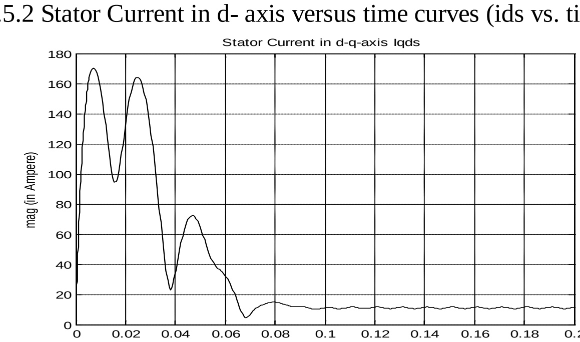

Fig.5.3 Stator Current in dq- axis versus time curves (i_{qds} vs. time)

The peak value of the stator current in d- axis is greater than the value of resultant q-d axis stator current. All absolute peaks are calculated from the transient condition of these current whereas from this steady state condition, the average values of the stator and rotor currents are calculated and all are

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mentioned in Table 5.1 and Table 5.2

Table-5.1

Absolute Peak value and Average Value of Stator Current

Type	Stator Current (I_a) (amp)	Stator Current (I_b) (amp)	Stator Current (I_c) (amp)	Stator Current in q-axis (I_{qs}) (amp)	Stator Current in d-axis (I_{ds}) (amp)	Stator Current in q-d axis (I_{qds}) (amp)
Average Value	0.003427	0.004096	0.0004784	-16.19	3.563	11.06
Absolute Peak Value	214.5096	218.3873	255.0835	192.6226	214.4895	170.1812

Table-5.2

Absolute Peak value and Average Value of rotor current in d-q axis:

Type	Rotor Current in q-axis (I_{qr}) (amp)	Rotor Current in d-axis (I_{dr}) (amp)	Rotor Current in q-d axis (I_{qdr}) (amp)
Average Value	0.0984	2.913	1.983
Absolute Peak Value	173.33	215	160.4594

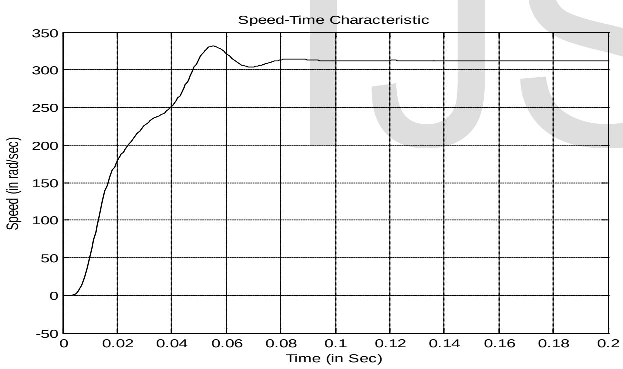

Fig5.4 Torque Characteristics

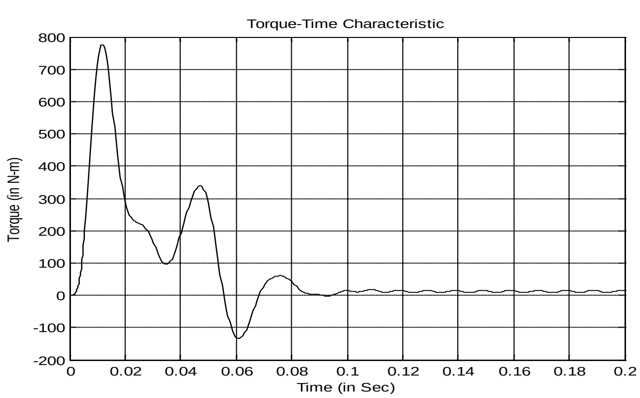

Fig5.5 Speed Characteristics

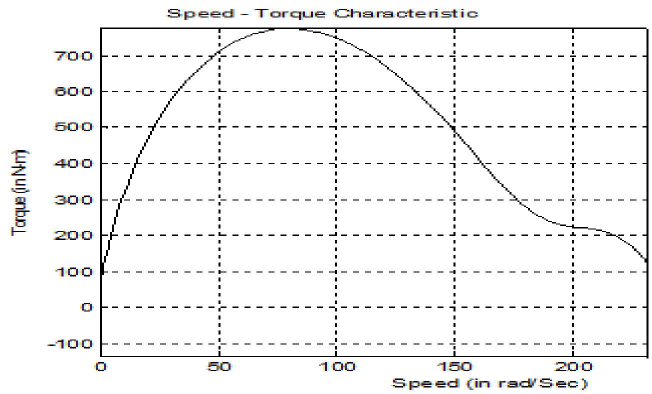

Fig 5.6 Speed - Torque Characteristics

6 Result & Discussion

To analyze the performance of induction motor with Matlab/Simulink, the model is simulated when pure sinusoidal three phase voltage is applied. In this paper, the dynamic responses of speed and stator currents for the starting process with constant torque applied and a constant command flux are shown in simulation results. The peak values and the average values of speed and torque are shown in above. It can be said that the rotor angular velocity is one fourth (¼) of the rated angular speed.

In this paper, the comparison between simulink implemented model and Matlab/Simulink model in explained. The simulink implemented model means which is implemented by us based on detail mathematical equation, as discussed in above. On the other hand the Matlab/Simulink demo model means the model which is already exists in the MATLAB/Simulink software. For this comparison of three phases IM, same parameters for both models should be taken, which are already mentioned in table-6.1. The fundamental supply voltage is applied to the both models for this comparison.

Table-6.1

Parameters of three phase Induction Motor

Motor Parameters	Motor 1
Rated Voltage (V)	220
Stator resistance (Ω)	0.435
Rotor resistance (Ω)	0.816
Stator leakage inductance (Ω)	0.754
Rotor leakage inductance (Ω)	0.754
Mutual inductance (Ω)	26.13
Load torque (N-m)	11.9
Moment of inertia (Kg-m^2)	0.089

Matlab simulink model of three phase asynchronous machine is taken from the MATLAB/Simulink software. After getting the model, the parameters are putted, which are already used to the implemented model. These detail natures of comparison

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are shown in below figure. Here firm line denotes the Matlab implemented simulink model, whereas, dotted line denotes the Matlab / Simulink demo model.

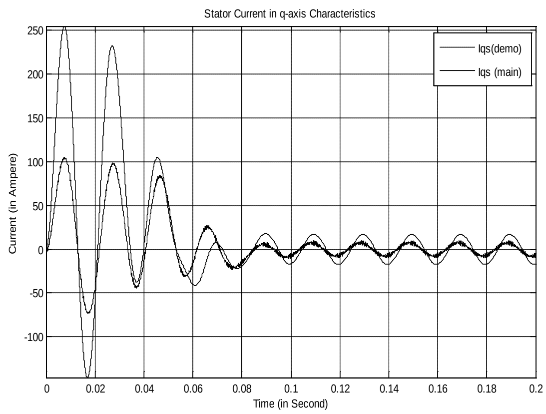

Fig.6.1 Stator Current in q- axis versus time curves (iqs vs. time)

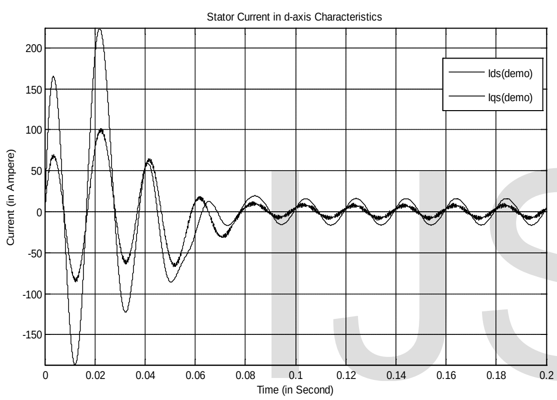

Fig.6.2 Stator Current in d- axis versus time curves (ids vs. time)

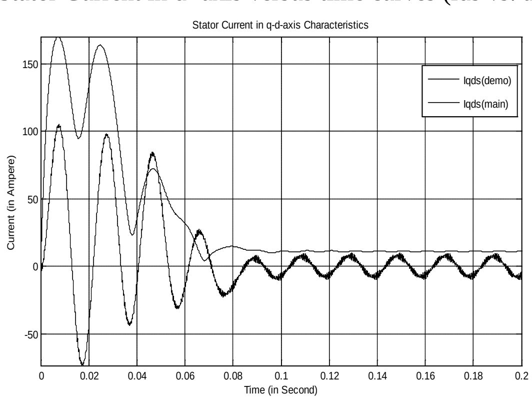

Fig.6.3 Stator Current in dq- axis versus time curves (i_{qds} vs. time)

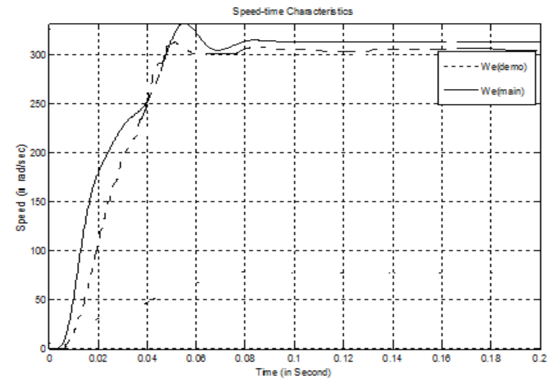

Fig6.4 Torque Characteristics

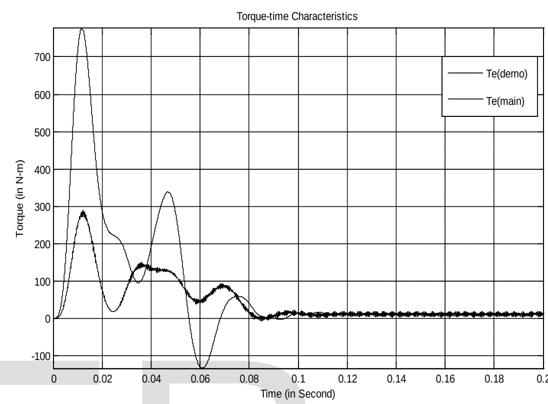

Fig6.5 Speed Characteristics

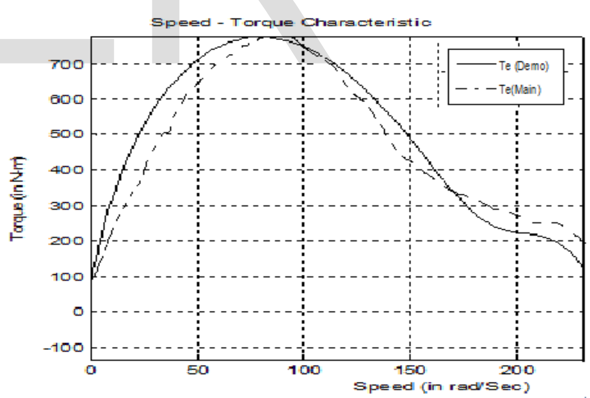

Fig 6.6 Speed - Torque Characteristics

Conclusion

In this paper, a simulation approach was proposed to analyze the transient behavior as well as steady state behavior of three phase induction motor. Electrical and mechanical parts of induction motor were implemented by detail mathematical equations which are explained. The dynamic model is presented in this paper has shown very accurate simulation results. The main disadvantage of this implementing IM model is the value of the rotor angular velocity is ¼ times of actual rated rotor angular velocity.

Future Work

Future work will be on the simulation of induction motor model by taking the effect of saturation of flux in supply side and variable load torque, with and without MOI and friction co-efficient. Also the work will be on operation of the Induction motor model to simulate for generator responses at a variable load torque. Apart from this, we will consider the effect of higher order odd harmonics on induction motor. The total MATLAB/Simulink model will be implemented by the State space equation of the IM.

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"Excellence is not a destination; it is a continuous journey that never ends"

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