Deciduous Performance Analysis of Three Phase Squirrel Cage Induction Motor using Matlab-Simulink

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Abstract: This paper aimed at a complete dynamic model of three phase induction motor based on mathematical equation to simulate the deciduous performance of induction motor which is greatly affected by sudden change in its supply system, operating speed and shaft load including any variation in moment of inertia (MOI) due to gear arrangement application. As the nonlinear relationship of induction motor between its input and output variables are complex and the physical simulation of the induction motor is difficult. Therefore, a detailed and accurate computer base mathematical model is essential to investigate the characteristics of its and predicting the transient behaviour of induction motor for any specific application. The dynamic mathematical model of induction motor, which was used in the motor dynamic studies, is expressed by the six differential equations of three-phase instantaneous voltage and current. In conclusion, the effect of change in load torque and MOI on motor performance characteristics resulted as observed from fig. 5, fig. 7 and fig. 8 and table III, which show that: (i) MOI greatly affects the inrush current drawn by the induction motor, (ii) moment of inertia has significant effects during starting in contrast of steady state operations, (iii) low values of MOI results into a low settling time, whereas it is increasing with increase in MOI and (iv) speed build up is found to be smooth with large value of MOI.

Keywords: Induction motor, moment - inertia, simulation, matlab simulink , motor control, transient performance.

I. INTRODUCTION

Three phase squirrel cage induction motor are commonly used in any industry due to its good self-starting capability, simple and rugged structure, low cost and reliability. The transient performance of this motor depends on sudden change in shaft load torque and variation of inertia due to gear arrangement application in motor driven system. As the nonlinear relationship of induction motor between its input and output variables are also complex and therefore the physical simulation of the induction motor is difficult. So, therefore, a detailed and accurate computer base mathematical model is essential to investigate the characteristics of its and predicting the transient behaviour of induction motor for any specific application.

The Simulink based dynamic induction motor models are available in many books [1] - [5] and research paper [6] – [8] but they describe the model 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 mathematical model of induction motor, which is frequently used in motor dynamic studies like motor control, drive specifications, electrical protection, starting high inertia loads, fast and large load changing, successive starting, locked rotor, etc is expressed by the six differential equations of three-phase instantaneous voltage and current. And the torque of an electric equation is related to the motion equations of motor and driven machine in the mathematical model. This model was developed many years ago and it is presented in many books and papers among them it could be mentioned [l] to [3]. It is very familiar to the researchers dealing with electrical machine dynamic studies. The parameters appearing in the equations is machine winding electrical resistances (R_s, R_r), the leakage and magnetizing reactance **(** X_{ls}, X_{lr}, X_m **)**, included in the linkage fluxes.

MATLAB/Simulink, which has been found to be a very useful tool for modelling of electrical machine and it is used to predict the dynamic behaviour of machines.

Transient performance of any electrical machine is greatly affected by sudden changes in its supply system, operating speed, shaft load including any variations in moment of inertia due to gear arrangement applications.

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 load torque and moment of inertia on motor performance characteristics. This paper also presents a MATLAB/Simulink based dynamic model of induction motor to analyse the transient performance of three different induction motor of different size

2.MATHEMATICAL MODELLING OF INDUCTION MOTOR

The qd0 reference frames are universally accepted on the basis of convenience or compatibility of other network components to determine transient analysis using either stator reference frame or rotor reference frame or synchronously rotating reference frame. In this paper rotor reference frame is used for the simulation study of IM in order to study the effect of disturbance in rotor side such as sudden change in shaft load, moment of inertia etc.

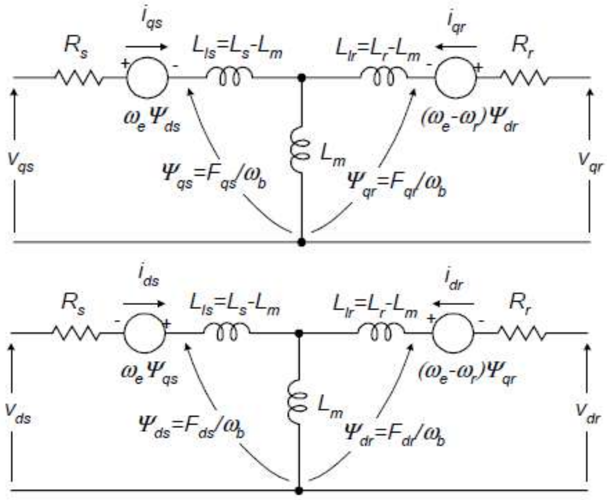


Fig. 1. Dynamic or d-q equivalent circuit of an IM

A. Mathematical Modelling of IM

Based on this model, the mathematical equations of flux linkage of three phase squirrel cage induction motor in stationary reference frame are as follows:

$$\dot{\psi}_{ds} = \omega_b \left[v_{ds} + \frac{\omega_c}{\omega_b}\psi_{qs} + \frac{R_s}{X_{ls}}\left(\psi_{md} - \psi_{ds}\right) \right] \qquad (1)$$

$$\dot{\psi}_{qs} = \omega_b \left[v_{qs} - \frac{\omega_c}{\omega_b}\psi_{ds} + \frac{R_s}{X_{ls}}\left(\psi_{mq} - \psi_{qs}\right) \right] \qquad (2)$$

$$\dot{\psi}_{dr} = \omega_b \left[v_{dr} + \left(\frac{\omega_c - \omega_r}{\omega_b}\right)\psi_{qr} + \frac{R_r}{X_{lr}}\left(\psi_{md} - \psi_{dr}\right) \right] \qquad (3)$$

$$\dot{\psi}_{qr} = \omega_b \left[v_{qr} - \left(\frac{\omega_c - \omega_r}{\omega_b}\right)\psi_{dr} + \frac{R_r}{X_{lr}}\left(\psi_{mq} - \psi_{qr}\right) \right] \qquad (4)$$

$$\psi_{md} = L_{ad}\left(\left(\frac{\psi_{ds}}{L_{ls}}\right) + \left(\frac{\psi_{dr}}{L_{lr}}\right)\right) \qquad (5)$$

$$\psi_{mq} = L_{aq}\left(\left(\frac{\psi_{qs}}{L_{ls}}\right) + \left(\frac{\psi_{qr}}{L_{lr}}\right)\right) \qquad (6)$$

$$\frac{1}{L_a} = \frac{1}{L_{ls}} + \frac{1}{L_{lr}} + \frac{1}{L_m} \qquad (7)$$

$$L_{ad}, L_{aq} = L_a \qquad (8)$$

The voltage and current equation of induction motor are

$$v_{ds} = v_{an} \text{ and } v_{qs} = \frac{1}{\sqrt{3}}\left(v_{bn} - v_{cn}\right) \qquad (9)$$

$$i_{ds} = \frac{\psi_{ds} - \psi_{md}}{X_{ls}} \text{ and } i_{qs} = \frac{\psi_{qs} - \psi_{mq}}{X_{ls}} \qquad (10)$$

$$i_{dr} = \frac{\psi_{dr} - \psi_{md}}{X_{lr}} \text{ and } i_{qr} = \frac{\psi_{qr} - \psi_{mq}}{X_{lr}} \qquad (11)$$

The voltage equation of IM in q-d axis in arbitrary reference frame is as follows

$$\begin{bmatrix} v_{qd0s} \\ v_{qd0r} \end{bmatrix} = [Z]\begin{bmatrix} i_{qd0s} \\ i_{qd0r} \end{bmatrix} \qquad (12)$$

Where $\qquad Z = R + Lp + G\omega \qquad (13)$

$$[Z] = \begin{bmatrix} R_s + pL_{ss} & \omega_c L_{ss} & 0 & pL_m & \omega_c L_m & 0 \\ -\omega_c L_{ss} & R_s + pL_{ss} & 0 & -\omega_c L_m & pL_m & 0 \\ 0 & 0 & R_s + pL_{ls} & 0 & 0 & 0 \\ pL_m & (\omega_c - \omega_r)L_m & 0 & R_r + pL_{rr} & (\omega_c - \omega_r)L_{rr} & 0 \\ -(\omega_c - \omega_r)L_m & pL_m & 0 & -(\omega_c - \omega_r)L_{rr} & R_r + pL_{rr} & 0 \\ 0 & 0 & 0 & 0 & 0 & R_r + pL_{lr} \end{bmatrix}$$

In order to study the effects of rotor side disturbances such as sudden change in shaft load, moment of inertia etc of machine, rotor reference frame as explained above may be adopted successfully. For rotor reference frame $\omega_c = \omega_r$, stationary reference frame $\omega_c = 0$ and synchronous rotating frame $\omega_c = \omega_s$.

The electromagnetic torque of IM is

$$T_{em} = \frac{3}{2}\frac{P}{2}L_m\left(i_{qs}i_{dr} - i_{ds}i_{qr}\right) \qquad (14)$$

The equation of rotor speed is obtained by equating the inertia torque to accelerating torque, that is

$$J\frac{d\omega_r}{dt} = T_{em} - T_l - T_{damp} \qquad (15)$$

Where $\qquad T_{damp} = B_m \omega_r \qquad (16)$

3. SIMULATION MODEL OF THREE PHASE IM

In this paper the transient performance of three different induction motor of different size is studied. The first one of these motor is smaller (M1), the second one is medium (M2) and last one is much bigger in size (M3). The proposed induction motor model is shown in Fig. 2.

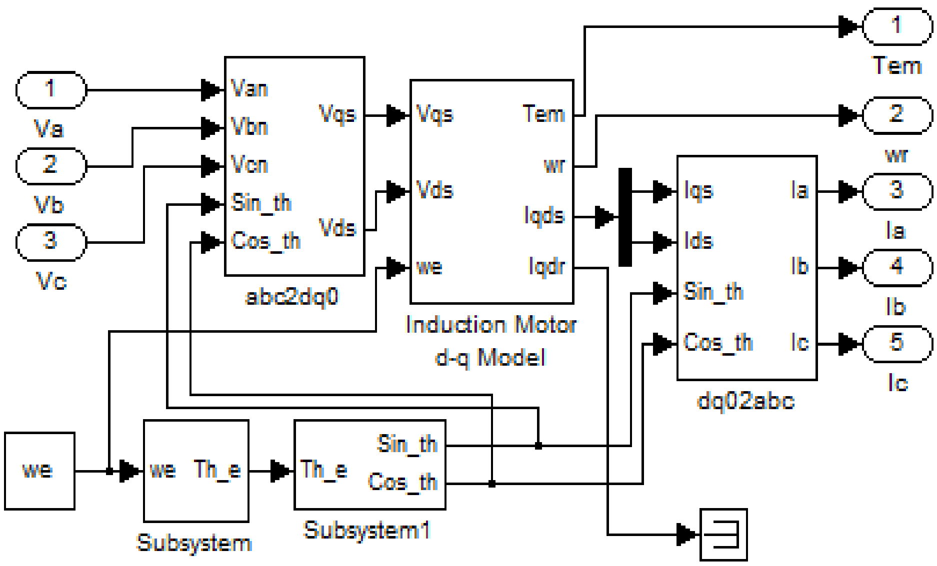


Fig. 2. matlab simulink model of proposed system

The flux linkage and stator current may be computed by solving the differential equation (1-11). Equation (14), (15) and (16) may be used to determine electromagnetic torque and rotor speed.

The simulation results are obtained for three different motor and compared to illustrate the effects of the machine outputs i.e. on electromagnetic torque and rotor speed. Mainly the effect of change in load torque and moment of inertia on the machine's performance is studied.

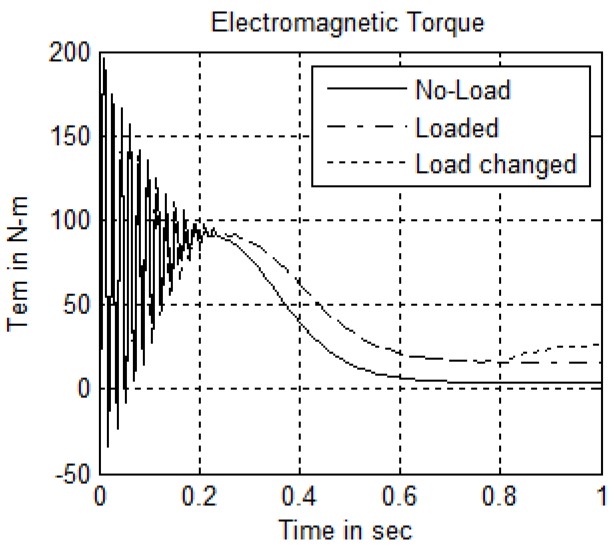
The parameter of these three machine are tabulated in appendix. Here, X_m has been assumed to be constant due to the fact that the machine is directly connected to the grid and thus output voltage of machine is equal to the grid.

4.RESULTS AND DISCUSSIONS

SIMULATION EXPERIMENT WITH THE MODELS ESTABLISHED ON MATLAB AND CURVE OF MOTOR ARE ANALYSED. IN SIMULATION 4TH ORDER RUNGA-KUTTA METHOD WAS USED FOR SOLUTIONS OF STATE EQUATION.

The motor inertia have play great role in transient behavior of the induction machine. The larger the size of machine i.e. the larger its moment of inertia (MOI) (J) result larger electromagnetic torque is required during the start-up period to speed it up. After reaching the synchronous speed (in the case of no-load machine) the larger machine's speed will overshoot, taking some time to stabilize at around the synchronous speed. This implies the possibility of instability in big machines if connected directly to the grid. Furthermore, the very large inrush currents at start-up of large machines can damage the wiring of the machine.

The simulation of effect of change in load torque in electromagnetic torque and p.u. rotor speed of induction motor is done in three different conditions: no-load, with load and sudden change in load after first starting transition. The load changed in M1, M2 and M3 in 0.8 sec, 2.5 sec and 4 sec respectively. In this simulation load is changed to 2, 5 and 10 times of rated load for three different machines respectively.



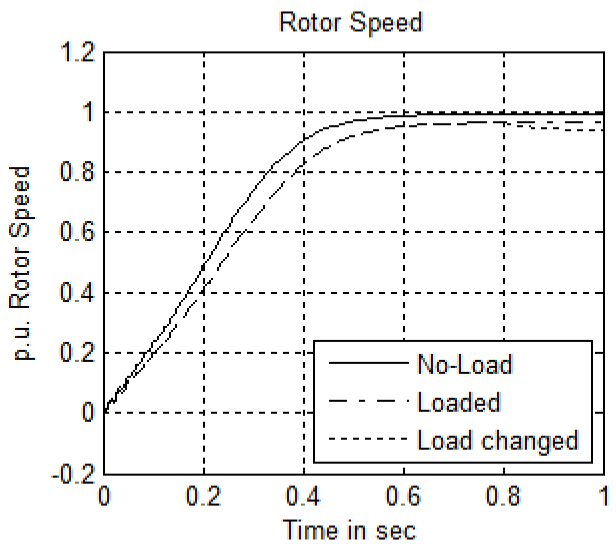


Fig. 3. Electromagnetic torque and p.u. Rotor speed for M1.

Fig. 3, Fig. 4 and Fig. 5 correspond to the case of machine M1, M2 and M3 respectively. Fig. 3 clearly shows that the developed electromagnetic torque goes to almost zero after the initial transition and the rotor speed very close to the synchronous speed when operating at no-load. Now, for higher rating machine same curves will be gated with oscillatory behavior which is less acceptable than that of the smaller one. In fact, the best curves for comparison are those for the no-load machine from standstill to synchronous speed. Again comparison between Fig.3, Fig 4 and Fig.5 clearly proves that the smaller machine has almost no overshoot and oscillation while the larger has a considerable overshoot as well as oscillation and also the transient period is almost 2-3 times longer than that of the smaller machine.

When the machines are operated at load the electromagnetic torque is increased and rotor speed is decreased. It is also seen that for larger machine, the electromagnetic torque is much more affected due to the change of load torque but the rotor speed is more sensitive to the change of load torque for the smaller machines than the larger one.

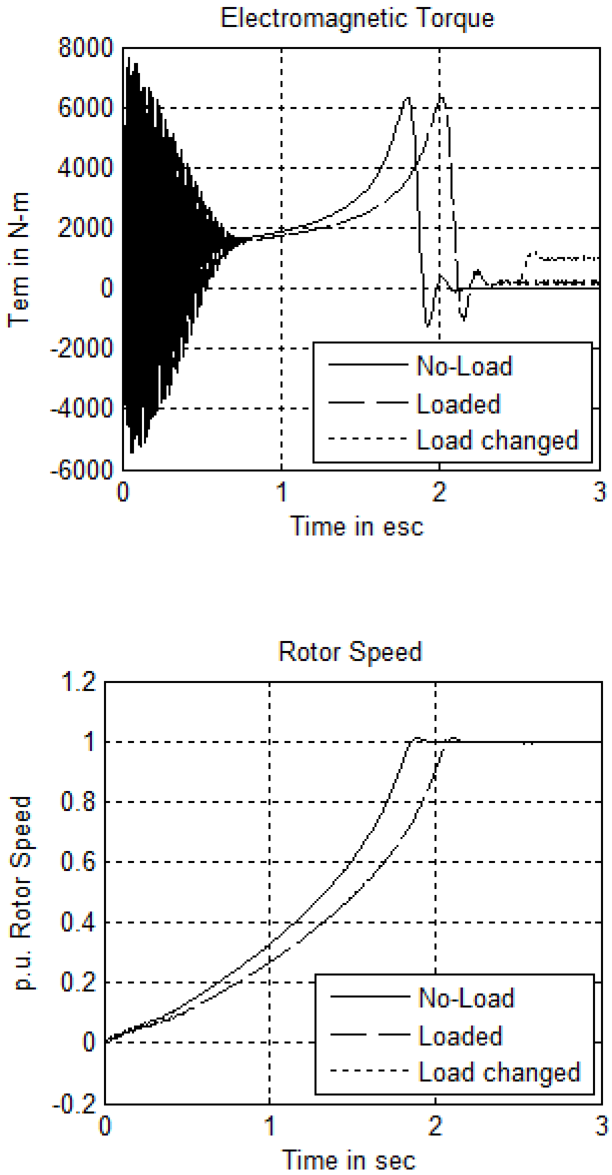


Fig. 4. Electromagnetic torque and p.u. Rotor speed for M2.

Table I

DIFFERENT VALUE OF MOTOR INERTIA

	M1	M2	M3
Rated MOI (kg-m^2)	0.089	11.06	63.87
Lower MOI (kg-m^2)	0.069	5.06	50.87
Higher MOI (kg-m^2)	0.109	13.06	76.87

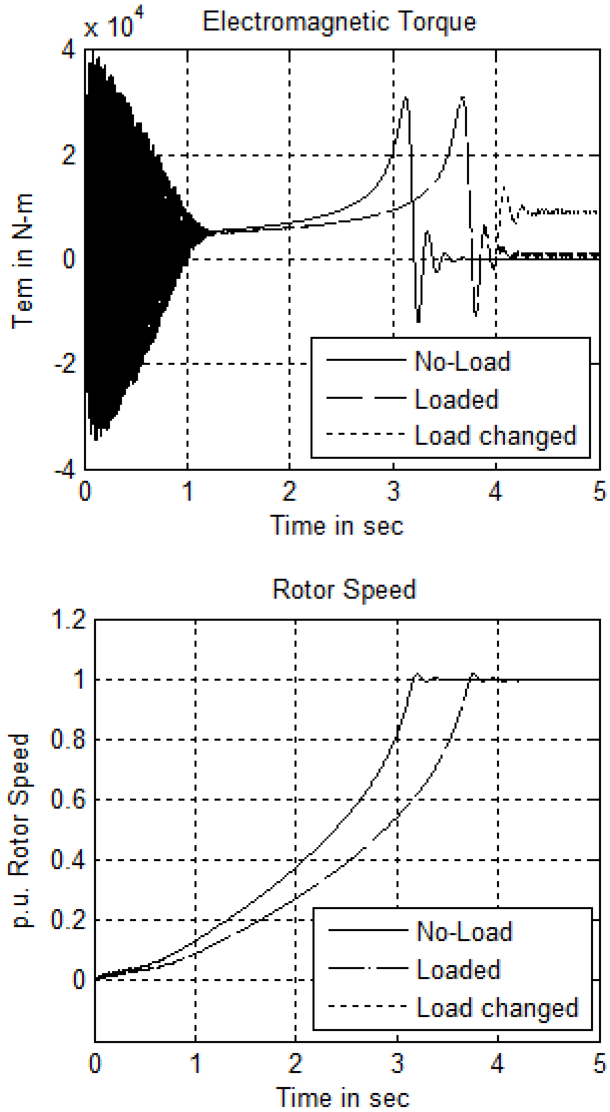


Fig. 5. Electromagnetic torque and p.u. Rotor speed for M3

The general conclusion based on the comparison between three machines of different size can be summarized as follows:

i. The smaller machine has smaller inertia and shows shorter transient period and less overshoot during start-up or following any changes in the inputs. Generally speaking, it has better transient behavior compared to the larger machine.

ii. The larger machine is more stable after reaching the steady-state, since sudden changes in input torque cannot accelerate or decelerate the machine as easily as in the case of the 3-hp machine

Effect of Change in Motor Inertia: The simulation study of effect of change in motor inertia on electromagnetic torque and rotor speed of induction motor is performed for same three different motor i.e M1, M2 and M3. The comparison of simulated results has been carried out for three different value of MOI which are tabulated in Table I.

Fig. 6, Fig. 7 and Fig. 8 correspond to the case of machine M1, M2 and M3 respectively.

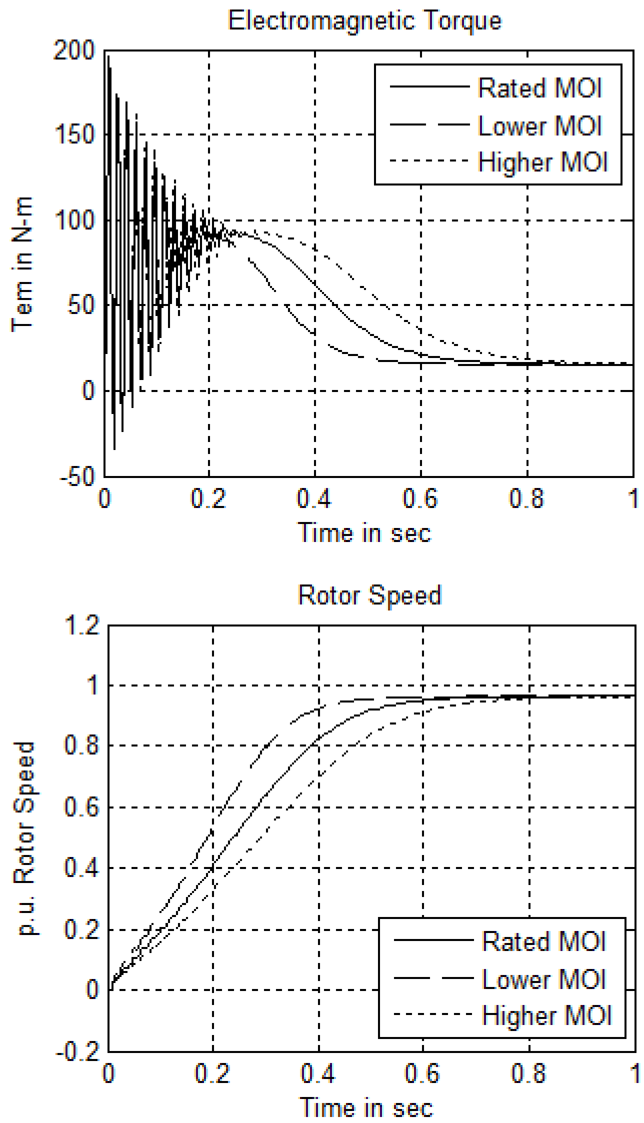
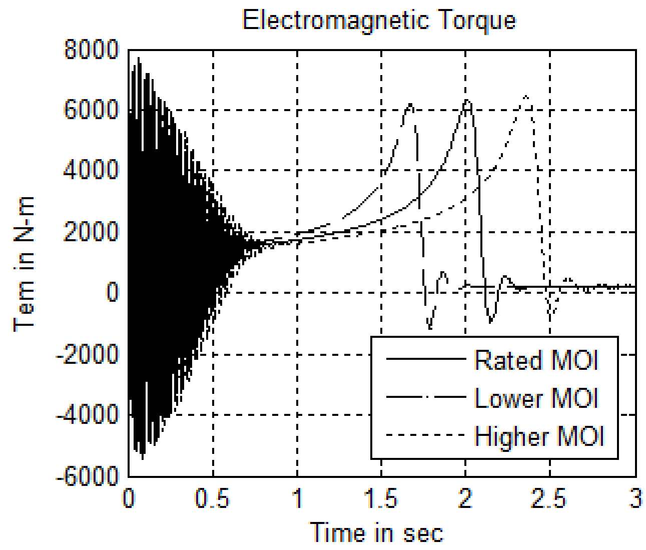


Fig. 6. Electromagnetic torque and p.u. Rotor speed for M1.



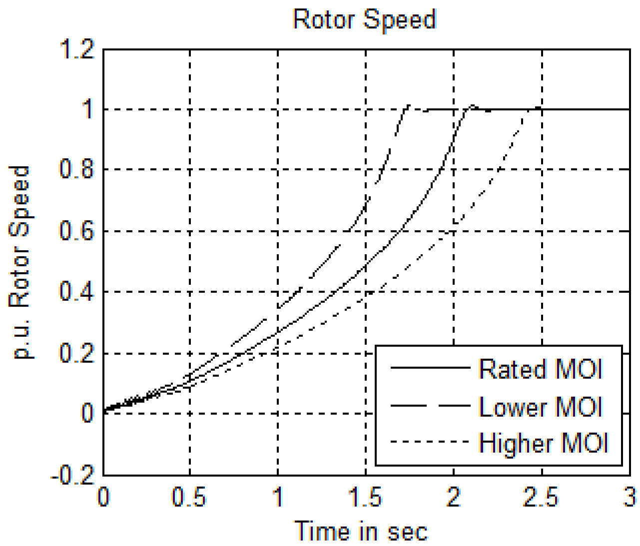


Fig. 7. Electromagnetic torque and p.u. Rotor speed for M2.

Fig. 6-8 clearly shows that the change in motor inertia does not change the shape of electromagnetic torque and rotor speed curve i.e. no overshoot or oscillation or fluctuation occur but the settling time of these curve is changed.

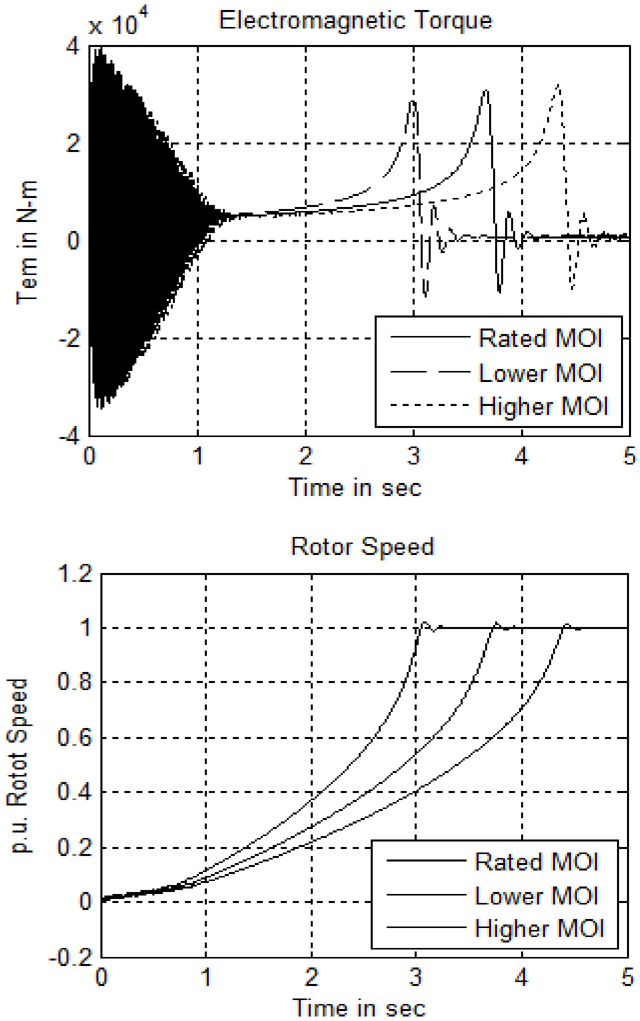


Fig. 8. Electromagnetic torque and p.u. Rotor speed for M3.

As observed from Fig. 5, Fig. 7 and Fig. 8 and Table III, effect of MOI transient behavior of induction motor can be summarized as follows:

i. MOI greatly affects the inrush current drawn by the induction motor.
ii. Moment of inertia has significant effects during starting in contrast of steady state operations.
iii. Low values of MOI results into a low settling time, whereas it is increasing with increase in MOI.
iv. Speed build up is found to be smooth with large value of MOI.

5.CONCLUSIONS

In this paper an attempt has been made to study the effect of change of shaft load torque and moment of inertia on transient performance of an induction motor. The main drawback of the proposed model is that the saturation of flux in core is not conceded in starting when large amount of current is flowing in stator.

In conclusion, the effect of change in load torque and MOI on motor performance characteristics resulted as observed from fig. 5, fig. 7 and fig. 8 and table III, which show that: (i) MOI greatly affects the inrush current drawn by the induction motor, (ii) moment of inertia has significant effects during starting in contrast of steady state operations, (iii) low values of MOI results into a low settling time, whereas it is increasing with increase in MOI and (iv) speed build up is found to be smooth with large value of MOI.

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APPENDIX

The parameter of 3 phase, 4 pole, 60 Hz star connected induction more are as follows

Motor Parameter	M1	M2	M3
Rated Power (HP)	3	500	2250
Rated Voltage (V)	220	2300	2300
Stator Resistance (Ω)	0.435	0.262	0.029
Rotor Resistance (Ω)	0.816	0.187	0.022
Stator Leakage Inductance (Ω)	0.754	1.206	0.226
Rotor Leakage Inductance (Ω)	0.754	1.206	0.226
Mutual Inductance (Ω)	26.13	54.02	13.04
Load Torque (N-m)	11.9	198	900
Motor Inertia (kg-m^2)	0.089	11.06	3.87

NOMENCLATURE

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.
v_{qd0s}, v_{qd0r}	Stator and rotor q, d and 0 axis voltage in rotor reference frame.
i_{qd0s}, i_{qd0r}	Stator and rotor q, d and 0 axis voltage in rotor reference frame.
$\psi_{ds}, \psi_{qs}, \psi_{dr}, \psi_{qr}$	d-axis and q-axis Stator and Rotor flux linkage
ψ_{md}, ψ_{mq}	d-axis and q-axis magnetizing flux linkage
R_s, R_r	Stator and rotor resistance.
L_s, L_r	Stator and rotor self inductance.
L_m	Mutual inductance between stator and rotor.
T_{em}, T_l, T_{damp}	Electromagnetic, load and damping torque.
p	Operator for differentiation.
ω_c	Stator electrical angular velocity
ω_r	Rotor electrical angular velocity
ω_b, ω_s	Motor electrical angular velocity (base and synchronous)
J	Moment of Inertia
B_m	Frictional co-efficient

q	Quadrature Axis	s	Stator Quantities
d	Direct Axis	r	Rotor Quantitie