Induction Machine Modeling and its Study of Variation in Torque for Variable Parameters During free Acceleration Period

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Abstract- Induction machine(IM) is one of the most common form of electromechanical drive used in industrial, commercial and domestic applications & operate at essentially constant speed.IM have more advantages than DC motors. There are two types of instantaneous electromagnetic torque-controlled AC drives used for high performance applications such as vector control and direct torque control (DTC). DTC is a relatively novel IM control method, conventional DTC technique has some drawbacks such as large torque ripple due to the change of motor parameters. DTC method is sensitive to temperature variations, which lead to stator resistance changes. The flux estimated from the stator circuit variables, is highly dependent on the stator resistance of the Induction Motor. As In this paper the change in stator resistance which is due to change in with respective time and then the change in performance of motor torque has been studied during free acceleration characteristic of various reference frames. The simulation has been carried out using MATLAB/SIMULINK package**.**

I.INTRODUCTION

In recent years, many techniques have been developed to find out different solutions for the induction motor control having the features of precise and quick torque response and reduction of complexity of field oriented algorithms [1]. Recently, sensorless vector controls of induction motor drives are receiving wide attention in the literature. The estimation of stator flux, speed and frequency for flux oriented vector control methods, becomes inaccurate due to stator resistance variation [2].The inaccurate flux vector computation gives error not only in the flux magnitude, but in the phase angle also, which affects response of the drive. The direct torque control method of the induction motor drive is similarly affected by the error in stator flux estimation [3]. The stator – winding resistance primarily varies with winding temperature, which is given by the following equation:

$$R_t = R_{to} + \alpha R_{to} (T_t - 25°C) \qquad (1)$$

If a temperature- sensing thermistor is inserted in a distributed manner in the stator winding, the stator winding temperature can be monitored and correspondingly, stator resistance can be estimated accurately by using (1). The stator winding temperature with reasonable accuracy can be predicted by using adaptive systems. Basically, the losses in the machine contribute to stator winding temperature rise, and those losses classified as stator copper loss, rotor copper loss, stator iron loss, rotor iron loss and some amount of stray loss. The stator copper and iron losses will contribute to stator winding temperature rise. In this paper, the value of stator resistance changes based on estimation of stator winding temperature has been studied.

II. Mathematical model of induction motor

An induction motor is modeled using voltage and flux equations which are referred to synchronous reference frame, denoted by the superscript ‘e ‘and equivalent circuit diagram is shown in fig 1[4].

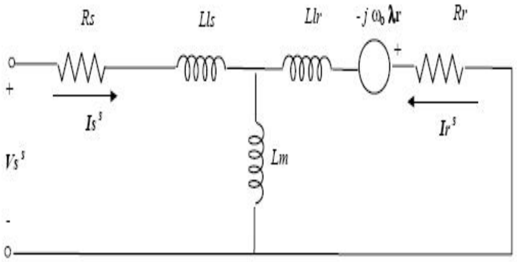


Fig.1. Dynamic Equivalent Circuit on a Synchronous Reference Frame

The various equations are [5]

Stator voltage equation

$V_s^e = R_s i_s^e + j\omega_e \lambda_s^e + p\ \lambda_s^e$ (2)

Rotor voltage equation

$0 = R_r\, i_r^e + j(\omega_e - \omega_r)\ \lambda_r^e + p\ \lambda_r^e$ (3)

Stator flux equation

$\lambda_r^e = L_r\ \ i_r^e + L_m\ I_s^e$

(4)

Mechanical equation

$T_e - T_l = J_m\ P\ \omega_r + B_m \omega_r$ (5)

$T_e = 3P/2\ (\ \lambda_{sd}^e i_{sq}^e - \lambda_{sq}^e i_{sd}^e)$ (6)

By referring to a stationary reference frame, denoted by the superscript “s” , with d-axis attached on the stator winding of phase “A”, the mathematical equation of induction motor can be rewritten as follows.

Stator voltage equation

$V_s^s = R_s\ i_s^s + P\lambda_s^s$ (7)

Rotor voltage equation

$0 = R_r\ i_r^s - j\omega_r \lambda_r^s + P\lambda_r^s$ (8)

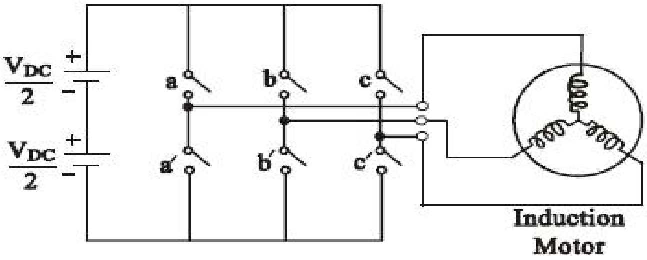
Stator flux equation

$\lambda_r^s = L_r\ i_r^s + L_m\ i_s^s$ (9)

Mechanical equation

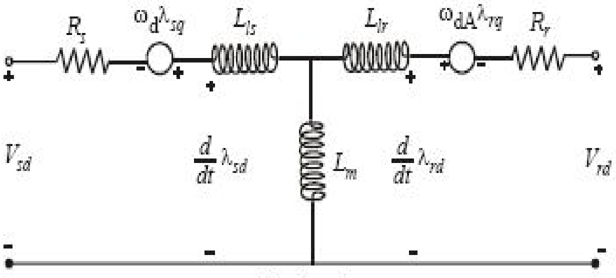
III.INDUCTION MOTOR MODELING

In the control of any power electronics drive system (say a motor), to start with a mathematical model of the plant is required. This mathematical model is required further to design the type of controller to control the process of the plant. Induction motor model is established using a rotating (*d*,*q*) field reference (without saturation) concept. The power circuit of the 3-ϕ induction motor is shown in the Fig.2 [6]. The equivalent circuit used for obtaining the mathematical model of the induction motor is shown in the Fig. 3[7] –[8]

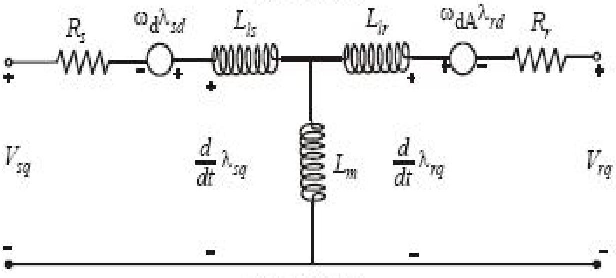


(3.11)

Fig.2.Power circuit connection diagram for the IM



(a) *d*-axis



(b) *q*-axis

Fig.3. Equivalent circuit of induction motor in
(a) *d – axis* frame and (b) *q – axis* frame

An induction motor model is then used to predict the voltage required to drive the flux and torque to the demanded values within a fixed time period. This calculated voltage is then synthesized using the space vector modulation. The stator & rotor voltage equations are given by [7] – [8]

$$V_{sd} = R_s i_{sd} + \frac{d}{dt}\lambda_{sd} - \omega_d \lambda_{sq} \tag{13}$$

$$V_{sq} = R_s i_{sq} + \frac{d}{dt}\lambda_{sq} - \omega_d \lambda_{sd} \tag{14}$$

$$V_{rd} = R_r i_{rd} + \frac{d}{dt}\lambda_{rd} - \omega_{dA} \lambda_{rq} \tag{15}$$

$$V_{rq} = R_r i_{rq} + \frac{d}{dt}\lambda_{rq} - \omega_{dA} \lambda_{rd} \tag{16}$$

Where V_{sd} and V_{sq}, V_{rd} and V_{rq} are the direct axes & quadrature axes stator and rotor voltages. The squirrel-cage induction motor considered for the simulation study, has the *d* and *q*-axis components of the rotor voltage zero. The flux linkages to the currents are related by the Eq.(17) as the electrical part of an induction motor can thus be described by a fourth-order state space model (4×4), which is given in Eq.(18),by combining equations (13) - (17) [8]

$$\begin{bmatrix}\lambda_{sd}\\ \lambda_{sq}\\ \lambda_{rd}\\ \lambda_{rq}\end{bmatrix} = M \begin{bmatrix} i_{sd}\\ i_{sq}\\ i_{rd}\\ i_{rq}\end{bmatrix};\ M = \begin{bmatrix} L_s & 0 & L_m & 0\\ 0 & L_s & 0 & L_m\\ L_m & 0 & L_r & 0\\ 0 & L_m & 0 & L_r\end{bmatrix}. \tag{17}$$

$$\begin{bmatrix} i_{sd}\\ i_{sq}\\ i_{rd}\\ i_{rq}\end{bmatrix} = \frac{1}{L_m^2 - L_r L_s} \times \left(A \begin{bmatrix} i_{sd}\\ i_{sq}\\ i_{rd}\\ i_{rq}\end{bmatrix} + \begin{bmatrix} L_s & 0 & L_m & 0\\ 0 & L_r & 0 & L_m\\ L_m & 0 & L_r & 0\\ 0 & L_m & 0 & L_r\end{bmatrix} \begin{bmatrix} V_{sd}\\ V_{sq}\\ V_{rd}\\ V_{rq}\end{bmatrix} \right), \tag{18}$$

where, *A* is given by

$$A = \begin{bmatrix} L_r R_s & \omega_{dA} L_m^2 - \omega_s L_r L_s & -L_m R_r & -L_r L_m(\omega_s - \omega_{dA})\\ -(\omega_{dA} L_m^2 - \omega_s L_r L_s) & L_r R_s & L_r L_m(\omega_s - \omega_{dA}) & -L_m R_r\\ -L_m R_s & L_s L_m(\omega_s - \omega_{dA}) & L_s R_r & \omega_s L_m^2 - \omega_{dA} L_r L_s\\ -L_s L_m(\omega_s - \omega_{dA}) & -L_m R_s & -(\omega_s L_m^2 - \omega_{dA} L_r L_s) & L_s R_r \end{bmatrix} \tag{19}$$

By superposition, the torques acting on the *d*-axis and the *q*-axis of the rotor windings, the instantaneous torque produced in the electromechanical interaction is given by[9]

$$T_{em} = \frac{P}{2}\left(\lambda_{rq} i_{rd} - \lambda_{rd} i_{rq}\right) \tag{20}$$

The electromagnetic torque expressed in terms of inductances is given by

$$T_{em} = \frac{P}{2} L_m \left(i_{sq} i_{rd} - i_{sd} i_{rq}\right) \tag{21}$$

The mechanical part of the motor is modeled by the equation

$$\frac{d}{dt}\omega_{Mech} = \frac{T_{em} - T_L}{J_{eq}} = \frac{\frac{P}{2} L_m \left(i_{sq} i_{rd} - i_{sd} i_{rq}\right) - T_L}{J_{eq}} \tag{22}$$

where,

J_{eq} = Equivalent MI; $L_s = L_{sl} + L_m$, $L_r = L_{rl} + L_m$

$\omega_{dA} = \omega slip = \omega_s - \omega_m$, $\omega_m = P\omega_{mech}/2$, $\omega_d = \omega_s$

IV SIMULIMK MODEL OF INDUCTION MOTOR

Detailed modeling of induction motor drive system is required for proper simulation of the system. Induction motor model and Torque sub model is as shown in figure 4.The d-q model has been developed on different rotating reference frame.

Various sub – systems are embedded to develop the Simulink model.

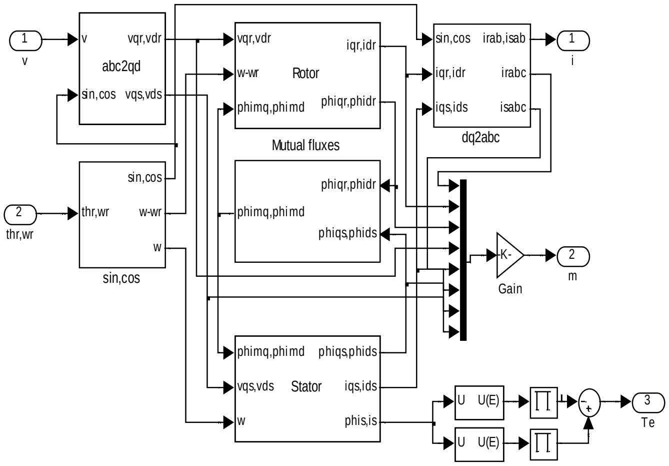


Fig.4. Simulink model of induction motor

ABC – DQ Converter

The Simulink model of abc – dq converter is as shown above in fig.5. The value of voltages and the theta is fed and using the Park's Transformation and the direct axis voltage v_d and quadrature axis voltage v_q are obtained.

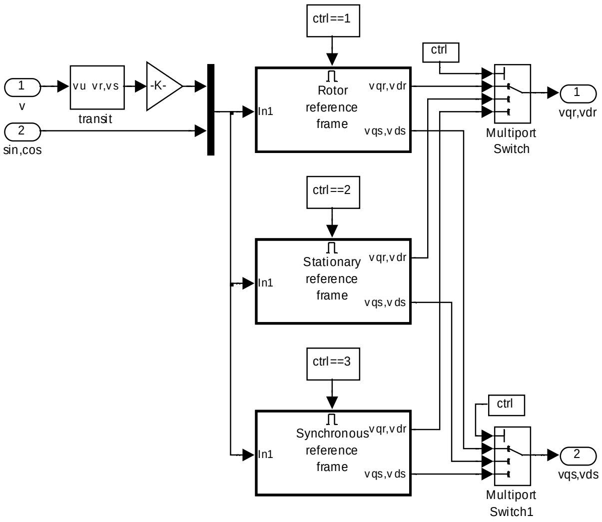


Fig. 5. Simulink Model of abc –dq Converter

V.SIMULATION MODEL OF THE SYSTEM

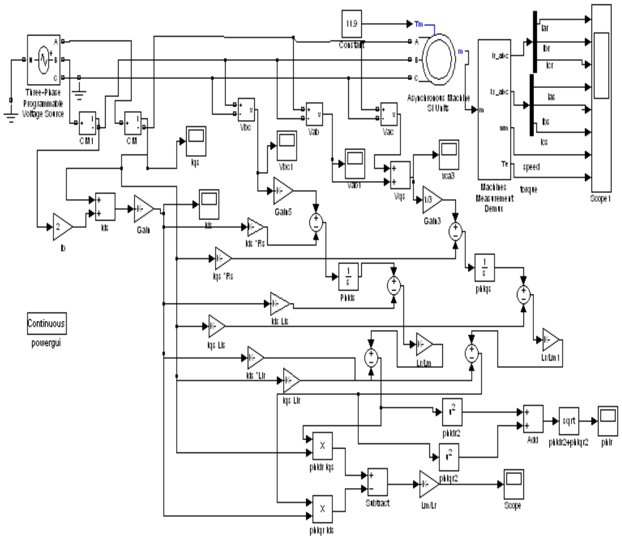


Fig.6 The SIMULINK model of three-phase induction motor

VI.RESULTS

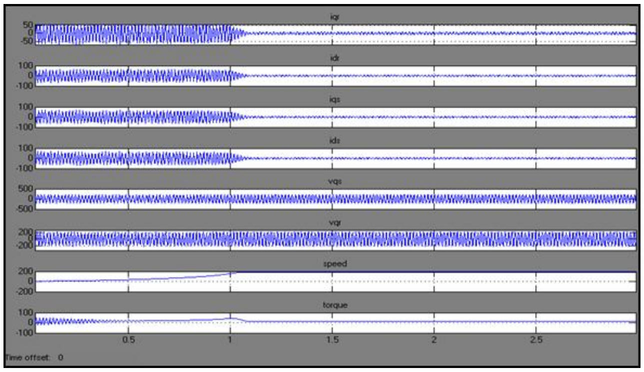


Fig 7. Free acceleration characteristic of a 10-hp induction motor in the stationary reference frame

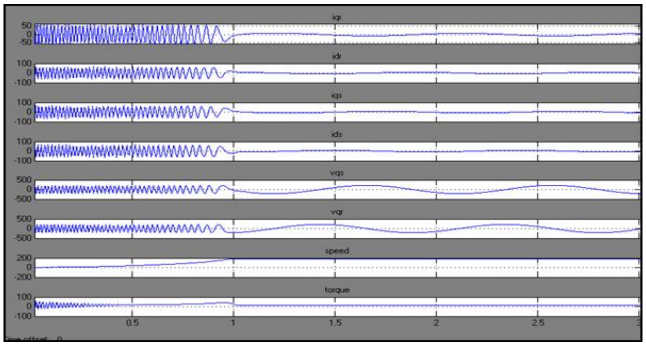


Fig 8. Free acceleration characteristic of a 10-hp induction motor in a reference frame fixed in a rotor

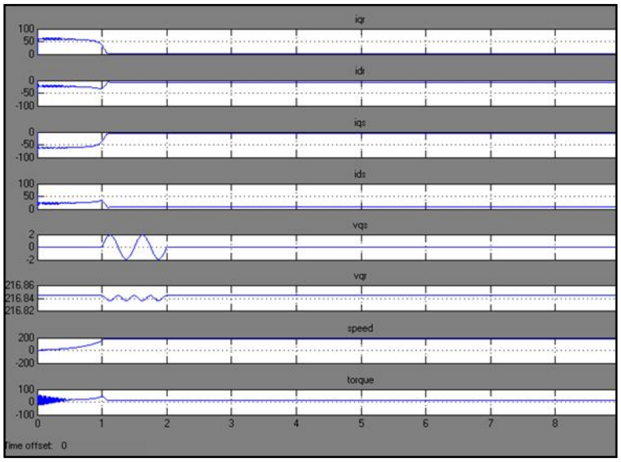


Fig 9. Free acceleration of a 10-hpinduction machines in a synchronously rotating reference frame

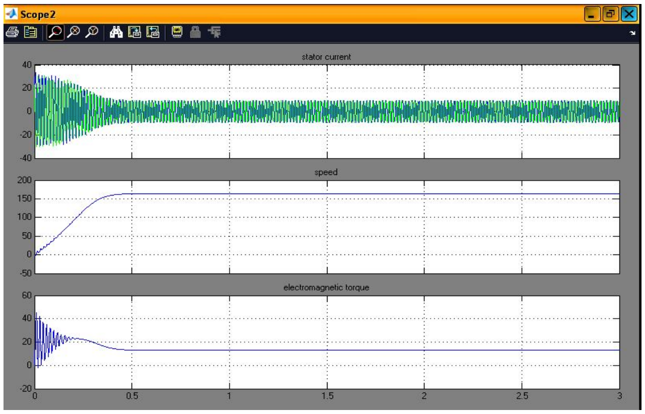


Fig 10 Stator current, Rotor speed and Electromagnetic torque for Stator Resistance (Rss) =0.6837

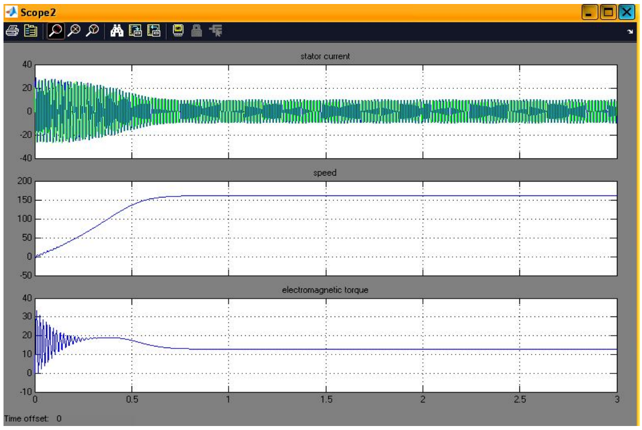


Fig 11 Stator current, Rotor speed and Electromagnetic torque for Stator Resistance (Rss) =1.0255

The free acceleration characteristics are shown in different reference frames in fig 7 through fig 9. The stationary reference frame variables during free acceleration are shown in fig 7. With the reference frame fixed in the stator the *qs* and *ds* variables are arithmetically related to the *abc* variables. The free acceleration characteristics with the reference frame fixed in the rotor is given in fig 8. it is noted that there is no much variations of time in settling the parameters, the torque oscillations are more in the initial state and get settled. Free acceleration with the reference frame rotating in synchronism with the electrical angular velocity of the applied voltage is shown in fig 9. Here It is noted that the zero position of the reference frame is selected; the torque oscillations are very large at the initial state and then get settled at the earliest.

The variation in torque oscillation due to stator resistance variation has been studied in fig 10 & fig 11 for different values of stator resistance. It is noted that the variation of stator resistance effects very large in the torque settling time. Figure 10 shows that torque and speed will come t required values between 0.2 to 0.3s, whereas from fig 11 it is clear that the settling time has increased to 0.55 to 0. 6s when stator resistance gets changed.

VII .CONCLUSION

The direct torque of an induction motor drive by means of the change in stator resistance which is due to change in with respective temperature and then the change in performance of motor torque concept has been reported in this paper. Since the stator resistance variation is primarily a function of the stator winding temperature. The study has been made for free acceleration characteristic of various reference frame. Simulation result of various value of stator resistance and various reference frames were carried out using Matlab / Simulink software package.

Future work

The stator resistance estimation in DTC can be made by adaptive control method with neural network, fuzzy logic and rough set theory.

APPENDIX

PARAMETERS OF INDUCTION MOTOR

The standard values of induction motor parameters have been taken from standard values from Matlab/ Simulink software package, a 3 phase, 4 poles,460V, 60Hz frequency, stator resistance of 0.6837, rotor resistance of 0.45.

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