

Dynamic Performance of Three-Phase Induction Motor

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Abstract –A dynamic model of an induction motor considers the instantaneous effects of varying voltage/currents, stator frequency, and torque disturbances. The dynamic model is derived, using a three phase motor in direct and quadrature axes. Theory of reference frames has been used to analyze the performance of induction machines. Reference frames gives a unique view of the system as well as simplification of system equation. In this paper relevant equations are stated, and then a generalized model of a three phase induction motor is developed and implemented in Simulink. The simulated results provide the steady-state behavior of the induction machine.

Keywords— Dynamic performance, transformation, abc-dq0 model, two-three phase transformation, Simulink implementation.

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 differential equations and it may involve some complexity. A change of variables can be used to reduce the complexity of these equations by eliminating all time-varying inductances. By this approach, a poly phase winding can be reduced to a set of two phase windings (q-d) with their magnetic axes formed in quadrature. In other words, the stator and rotor variables (voltages, currents and flux linkages) of an induction machine are transferred to a reference frame, which may rotate at any angular velocity or remain stationary. Such a frame of reference is commonly known in the generalized machines analysis as arbitrary reference frame [1, 2]

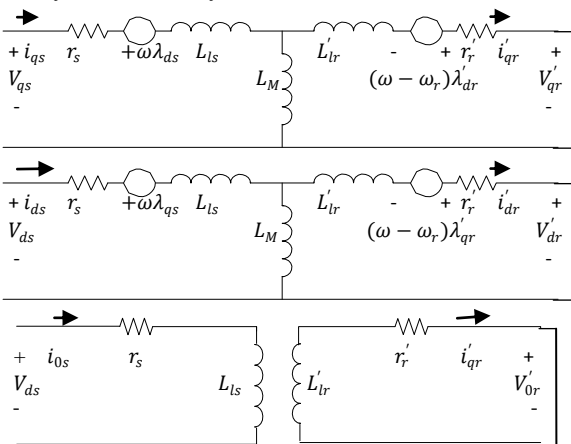


Fig.1 The dq0 equivalent circuit of an induction motor

The dynamic analysis of the symmetrical induction machines in the arbitrary reference frame has been intensively used as a standard simulation approach from which any particular mode of operation may then be developed. Simulink has an

advantage over other machine simulators in modeling the induction machine using dq0 axis transformation .It can be a powerful technique in implementing the machine equations as they are transferred to a particular reference frame. Thus, every single equation among the model equations can be easily implemented in one block so that all the machine variables can be made available for control and verification purposes. In this paper, Simulink is used to simulate the dynamic performance of an induction motor model whose stator and rotor variables are referred to an arbitrary reference frame. The implementation process is given for all the stated equation. The equivalent circuit of the induction machine in the arbitrary reference frame is shown in Fig. 1 above.

II. INDUCTION MOTOR MODEL

Driving the model equations can be generated from the dq0 equivalent circuit of the induction machine shown in Fig.1. The flux linkages equations associated with this circuit can be found as follows [3]:

$$\frac{d\Psi_{qs}}{dt} = \omega_b \left[V_{qs} - \frac{\omega_e}{\omega_b} \Psi_{ds} + \frac{R_s}{X_{ls}} (\Psi_{mq} - \Psi_{qs}) \right] \dots\dots\dots (1)$$

$$\frac{d\Psi_{ds}}{dt} = \omega_b \left[V_{ds} - \frac{\omega_e}{\omega_b} \Psi_{qs} + \frac{R_s}{X_{ls}} (\Psi_{md} - \Psi_{ds}) \right] \dots\dots\dots (2)$$

$$\frac{d\Psi_{qr}}{dt} = \omega_b \left[V_{qr} - \frac{(\omega_e - \omega_r)}{\omega_b} \Psi_{dr} + \frac{R_r}{X_{lr}} (\Psi_{mq} - \Psi_{qr}) \right] \dots\dots\dots (3)$$

$$\frac{d\Psi_{dr}}{dt} = \omega_b \left[V_{dr} - \frac{(\omega_e - \omega_r)}{\omega_b} \Psi_{qr} + \frac{R_r}{X_{lr}} (\Psi_{md} - \Psi_{dr}) \right] \dots\dots\dots (4)$$

Where

$$\Psi_{mq} = X_{ml} \left[\frac{\Psi_{qs}}{X_{ls}} + \frac{\Psi_{qr}}{X_{lr}} \right] \dots\dots\dots (5)$$

$$\Psi_{md} = X_{ml} \left[\frac{\Psi_{ds}}{X_{ls}} + \frac{\Psi_{dr}}{X_{lr}} \right] \dots\dots\dots (6)$$

$$X_{ml} = \left(\frac{1}{\frac{1}{X_{ml}} + \frac{1}{X_{ls}} + \frac{1}{X_{lr}}} \right) \dots\dots\dots (7)$$

Then substituting the values of the flux linkages to find the current are given below;

$$i_{qs} = \frac{1}{X_{ls}} (\Psi_{qs} - \Psi_{mq}) \dots\dots\dots (8)$$

$$i_{ds} = \frac{1}{X_{ls}} (\Psi_{ds} - \Psi_{md}) \dots\dots\dots (9)$$

$$i_{qr} = \frac{1}{X_{lr}} (\Psi_{qr} - \Psi_{mq}) \dots\dots\dots (10)$$

$$i_{dr} = \frac{1}{X_{lr}} (\Psi_{dr} - \Psi_{md}) \dots\dots\dots (11)$$

Based on the above equations, the torque and the rotor speed can be determined as follows:

$$T_e = \frac{3}{2} \left(\frac{P}{2}\right) \frac{1}{\omega_b} (\Psi_{ds} i_{qs} - \Psi_{qs} i_{ds}) \dots (12)$$

$$\omega_r = \int \frac{P}{2J} (T_e - T_L) \dots \dots \dots (13)$$

Where P: number of poles; J: moment of inertia (Kg/m²). For squirrel cage induction motor, the rotor voltages V_{qr} and V_{dr} in the flux in the flux equations are set to zero since the rotor cage bars are shorted. After driving the torque and speed equations in term of d-q flux linkages and currents of the stator, the d-q axis transformation should now be applied to the machine input (stator) voltage.

The three-phase stator voltages of an induction machine under balanced conditions can be expressed as:

$$V_a = \sqrt{2} V_{rms} \sin(\omega t) \dots \dots \dots (14)$$

$$V_b = \sqrt{2} V_{rms} \sin\left(\omega t - \frac{2\pi}{3}\right) \dots \dots (15)$$

$$V_c = \sqrt{2} V_{rms} \sin\left(\omega t + \frac{2\pi}{3}\right) \dots \dots (16)$$

These three-phase voltages are transferred to a synchronously rotating reference frame in only two phases (d-q axis transformation). This can be done using the following two equations.

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & \frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \dots \dots (17)$$

Then, the direct and quadrature axes voltages are

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} \dots (18)$$

The instantaneous values of the stator and rotor currents in three-phase system are ultimately calculated using the following transformation:

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} \dots (19)$$

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \dots \dots \dots (20)$$

III SIMULINK IMPLEMENTATION

In this section, the three phase induction machine model is simulated by using the Simulink. The Model is implemented using the same set of equations provided above in sections II.

Fig. 2 depicts the complete Simulink scheme of the described induction machine model [4, 5 and 6].

In this model the simulation starts with generating a three-phase stator voltages according to the equations (14-18) and then transforming these balanced voltages to two phase voltages referred to the synchronously rotating frame using Clarke and Park transformation as in equations .

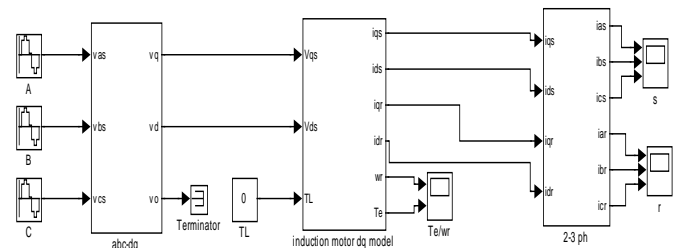


Fig.2 The 3-phase induction motor Simulink model

Fig. 3 illustrates the internal structure of the three-phase to two phase transformation, which represents the equations (14 to 18).

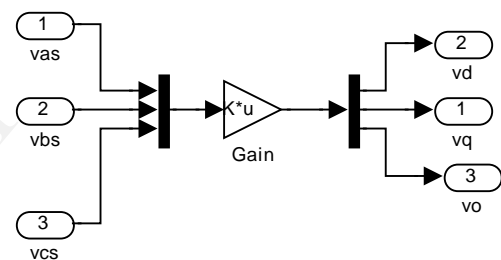


Fig. 3 internal structure of abc to dq model

Fig. 4 illustrates the internal structure of the induction machine d-q model by which the flux linkages, currents, torque and the rotor angular speed are calculated.

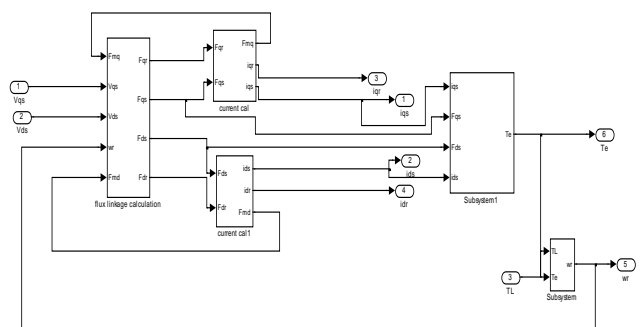


Fig. 4 The internal structure of the 3 phase induction motor d-q model

The Simulink model to find the flux linkages stated in equations (1) to (4) is shown in Fig. 5.

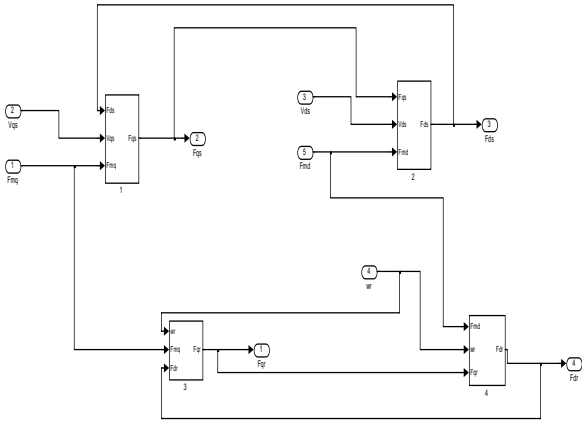


Fig. 5 The internal structure of the block to calculate the flux linkages

Fig. 6 show the Simulink blocks used to calculate the currents according to the equations (8) – (11) and also flux linkages in equations (5),(6). Fig. 7 & 8 show the implementation of torque T_e and angular speed as expressed in equations (12), (13) respectively.

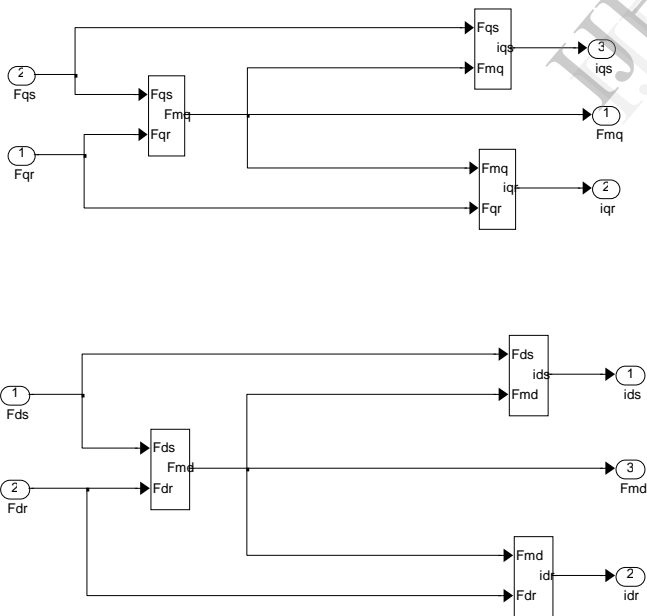


Fig. 6 The internal structure of the block to calculate the currents and fluxes

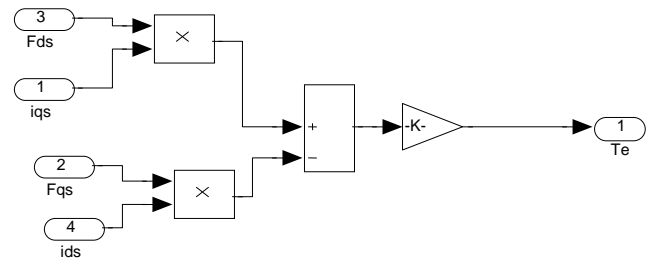


Fig. 7 the implementation of the torque equation T_e (12)

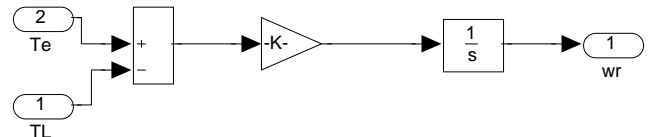
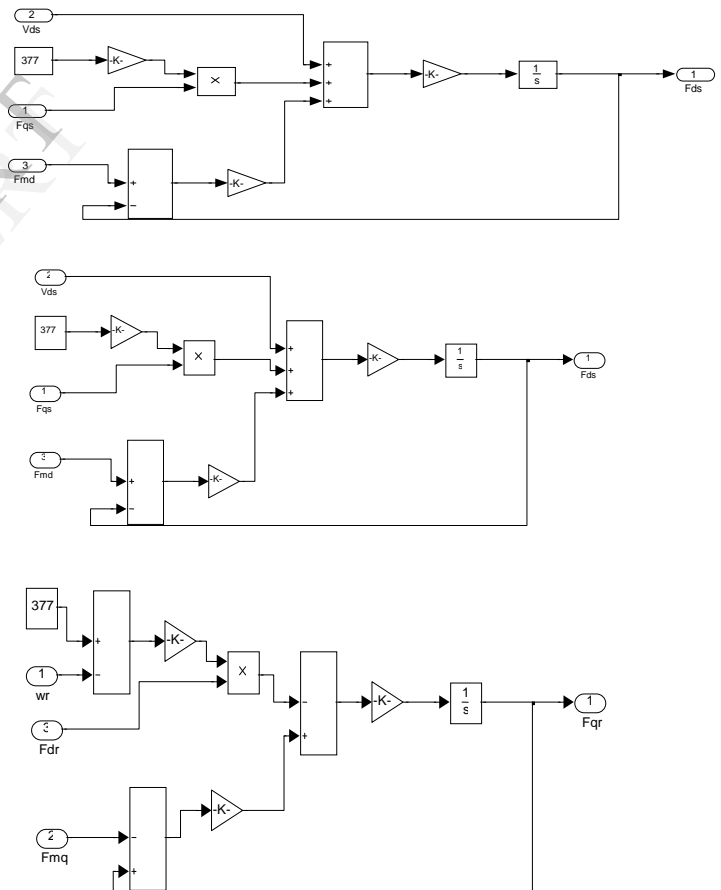


Fig. 8 the implementation of the angular speed equation (13)

Fig.9 shows the internal structure of the blocks (1- 4) in Fig. 4 in which the equations (1)-(4) are implemented in Simulink format.



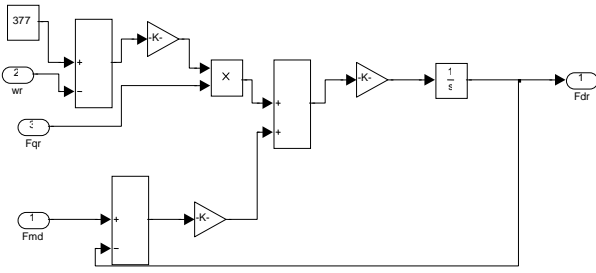


Fig. 9 The implementation of the equation (1)-(4)

Fig. 10 presents the implementation of the flux linkages found in Fig. 6. Also, Fig. 11 depicts how the current equations are constructed.

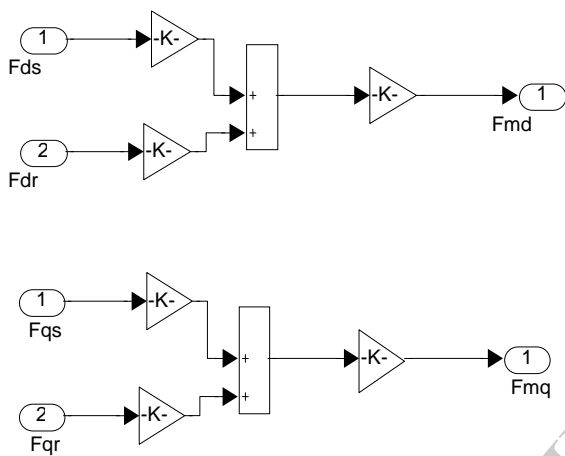


Fig.10 The calculation of the flux linkages Fmq and Fmd

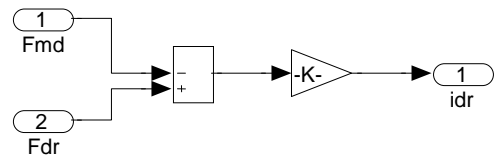
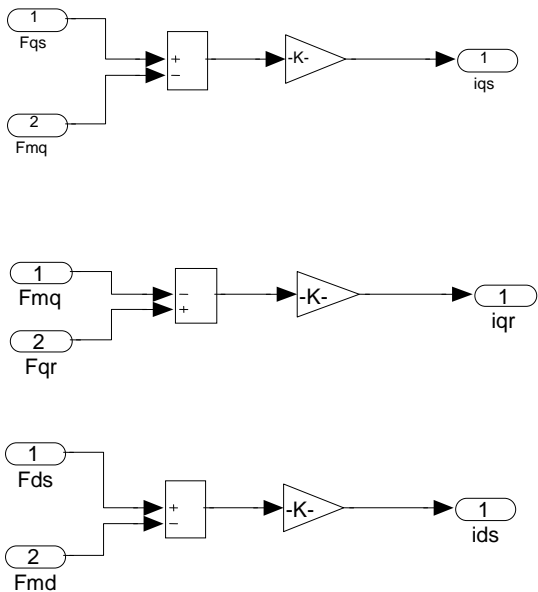


Fig. 11 The implementation of dq current equations

Fig. 12 represents the implementation of 2 phase to 3 phase conversion

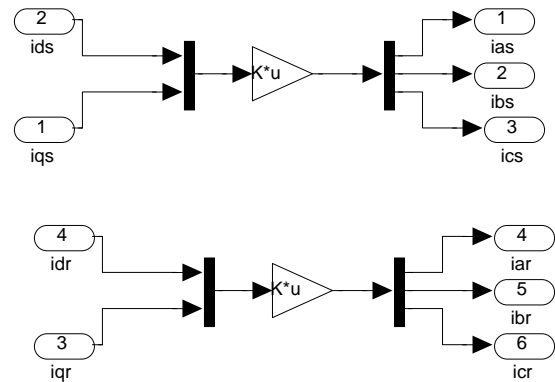


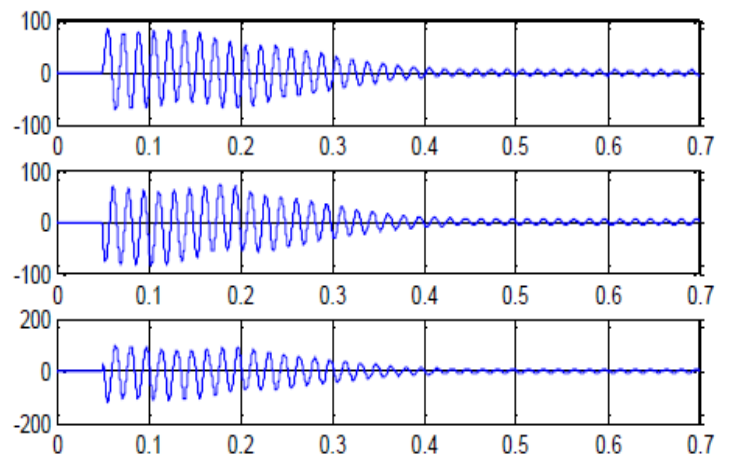
Fig. 12 The implementation of dq-abc model

Finally, the machine parameters should be defined to the simulated machine system in order to complete the simulation process. There are many ways to input the required data. The input is given and the results are observed.

IV. SIMULINK RESULTS

An induction motor is tested in this simulated model. The results of the simulation are given for the induction motor with the following specifications:

$H_p = 3$; $V_L = 220$; $f = 60$; $R_s = 0.435$; $X_{ls} = 0.754$; $P = 4$;
 $R_r = 0.816$; $X_{lr} = 0.754$; $J = 0.089$; $X_m = 26.13$; $rpm = 1710$



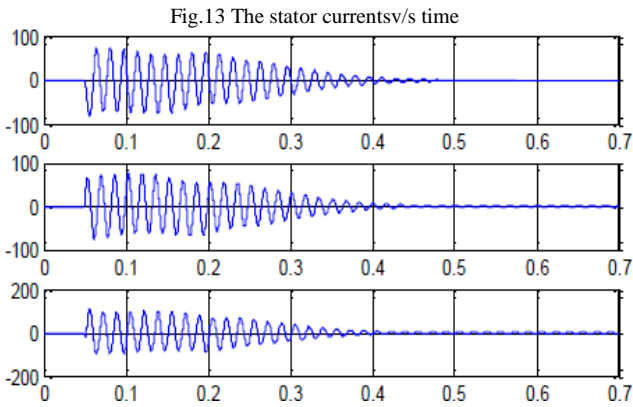
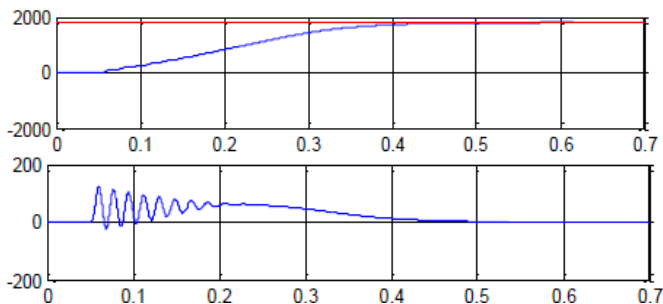


Fig. 14 The rotor currents v/s time

Fig.15 ω_r v/s time & T_e v/s time

V. CONCLUSIONS

In this paper, an implementation and dynamic modeling of a three-phase induction motor using Simulink are presented in a step-by-step manner. The dynamic model of a three phase induction machine is derived from the two phase machine by establishing equivalence between three and two phase and then, two phase motor in direct and quadrature axis. The model was tested for given ratings of a small induction motor. Satisfactory outputs are observed. This concludes that the Simulink is a reliable and sophisticated way to analyze and predict the behavior of induction motors using the theory of reference frames.

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