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Modeling and Simulation of an Induction Motor

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Abstract:- Induction motors are most widely used motors due to their reliability, robustness and low cost. The qd0 transformation theory is applied for the modeling and simulation of an induction motor on the stationary reference frame. The differential equations of system represents the dynamic behavior of the machine. The simulation are done in MATLAB/SIMULINK. The effective motor output variables namely phase current, motor speed and electromagnetic torque are examined. The results obtained by simulation clearly shows the elegance of qd0 transformation theory in machine modeling.

Keywords:- Dynamic modeling, induction machine, stationary reference frame, MATLAB/SIMULINK.

I. INTRODUCTION

The use of asynchronous motors particularly squirrel-cage rotor has increased tremendously since the day of its invention. They are being used as actuators in many types of industrial processes, robotics, house appliances (generally single-phase) and other similar applications. The reason for its daily increasing popularity can be primarily attributed to its simplicity in design, robust construction and cost effectiveness, high efficiency, reliability and good self –starting capability [1-3]. The analysis of induction motor is carried out in steady state whereby the machine is modeled as a second order electromechanical system.

Dynamic model of machine describes the transient and the steady state behavior of the induction machine. This model can be used to simulate the asynchronous motor drives and evaluate their transient performances including that of using the scalar control techniques. This model is also used when developing high performance control techniques for the asynchronous motor drives such as vector control or direct control (DTC) drives. During start-up and other motoring operations, this motor draws large currents, produce oscillatory torques, voltage dips and can even generate harmonics in the power system. So it is important to be able to model the asynchronous machine in order to predict these phenomenon. Various models have been developed and d-q axis model for the study of transient behaviour has been well tested and proven to be reliable and accurate [4]. It has been shown that the speed of rotation of the d, q axis can be arbitrary although there are three preferred speeds or reference frames as follows [4]:

a) The qd0 stationary reference frame where the d, q axes do not rotate.
b) The rotor reference frame when the d, q axes rotate at rotor speed.
c) The synchronously rotating reference frame where the d, q axes rotate at synchronous speed.

It is preferable to study multi-machine system and stability-analysis of controller design where the motor output equations must be linerized about an operating point in synchronously rotating reference frame [5, 6]. In this frame, the steady state variables are constant and do not vary sinusoidally with time. In this paper, induction machine model is described in the stationary reference frame and also the effects of the stepped sequence of mechanical loading on the motor output variables are observed.

II. INDUCTION MACHINE MODEL IN qd0 STATIONARY REFERENCE FRAME

For power system studies, induction machine loads, and the other types of power system components, are usually simulated on the system's synchronously rotating reference frame. But for the transient studies of variable-speed drives, it is easy to simulate an induction machine and its converter on a stationary reference frame.

The equation of the machine in the stationary reference frame can simply be obtained by setting the speed of the arbitrary reference frame, ω, to zero and ω_e , respectively [7, 8]. To distinguish among all these reference frame, variables in the stationary and synchronously rotating reference frames will be identified by an additional superscript: s, for the variables in the stationary reference frame and e for the variables in the synchronously rotating frame. The corresponding equivalent circuit representation are given in fig. 1

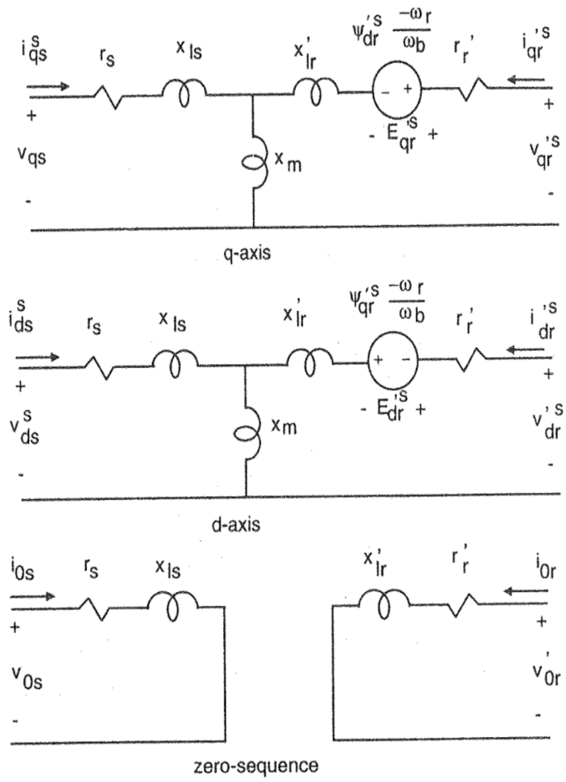


Fig 1: Equivalent circuit of an induction machine in stationary reference frame

III. SIMULINK IMPLEMENTATION

The model equations of the three-phase induction machine are rearranged in the following form for the simulation:

$$\psi_{qs}^{s} = \omega_b \int \left(v_{qs}^{s} + \frac{r_s}{x_{ls}} \left(\psi_{mq}^{s} - \psi_{qs}^{s} \right) \right) dt$$

$$\psi_{ds}^{s} = \omega_b \int \left(v_{ds}^{s} + \frac{r_s}{x_{ls}} \left(\psi_{md}^{s} - \psi_{ds}^{s} \right) \right) dt$$

$$i_{0s} = \frac{\omega_b}{x_{ls}} \int \left(v_{0s} - i_{0s} r_s \right) dt \qquad (1)$$

$$\psi_{qr}^{'s} = \omega_b \int \left(v_{qr}^{'s} + \frac{\omega_r}{\omega_b} \psi_{dr}^{'s} + \frac{r_r^{'}}{x_{lr}^{'}} \left(\psi_{mq}^{s} - \psi_{qr}^{'s} \right) \right) dt \qquad (2)$$

$$\psi_{dr}^{'s} = \omega_b \int (v_{dr}^{'s} - \frac{\omega_r}{\omega_b} \psi_{qr}^{'s} + \frac{r_r^{'}}{x_{lr}^{'}} (\psi_{md}^{'} - \psi_{dr}^{'s}))dt \qquad (3)$$

$$i_{0r}^{'} = \frac{\omega_b}{x_{lr}^{'}} \int (v_{0r}^{'} - i_{0r}^{'} r_r^{'})dt \qquad (4)$$

$$\psi_{mq}^{s} = x_m (i_{qs}^{s} + i_{qr}^{'s})$$

$$\psi_{md}^{s} = x_m (i_{ds}^{s} + i_{dr}^{'s}) \qquad (5)$$

$$\psi_{qs}^{s} = x_{ls} i_{qs}^{s} + \psi_{mq}^{s}$$

Implying that,

$$i_{qs}^{s} = \frac{\psi_{qs}^{s} - \psi_{mq}^{s}}{x_{ls}} \tag{6}$$

$$\psi_{ds}^{s} = x_{ls} i_{ds}^{s} + \psi_{md}^{s}$$

Implying that,

$$i_{ds}^{s} = \frac{\psi_{ds}^{s} - \psi_{md}^{s}}{x_{ls}} \tag{7}$$

$$\psi_{qr}^{'s} = x_{lr}^{'} i_{qr}^{'s} + \psi_{mq}^{s}$$

Implying that,

$$i_{qr}^{'s} = \frac{\psi_{qr}^{'s} - \psi_{mq}^{s}}{x_{lr}^{'}} \tag{8}$$

$$\psi_{dr}^{'s} = x_{lr}^{'} i_{dr}^{'s} + \psi_{md}^{s}$$

Implying that,

$$i_{dr}^{'s} = \frac{\psi_{dr}^{'s} - \psi_{md}^{s}}{x_{lr}^{'}} \tag{9}$$

Where,

$$\frac{1}{x_M} = \frac{1}{x_m} + \frac{1}{x_{ls}} + \frac{1}{x_{lr}^{'}} \tag{10}$$

And

$$\psi_{mq}^{s} = x_M \left(\frac{\psi_{qs}^{s}}{x_{ls}} + \frac{\psi_{qr}^{'s}}{x_{lr}^{'}} \right)$$

$$\psi_{md}^{s} = x_M \left(\frac{\psi_{ds}^{s}}{x_{ls}} + \frac{\psi_{dr}^{'s}}{x_{lr}^{'}} \right) \tag{11}$$

The torque equation is:

$$T_{em} = \frac{3}{2} \frac{p}{2\omega_b} \left(\psi_{ds}^{s} i_{qs}^{s} - \psi_{qs}^{s} i_{ds}^{s} \right) \tag{12}$$

The equation of rotor's motion is obtained by equating the inertia torque to the accelerating torque

$$J \frac{d\omega_r}{dt} = T_{em} + T_{mech} - T_{damp} \tag{13}$$

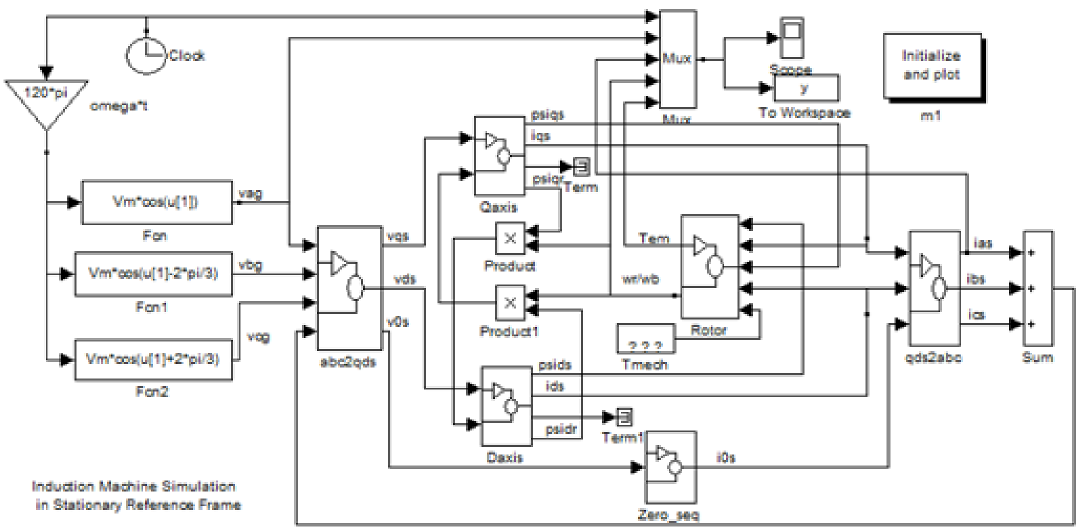
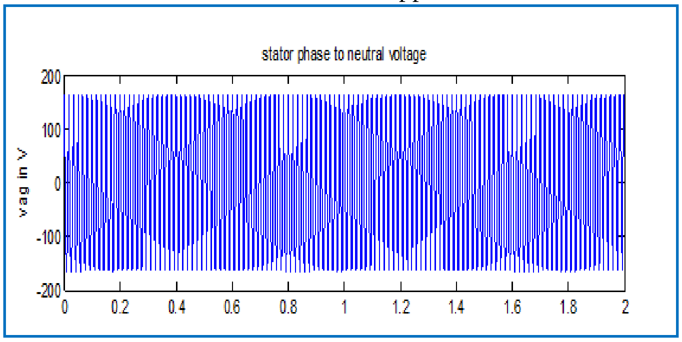


Fig 2: Complete simulink model of three-phase induction machine

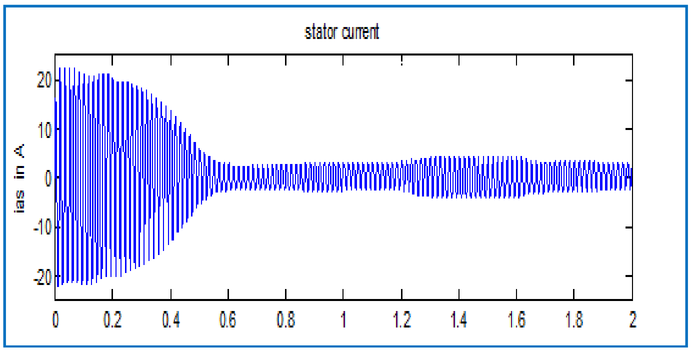
IV. SIMULATION RESULTS

A 1hp induction motor was tested in this simulation model [Appendix-I].



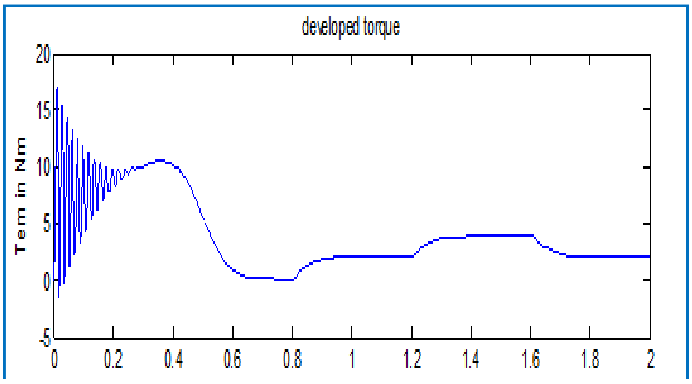
Time in sec

Fig 3: Stator phase to neutral voltage V_{ag} against time



Time in sec

Fig 4: Stator current i_{as} against time



Time in sec

Fig 5: Electromechanical torque T_{em} against time

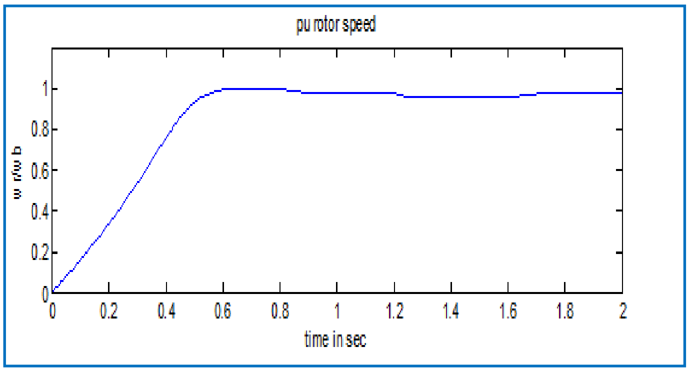


Fig 6: Per unit rotor speed ω_r / ω_b against time

At stall, the input impedance of the induction motor is essentially the stator resistance and leakage reactance in series with the rotor resistance and leakage reactance.

Consequently, with rated voltage applied, the starting current is large, in some cases of the order of 10 times the rated value. This is observed in Figure 4 and is a major limitation of the direct on-line starting of the motor. Therefore, it is recommended that reduced voltage starting methods such as star/delta, auto transformer, and soft start methods be employed to reduce the excess starting current.

It is observed in figure 6 that the rotor accelerates from stall with zero mechanical load torque and since friction and windage losses are not taken into account, the induction machine accelerates to synchronous speed. It can be seen from figure, that the machine has reached steady state at about 0.6 seconds.

It is observed that machine starting under no-load and with step changes in motoring a T_{mech} of 0 to 50 percent, 50 to 100 percent, and from 100 back down to 50 percent of rated torque applied at t = 0.8, 1.2 and 1.6 sec. respectively.

V. CONCLUSION

For the analysis of dynamic behavior of the induction machine, it is essential to study reference frames. This paper shows the elegance of MATLAB/SIMULINK in the dynamic modeling and simulation of a 1-hp asynchronous motor driving a mechanical load. The simulation motor is symmetrical and windage and friction losses are assumed negligible for easy analysis. The results obtained clearly shows the elegance of d-q axis transformation theory in modeling of induction machine, inherent limitations of the direct on-line starting of induction motor and effect of mechanical loading on various motor output variables.

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APPENDIX-I
MACHINE-DATA

Rated Power	**1 HP**
Rated Voltage, V_{rated}	200V
Rated Frequency, f_{rated}	60Hz
Number of Poles, P	4
Stator Resistance, r_s	0.435 ohm
Stator Leakage Reactance, x_{ls}	0.754 ohm
Rotor Referred Resistance, r_{pr}	0.816 ohm
Rotor Referred Reactance, x_{plr}	0.754 ohm
Moment of Inertia, J	0.089 Kg-m^2
Magnetizing Reactance, x_m	26.13 ohm