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Modeling and Simulation of Induction Machine using MATLAB/Simulink - A Modular Approach

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Abstract-This paper represents the dynamic model of three phase induction motor derived from detailed mathematical equations in MATLAB/Simulink. The dynamic behavior of the machine is represented by the system of the differential equations and from it matrix is implemented. The model is used for the steady states and transient analysis of the induction motor. This paper investigates the characteristic behaviors in rotor reference frame of a three-phase squirrel cage induction motor in dynamic state. Using these transformations, many properties of electric machines can be studied without complexities in the voltage equations.

Index Terms- d-q axis, Dynamic model, Torque, flux, MATLAB, Modeling, Induction Motor.

1. INTRODUCTION

Dynamic model describes the transient as well as the steady state behavior of the asynchronous machine. This model is used to simulate the asynchronous motor drives and evaluate its transient performance including that of using the scalar control technique. Asynchronous motor models are divided into two groups, (1) Physical models and (2) Behavioral models. In physical models, electromagnetism laws are used to describe the motor. These models vary in complexity and precision according to the method of modeling used. The behavioral models are the modified version of the physical models i.e., by introducing additional parameters. These behavioral models can be directly used for the diagnosis purpose. Based on the above considerations, the dynamic modeling of the induction motor is used for analysis. During start-up and other motoring operations, the asynchronous motor draws large current, produce voltage dips, oscillatory torque and can even generate harmonics in the power system. So, it is important to model the asynchronous machine in order to predict this phenomenon. Various models have been developed and the d-q axis model for the study of transient behavior has been well tested.

2. INDUCTION MOTOR MODEL CONSTRUCTED USING SIMULINK

The inputs of a squirrel cage induction machine are the 3-phase voltages, their fundamental frequency, and the load torque. The outputs, on the other hand, are the 3-phase currents, the electrical torque, and the rotor speed. The d-q model requires that all the 3-phase variables have to be transformed to the two phase synchronously rotating frame. Consequently, the induction machine model has will have blocks transforming the three phase voltages to the d-q frame and d-q currents back to three phases. The induction machine model implemented in this paper. It consists of five major blocks: the o-n conversion block, abc-syn conversion, syn-abc conversion, unit vector calculation, and the induction machine d-q model blocks. The following subsections will explain each block.

2.1 o-n Conversion Block

This block is required for an isolated neutral system, otherwise it can be bypassed.The transformation done by this block can be represented as follows:

$$\begin{bmatrix} Van \\ Vbn \\ Vcn \end{bmatrix} = \begin{bmatrix} 2/3 & -1/3 & -1/3 \\ -1/3 & 2/3 & -1/3 \\ -1/3 & -1/3 & 2/3 \end{bmatrix} \begin{bmatrix} Vao \\ Vbo \\ Vco \end{bmatrix}$$

2.2 Unit Vector Calculation Block

Unit vectors $\cos\theta_e$ and $\sin\theta_e$ are used in vector rotation blocks, "abc-syn Conversion Block" and "syn-abc Conversion Block".The angle θ_e is calculated directly by integrating the frequency of the three-phse input voltage.The unit vectors are obtained simply by taking the sine and cosine of θ_e.

$$\Theta_e = \int \omega_e \; dt$$

2.3 abc-syn Conversion Block

To convert three-phase voltage into two-phase synchronously rotating frame, they are first converted into two-phase stationary frame using below matrix and then from the stationary frame it is converted into synchronously rotating frame using below two equations.

$$\begin{bmatrix} Vqs^s \\ Vds^s \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & -1/\sqrt{3} & 1/\sqrt{3} \end{bmatrix} \begin{bmatrix} Van \\ Vbn \\ Vcn \end{bmatrix}$$

$$V_{qs} = V_{qs}^{s} \cos\Theta_e - V_{ds}^{s} \sin\Theta_e$$

$$V_{ds} = V_{qs}^{s} \sin\Theta_e + V_{ds}^{s} \cos\Theta_e$$

2.4 syn-abc Conversion Block

This block does oppose the "abc-syn Conversion Block" for the current variables using the same implementation techniques as below :

$$\begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & -\sqrt{3}/2 \\ -\frac{1}{2} & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} iqs^s \\ ids^s \end{bmatrix}$$

$$i_{qs}^{s} = i_{qs} \cos\Theta_e + i_{ds} \sin\Theta_e$$

$$i_{ds}^{s} = - i_{qs} \sin\Theta_e + i_{ds} \cos\Theta_e$$

2.5 Induction Machine d-q model Block

The d-q model of induction motor is implemented using following equations:

1. $\frac{dF_{qs}}{dt} = w_b \left[v_{qs} - \frac{w_e}{w_b} F_{ds} + \frac{R_s}{x_{ls}} \left(\frac{x_{ml}}{x_{lr}} F_{qr} + \left(\frac{x_{ml}}{x_{ls}} - 1 \right) F_{qs} \right) \right]$

2. $\boldsymbol{\frac{dF_{ds}}{dt} = w_b \left[v_{ds} + \frac{w_s}{w_b} F_{qs} + \frac{R_s}{x_{ls}} \left(\frac{x_{ml}}{x_{lr}} F_{dr} + \left(\frac{x_{ml}}{x_{ls}} - 1 \right) F_{ds} \right) \right]}$

3. $\frac{dF_{qr}}{dt} = w_b \left[-\frac{(w_e - w_r)}{wb} F_{dr} + \frac{R_r}{x_{lr}} \left(\frac{x_{ml}}{x_{lr}} F_{qs} + \left(\frac{x_{ml}}{x_{lr}} - 1 \right) F_{qr} \right) \right]$

4. $\frac{dF_{dr}}{dt} = w_b \left[\frac{(w_e - w_r)}{wb} F_{qr} + \frac{R_r}{x_{lr}} \left(\frac{x_{ml}}{x_{ls}} F_{ds} + \left(\frac{x_{ml}}{x_{lr}} - 1 \right) F_{dr} \right) \right]$

5. $\frac{dw_r}{dt} = \left(\frac{p}{2J} \right) (T_e - T_L)$

6. $F_{mq} = x_{ml} \left[\frac{F_{qs}}{x_{is}} + \frac{F_{qr}}{x_{lr}} \right]$

7. $F_{mq} = x_{ml} \left[\frac{F_{qs}}{x_{is}} + \frac{F_{qr}}{x_{lr}} \right]$

8. $i_{qs} = \frac{1}{x_{ls}} (F_{qs} - F_{mq})$

9. $i_{ds} = \frac{1}{x_{ls}} (F_{ds} - F_{md})$

10. $i_{qr} = \frac{1}{x_{lr}} (F_{qr} - F_{mq})$

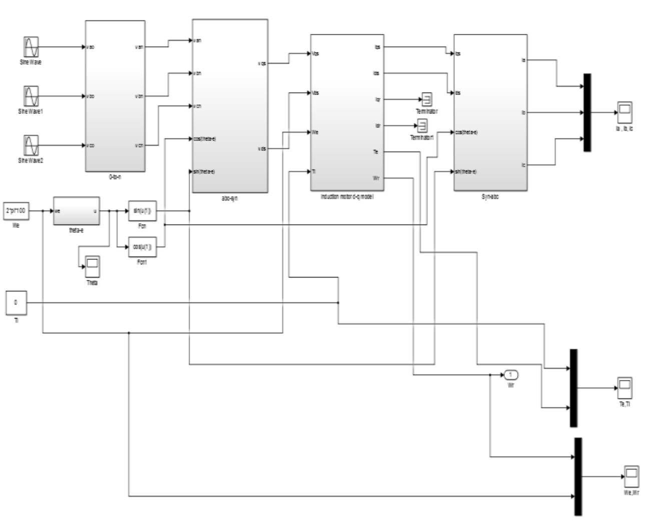
11. $i_{dr} = \frac{1}{x_{lr}} (F_{dr} - F_{md})$

12. $T_e = \frac{3}{2} \left(\frac{p}{2} \right) \frac{1}{w_b} \left(F_{ds} i_{qs} - F_{qs} i_{ds} \right)$

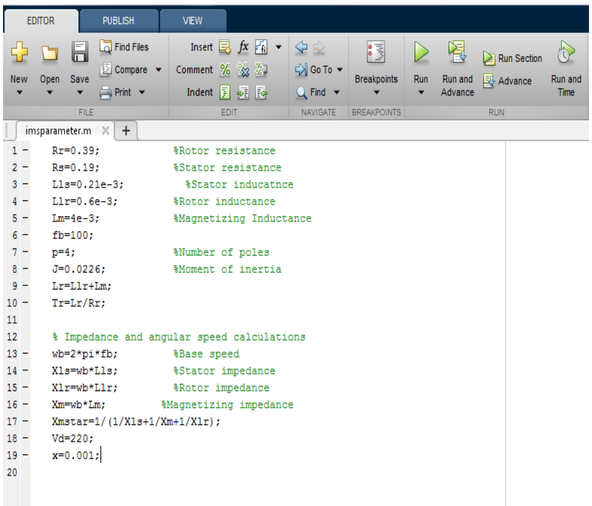
Where,

d : direct axis
q : quadrature axis
s : stator variable
r : rotor variable
F_{ij} : flux linkage (i=q or d and j=s or r)
V_{qs}, V_{ds} : q and d-axis stator voltages
V_{qr},V_{dr} : q and d-axis rotor voltages
F_{mq}, F_{md} : q and d-axis magnetizing flux linkages
R_r : rotor resistance
R_s : stator resistance
X_{ls} : stator leakage reactance
X_{lr} : rotor leakage reactance
i_{qs}, i_{ds} : q and d-axis stator current
i_{qr}, i_{dr} : q and d-axis rotor current
p : number of poles
J : moment of inertia
T_e : electrical output torque
T_l : load torque
W_e : stator angular electrical frequency
W_b : motor angular electrical base frequency
W_r : rotor angular electrical speed

3. INDUCTION MOTOR MODEL IN SIMULINK



4. INDUCTION MOTOR MODEL INITIALIZATION FILE



5. SIMULATION RESULTS

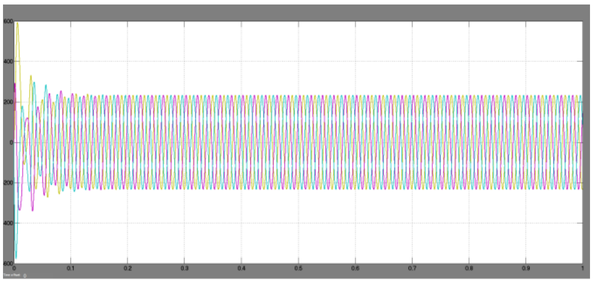


Fig. 5.1. Currents i_a , i_b, i_c

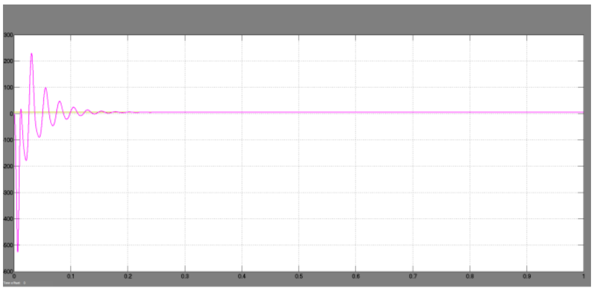


Fig. 5.2. Torque T_e and T_l

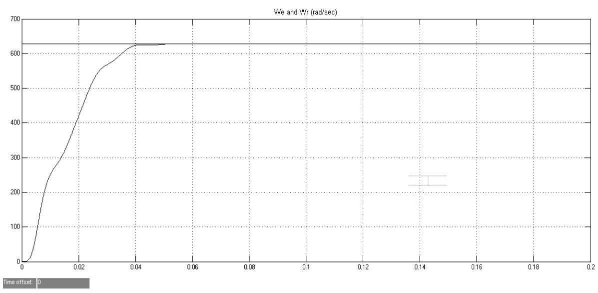


Fig. 5.3. Speed W_e and W_r

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