

## Parameter Estimation of Three Phase Squirrel Cage Induction Motor

Sonakshi Gupta

Department of Electrical Engineering  
Madhav Institute of Technology & Science Gwalior,  
India sonakshigupta1112@gmail.com

Dr. Sulochna Wadhvani

Department of Electrical Engineering  
Madhav Institute of Technology & Science  
Gwalior, India  
adhwani\_sulochna@rediffmail.com

**Abstract:** This paper presents the dynamic d-q modeling (Synchronously Rotating Reference Frame-Dynamic Model) of the induction motor using state space analysis. The motor variables like d-q stator and rotor currents ( $i_{qs}$ ,  $i_{ds}$ ,  $i_{qr}$ ,  $i_{dr}$ ), d-q voltages ( $V_{qs}$ ,  $V_{ds}$ ) and torque are examined. The systems of the differential equations representing dynamic behavior of the machine are implemented in MATLAB. Flux linkages are considered as the main variables in the system of the differential equations.

**Keywords:** Induction motor, D-Q modeling, State space equations, MATLAB

### I. INTRODUCTION

The use of asynchronous motors has increased tremendously since the day of its invention because of its simplicity in design, robust construction and reliability, excellent self starting capability and high efficiency. This has motivated the study of induction motor performance in several drives. [1]

Traditionally machine parameters are estimated by performing no-load test and locked rotor test. These tests are not convenient because they require human electrical measurements and intervention on machine. The locked rotor test results in very high slip frequency, and increasing skin-effect influence on the rotor resistance. This leads to incorrect operating conditions and inaccurate parameter estimation.

The voltage and torque equations that describe the dynamic behavior of an induction motor are time-varying. The time varying behavior is described by the differential equations. Solving these differential equations using Laplace transform or any other transform is complex.

A change of variables can be used to reduce the complexity of these equations by eliminating all time-varying inductances, due to electric circuits in relative motion, from the voltage equations of the machine [2, 3].

Using this approach a ploy-phase winding can be converted into two-phase winding (q-d) with their magnetic axes in quadrature. The stator and rotor variables (voltages, currents and flux linkages) of an

induction machine are transferred to a reference frame, which can rotate at any angular velocity or remain stationary. This frame of reference is commonly called as arbitrary frame of reference.

### II. D-Q MODEL

The dynamic model of the induction motor is derived by using a two-phase motor in direct and quadrature axes. This approach is useful because of the conceptual simplicity obtained with two set of windings, one on the stator and other on the rotor. [5]

The three-phase stationary reference frame (a-b-c) into two-phase reference frame (d-q-0) is carried out by following equation [4]:

$$\begin{aligned} &= \\ &- \\ & \end{aligned} \tag{1}$$

where  $V_a$ ,  $V_b$ ,  $V_c$  are the three phase stator voltages of an induction machine under balanced condition.  $V_a$ ,  $V_b$ ,  $V_c$  can be expressed as:

$$V_a = 220 \sin(\omega t) \tag{2}$$

$$V_b = 220 \sin(\omega t - 2\pi/3) \tag{3}$$

$$V_c = 220 \sin(\omega t + 2\pi/3) \tag{4}$$

and  $V_0$  is the zero sequence component, which may or may not be present.

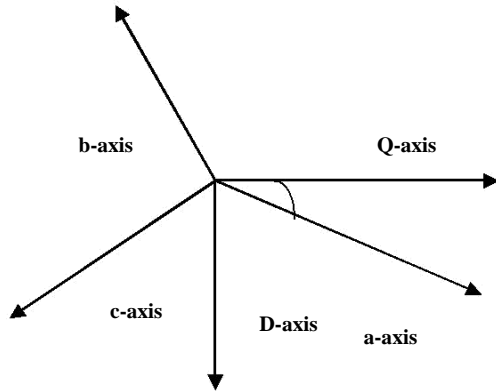


Figure (a): a-b-c to d-q Transformation

### III. DYNAMIC MODELLING OF THREE PHASE INDUCTION MACHINE

The dynamic machine model in state-space form is important transient analysis and for the computer simulation study. 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. The motor was represented as a set of equations in a matrix form to be solved to give stator, rotor currents. The motor is represented by a set of differential equations in the d-q reference frame.

It is assumed that rotor cage bars are shorted hence  $V_{qr} = V_{dr} = 0$  for squirrel cage asynchronous machine. An asynchronous machine model can be represented with following equations [4]

$$- F_{qs} = \omega_b [v_{qs} - (\frac{\omega}{\omega_b} F_{ds}) - (F_{qs} - F_{qm})] \quad (5)$$

$$- F_{ds} = \omega_b [v_{ds} + (F_{qs}) - (F_{ds} - F_{dm})] \quad (6)$$

$$- F_{qr} = -\omega_b [F_{dr} + (F_{qr} - F_{qm})] \quad (7)$$

$$- F_{dr} = -\omega_b [-F_{dr} + (F_{dr} - F_{qm})] \quad (8)$$

$$i_{qs} = (F_{qs} - F_{qm}) / X_{ls} \quad (9)$$

$$i_{qr} = (F_{qr} - F_{qm}) / X_{lr} \quad (10)$$

$$i_{ds} = (F_{ds} - F_{dm}) / X_{ls} \quad (11)$$

$$i_{dr} = (F_{dr} - F_{dm}) / X_{lr} \quad (12)$$

Where  $F_{qm} = [F_{qs} + F_{qr}]$

$$F_{dm} = [F_{ds} + F_{dr}]$$

$$X_{m1} = \dots$$

$T_e = [F_{ds}^* i_{qs} - F_{qs}^* i_{ds}]$  (13) Equations (5) to (8) are popularly known as Kron's Equations.

### IV. STATE SPACE MODELING

The state space or internal representation of a dynamic system is an effective path to model linear systems. The system of state space is described by the following equations:

$$\dot{x}(t) = Ax(t) + Bu(t) \quad (14)$$

$$y(t) = Cx(t) + Du(t) \quad (15)$$

Where  $x(t)$  is the state vector,  $y(t)$  is the output vector,  $u(t)$  is input vector and  $\dot{x}(t)$  is the derivative vector. Now describing equations (5) to (12) into state space representation

$$\begin{bmatrix} \dot{F}_{qs} \\ \dot{F}_{ds} \\ \dot{F}_{qr} \\ \dot{F}_{dr} \end{bmatrix} = \begin{bmatrix} -\omega_b & 0 & 0 & 0 \\ 0 & -\omega_b & 0 & 0 \\ 0 & 0 & -\omega_b & 0 \\ 0 & 0 & 0 & -\omega_b \end{bmatrix} \begin{bmatrix} F_{qs} \\ F_{ds} \\ F_{qr} \\ F_{dr} \end{bmatrix} + \begin{bmatrix} \omega_b v_{qs} \\ \omega_b v_{ds} \\ -\omega_b F_{qr} \\ -\omega_b F_{dr} \end{bmatrix} + \begin{bmatrix} \omega_b F_{dm} \\ -\omega_b F_{qm} \\ 0 \\ 0 \end{bmatrix} \quad (16)$$

$$\begin{bmatrix} \dot{i}_{qs} \\ \dot{i}_{ds} \\ \dot{i}_{qr} \\ \dot{i}_{dr} \end{bmatrix} = \begin{bmatrix} -\omega_b & 0 & 0 & 0 \\ 0 & -\omega_b & 0 & 0 \\ 0 & 0 & -\omega_b & 0 \\ 0 & 0 & 0 & -\omega_b \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix} + \begin{bmatrix} \omega_b v_{qs} \\ \omega_b v_{ds} \\ -\omega_b F_{qr} \\ -\omega_b F_{dr} \end{bmatrix} + \begin{bmatrix} \omega_b F_{dm} \\ -\omega_b F_{qm} \\ 0 \\ 0 \end{bmatrix} \quad (17)$$

Where  $\omega_b$  = base speed

$\omega_e$  = Stator frequency

$\omega_r$  = Rotor speed

$V_{qs}$  = Q-axis stator voltage

$V_{ds}$  = D-axis stator voltage

$V_{qr}$  = Q-axis rotor voltage

$V_{dr}$  = D-axis rotor voltage

$F_{qs}$  = Stator flux linkage along Q- axis

$F_{ds}$  = Stator flux linkage along D-axis

$F_{qr}$  = Rotor flux linkage along Q-axis

$F_{dr}$  = Rotor flux linkage along D-axis  
 $I_{qs}$  = Stator current along Q-axis  
 $I_{ds}$  = Stator current along D-axis  
 $I_{qr}$  = Rotor current along Q-axis  
 $I_{dr}$  = Rotor current along D-axis  
 $X_{ls}$  = Stator leakage reactance  
 $X_{lr}$  = Rotor leakage reactance  
 $X_m$  = Magnetizing reactance  
 $R_s$  = Stator resistance  
 $R_r$  = Rotor resistance  
 $T_e$  = Torque  
 $P$  = Number of poles

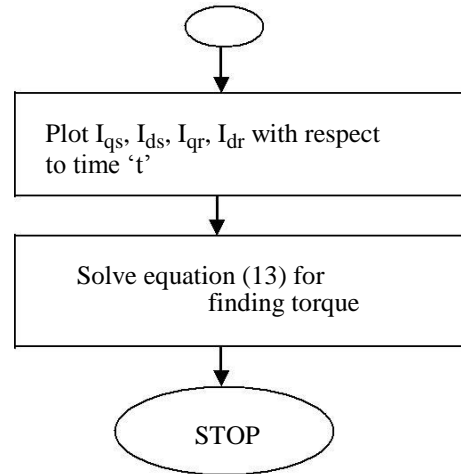
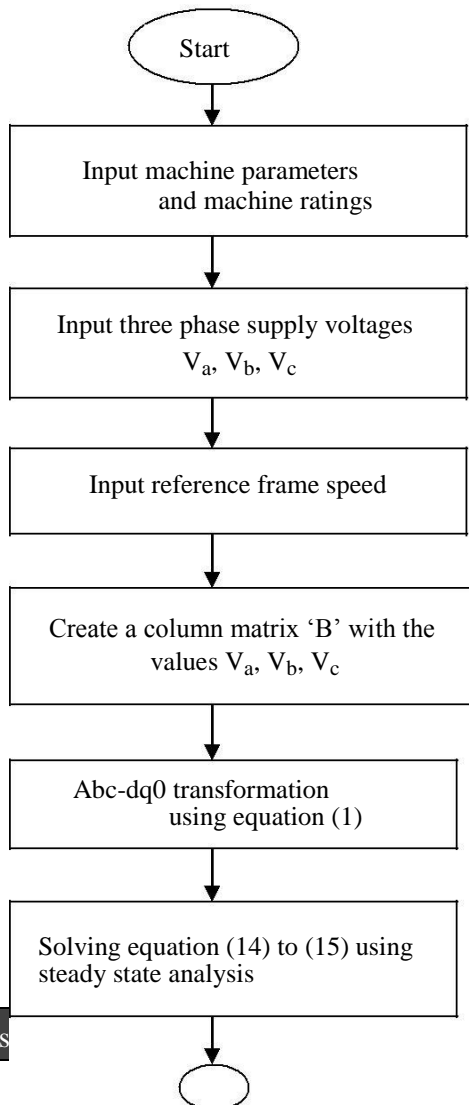


Figure (b): Flowchart for MATLAB Implementation

Figure (b) shows the flowchart for the MATLAB program developed for the analysis of induction machine performance using equations (1) to (12)



## V. EXPERIMENTAL DATA

The specifications of the induction machine are as follows:

$H_p = 3, f = 50 \text{ Hz}$

$R_s = 0.435\Omega, X_{ls} = 0.754\Omega$

$R_r = 0.816\Omega, X_{lr} = 0.754\Omega, X_m = 26.13 \Omega$

$P = 4$

$\omega_b = 377 \text{ rpm}, \omega_e = 377 \text{ rpm}, \omega_r = 1710 \text{ rpm}$

## VI. MATLAB IMPLEMENTATION RESULTS

This section represents plot for the stator voltages in d-q axis [ $V_{qs}$  &  $V_{ds}$  (Figure 1)]; plot for the stator and the rotor currents in d-q axis [ $I_{qs}$ : Figure 2;  $I_{ds}$ : Figure 3;  $I_{qr}$ : Figure 4;  $I_{dr}$ : Figure 5]; Figure 6: plot for the torque

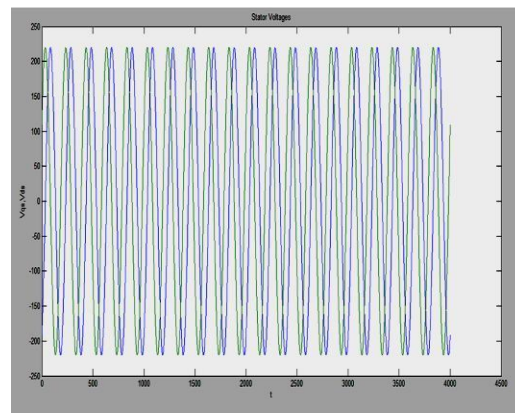


Figure 1: Stator Voltages

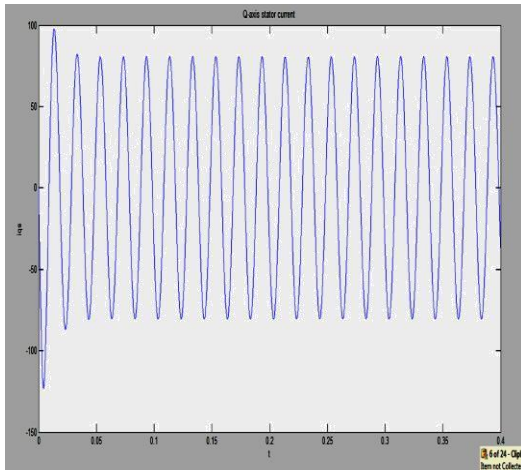


Figure 2: Q-axis Stator Current

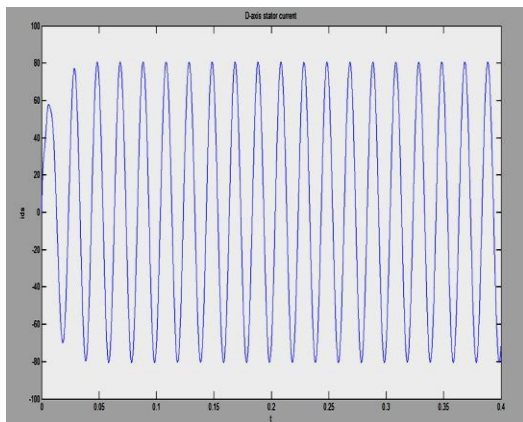


Figure 3: D-axis Stator current

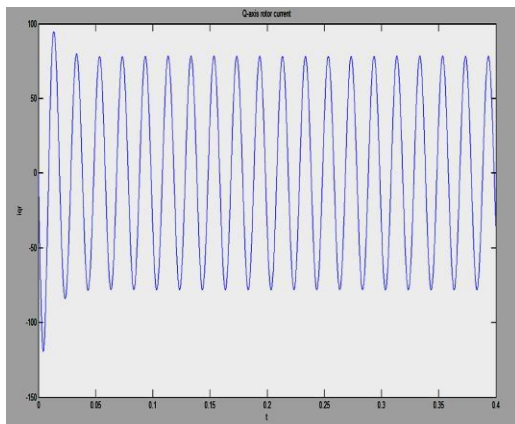


Figure 4: Q-axis Rotor Current

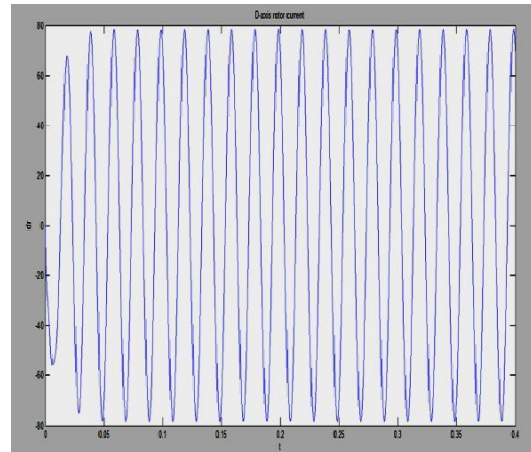


Figure 5: D-axis Stator Current

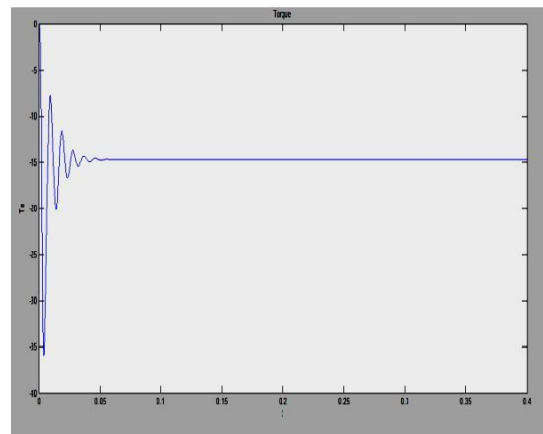


Figure 6: Torque

## VII. CONCLUSIONS

This paper presents the steady state analysis of the dynamic model of asynchronous motor with rotor cage bars shorted. This analysis is beneficial for the studying the steady state and transient behavior of the machine. The above analysis does not have any complexity in solving the differential equations of the induction motor.

## REFERENCES

- [1] Shakuntla Boora, S.K Agarwal, K.S Sandhu, "Dynamic d-q axis modeling of Three-phase asynchronous machine using matlab," International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering. Vol. 2, Issue 8, August 2013.
- [2] P.C. Krause and C. H. Thomas, "Simulation of Symmetrical Induction Machinery", IEEE Transaction on Power Apparatus and Systems, Vol. 84, November 1965, pp. 1038-1053.

- [3] M. L. de Aguiar, M. M. Cad, "The concept of complex transfer functions applied to the modeling of induction motors", Power Engineering Society Winter Meeting, 2000, pp. 387–391
- [4] Bimal K.Bose, "Modern Power Electronics and AC Drives,"Prentice Hall India, 2005.
- [5] R. Krishan, "Electric motor drives: Modelling, analysis and control," Prentice Hall Company, New Jersey, 2001
- [6] Prof. Himanshu K. Patel," Steady State and Transient Performance Analysis of Three Phase Induction Machine using MATLAB Simulations", International Journal of Recent Trends in Engineering, Vol 1, No. 3, May 2009