

MODELLING AND SIMULATION OF AN INDUCTION MACHINE

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Abstract: Dynamic modelling approach is the easiest method used to describe an induction machine. Dynamic model gives information about transient behaviour of the system. In this paper, the dynamic model of the induction motor is represented in state space using Krause modelling equations. Synchronous reference frame is used to develop a model and flux equations are expressed in terms of reactance. The equations are grouped and for each group a subsystem is developed. Initially d-q modelling method is used for modelling of healthy induction machine. The result is simulated using MATLAB/SIMULINK.

Keywords: Induction Machine, d-q model, Flux Linkage, MATLAB/SIMULINK

I. INTRODUCTION

Induction machines are the commonly used machine in the industry because of its reliable operation, simple construction, low initial cost, easy operation, high efficiency, simple maintenance. Three phase induction machine is a self starting motor. It runs at constant speed from no load to full load. Compared to DC machine, the cost of induction machine per kVA is less and induction machine can be operated in hostile environment. Most electrical motor failure reduces production, interrupts a process and may damage other machineries related to motor. It is necessary to model a method which prevents unscheduled downtimes of induction machine. And also maintenance cost must be less.

Induction machine dynamic modelling and simulation is the most commonly used method in industry and academia. Dynamic modelling can be developed by writing differential equations. This type of modelling assumes that both stator and rotor windings are symmetric and MMF is sinusoidally distributed. Equivalent resistance and inductance matrices are diagonal. This type of modelling is simple for computer simulation.

By establishing equivalence based on the equality of the MMF produced in the two phase and three phase windings and equal current magnitudes, dynamic model of the three phase induction machine is developed. Using Modular approach, it is easy to describe induction machine. Using this method, all of the machine parameters are easily accessible. Krause model is one of the most popular approaches. Study of Dynamic behaviour of induction machine has an effect upon the overall performance of the system. Using d-q transformation theory it is possible to get DC quantities from sinusoidal variable quantities and also, it is possible to control speed and torque of machine independently.

The induction machine dynamic model and equations used in this paper are from Bimal K.Bose, "Modern Power Electronics and AC Drives" [1] and R.Krishnan, "Electric motor drives: Modelling, analysis and Control" [5]. Lakhya Jyoti Phukon, Neelanjana Baruah[3] developed a generalized MATLAB SIMULINK model of a three phase induction motor. A model is tested for load and no load conditions. They presented that using s-function technique does not make use of the power of SIMULINK block. They concluded that using MATLAB/SIMULINK it is easy to predict and analyse the behaviour of an induction machine.

Burak Ozpineci and Leon M Tolbert [2] presented a paper on modular SIMULINK implementation of Induction machine model. They developed a subsystem block for each model equation. From this it is possible to get all of the machine parameters for control and verification. After the induction machine model, they presented a model for open loop constant V/Hz control and indirect vector current.

II. INDUCTION MOTOR MODEL

To model an induction machine, the equations are obtained from dq0 equivalent circuit.

The flux linkage model equations are as follows:

$$\frac{dF_{sq}}{dt} = \omega_b \left[v_{sq} - \frac{\omega_e}{\omega_b} F_{sd} + \frac{R_s}{X_{sl}} (F_{qm} + F_{sq}) \right] \quad (1)$$

$$\frac{dF_{sd}}{dt} = \omega_b \left[v_{sd} + \frac{\omega_e}{\omega_b} F_{sd} + \frac{R_s}{X_{sl}} (F_{dm} + F_{sd}) \right] \quad (2)$$

$$\frac{dF_{rq}}{dt} = \omega_b \left[v_{rq} - \frac{(\omega_e - \omega_r)}{\omega_b} F_{rd} + \frac{R_r}{X_{rl}} (F_{qm} - F_{rq}) \right] \quad (3)$$

$$\frac{dF_{rd}}{dt} = \omega_b \left[v_{rd} + \frac{(\omega_e - \omega_r)}{\omega_b} F_{rq} + \frac{R_s}{X_{sl}} (F_{qm} + F_{dr}) \right] \quad (4)$$

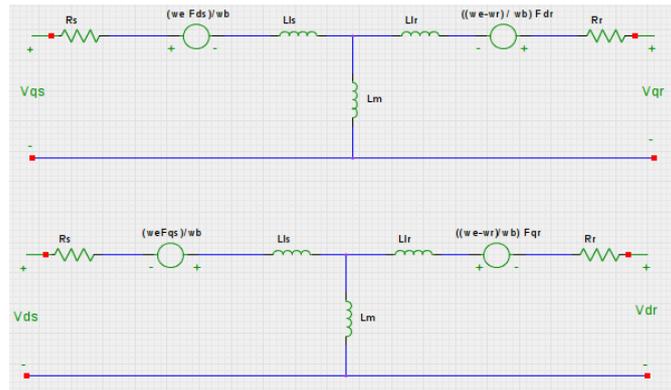


Figure 1: Synchronous frame DQ Equivalent Circuit of an Induction machine

$$F_{qm} = X_{ml} * \left[\frac{F_{sq}}{X_{sl}} + \frac{F_{rq}}{X_{rl}} \right] \quad (5)$$

$$F_{dm} = X_{ml} * \left[\frac{F_{sd}}{X_{sl}} + \frac{F_{rd}}{X_{rl}} \right] \quad (6)$$

$$i_{sq} = \frac{1}{X_{sl}} (F_{sq} - F_{qm}) \quad (7)$$

$$i_{sd} = \frac{1}{X_{sl}} (F_{sd} - F_{dm}) \quad (8)$$

$$i_{rq} = \frac{1}{X_{rl}} (F_{rq} - F_{qm}) \quad (9)$$

$$i_{rd} = \frac{1}{X_{rl}} (F_{rd} - F_{dm}) \quad (10)$$

$$T_e = \frac{3}{2} \left(\frac{P}{2} \right) \frac{1}{\omega_b} (F_{sd} i_{sq} - F_{sq} i_{sd}) \quad (11)$$

$$T_e - T_L = \left(\frac{2}{J} \right) \left(\frac{1}{P} \right) \frac{d\omega_r}{dt} \quad (12)$$

where, d is Direct Axis, q is quadrature Axis, s is Stator Variable, r is Rotor Variable, F_{ji} : Flux Linkage ($j=s$ or r and $i=q$ or d) v_{sq}, v_{sd} : Stator voltages of q and d axis, v_{rq}, v_{rd} : rotor voltages of q and d axis, F_{qm}, F_{dm} : q and d axis flux linkage, i_{sq}, i_{sd} : stator currents of q and d-axis, i_{sq}, i_{sd} : rotor currents of q and d-axis, T_e : Torque of Electrical output, T_L : Torque of Load, ω_e : Electrical Frequency of stator angle, ω_b : Electrical base Frequency of motor angle, ω_r : Electrical Frequency of rotor angle.

For an induction machine v_{qs} and v_{ds} are zero in equation (3) and (4). Before solving, differential equation are arranged in state space form by inserting equations F_{qm} and F_{dm} in Flux Linkage Equation and by rearranging then modelling equation in state-space is obtained as follows:

$$\frac{dF_{sq}}{dt} = \omega_b \left[v_{sq} - \frac{\omega_e}{\omega_b} F_{sd} + \frac{R_s}{X_{sl}} \left(\frac{X_{ml}^*}{X_{rl}} F_{rq} + \left(\frac{X_{ml}^*}{X_{sl}} - 1 \right) F_{sq} \right) \right] \quad (13)$$

$$\frac{dF_{sd}}{dt} = \omega_b \left[v_{sd} + \frac{\omega_e}{\omega_b} F_{sq} + \frac{R_s}{X_{sl}} \left(\frac{X_{ml}^*}{X_{rl}} F_{rd} + \left(\frac{X_{ml}^*}{X_{sl}} - 1 \right) F_{sd} \right) \right] \quad (14)$$

$$\frac{dF_{rq}}{dt} = \omega_b \left[-\frac{(\omega_e - \omega_r)}{\omega_b} F_{rd} + \frac{R_r}{X_{rl}} \left(\frac{X_{ml}^*}{X_{sl}} F_{sq} + \left(\frac{X_{ml}^*}{X_{rl}} - 1 \right) F_{rq} \right) \right] \quad (15)$$

$$\frac{dF_{rd}}{dt} = \omega_b \left[\frac{(\omega_e - \omega_r)}{\omega_b} F_{rq} + \frac{R_r}{X_{rl}} \left(\frac{X_{ml}^*}{X_{sl}} F_{sd} + \left(\frac{X_{ml}^*}{X_{rl}} - 1 \right) F_{rd} \right) \right] \quad (16)$$

$$\frac{d\omega_r}{dt} = \left(\frac{P}{2J} \right) (T_e - T_L) \quad (17)$$

III. SIMULINK IMPLEMENTATION

A. Supply voltage Equation

$$v_a = v_{pm} \sin \omega t \quad (18)$$

$$v_b = v_{pm} \sin \left(\omega t - \frac{2\pi}{3} \right) \quad (19)$$

$$v_c = v_{pm} \sin \left(\omega t + \frac{2\pi}{3} \right) \quad (20)$$

B. o-n Conversion block

o-n conversion block is used only in isolated neutral system. The transformation can be done as follows:

$$\begin{bmatrix} v_{an} \\ v_{bn} \\ v_{cn} \end{bmatrix} = \begin{bmatrix} \frac{2}{3} & -\frac{1}{3} & -\frac{1}{3} \\ -\frac{1}{3} & \frac{2}{3} & -\frac{1}{3} \\ -\frac{1}{3} & -\frac{1}{3} & \frac{2}{3} \end{bmatrix} \begin{bmatrix} v_{a0} \\ v_{b0} \\ v_{c0} \end{bmatrix} \quad (21)$$

C. Unit Vector calculation Equation

Unit Vectors $\sin \theta_{es}$ and $\cos \theta_{es}$ are used in abc-syn and syn-abc conversion blocks. θ_{es} is the integration of input voltage frequency Ω_e . Unit vector are calculated by taking sine and cosine of angle θ_{es} .

$$\theta_{es} = \int \omega_e dt \quad (22)$$

D. Abc to syn calculation block

Using below equations three-phase voltages are converted to two-phase synchronous frame voltages.

$$\begin{bmatrix} v_{sq}^s \\ v_{sd}^s \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & -\frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} \end{bmatrix} \begin{bmatrix} v_{an} \\ v_{bn} \\ v_{cn} \end{bmatrix} \quad (23)$$

$$v_{sq} = v_{sq}^s \cos \theta_e - v_{sd}^s \sin \theta_e \quad (24)$$

$$v_{sd} = v_{sq}^s \sin \theta_e + v_{sd}^s \cos \theta_e \quad (25)$$

E. Syn-abc conversion block

The two phase synchronous frame currents are converted to two phase stator reference frame and then to three phase current.

$$i_{sq}^s = v_{sq} \cos \theta_e + v_{sd} \sin \theta_e \quad (26)$$

$$i_{sd}^s = -v_{sq} \sin \theta_e + v_{sd} \cos \theta_e \quad (27)$$

$$\begin{bmatrix} i_{a0} \\ i_{b0} \\ i_{c0} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{sq}^s \\ i_{sd}^s \end{bmatrix} \quad (28)$$

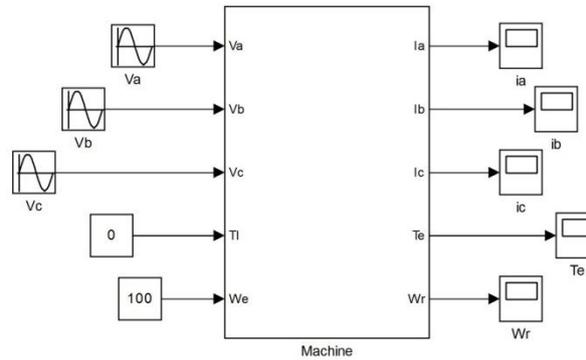
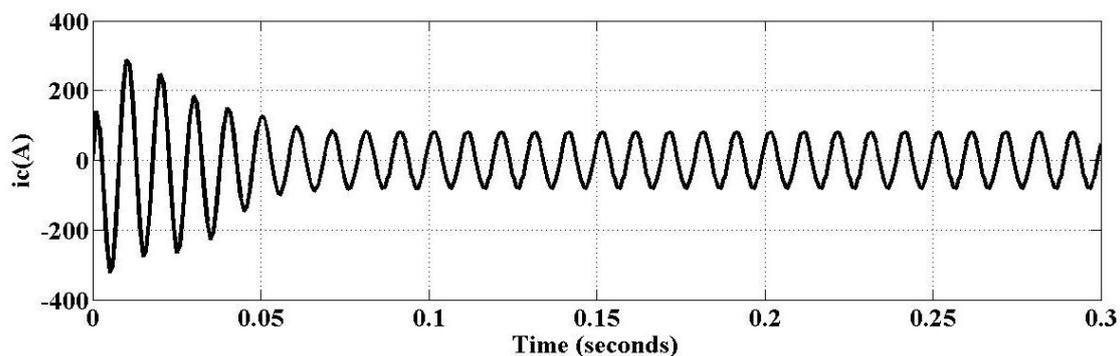
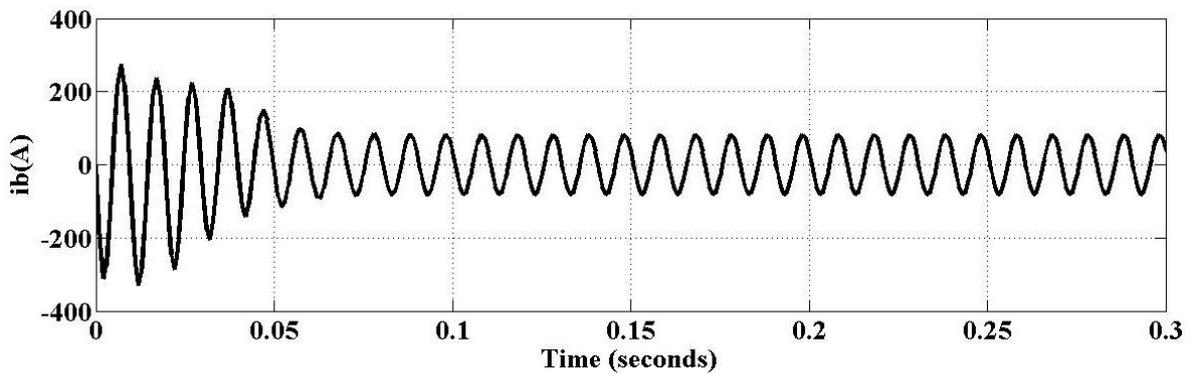
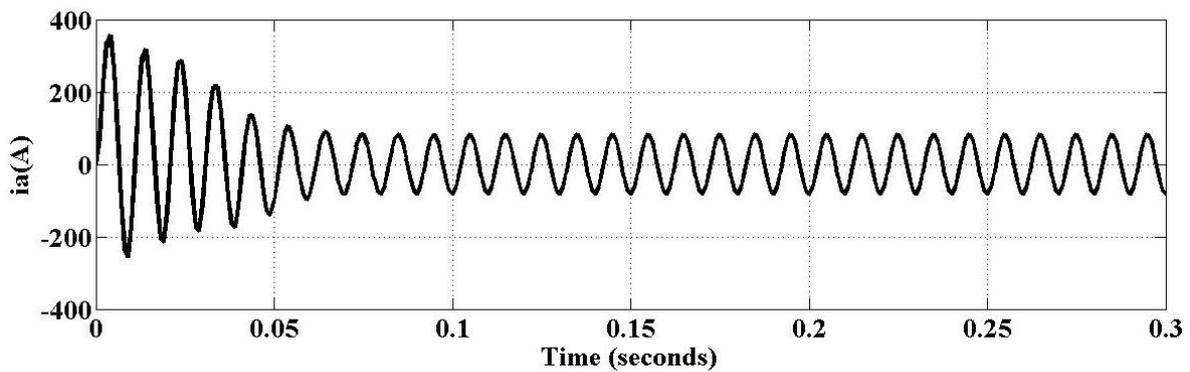


Figure 2: Induction Machine SIMULINK Model

IV. RESULTS

The machine parameters have to be initialized before simulation by a m-file created in MATLAB. In this paper, a 30KW machine is modelled using MATLAB/SIMULINK. The input applied is 220V and frequency is 60Hz. Initially, machine is tested at no load condition. I.e. by keeping load torque, $T_L=0$. The results show that the three phase currents speed and torque goes to steady state after some interval.



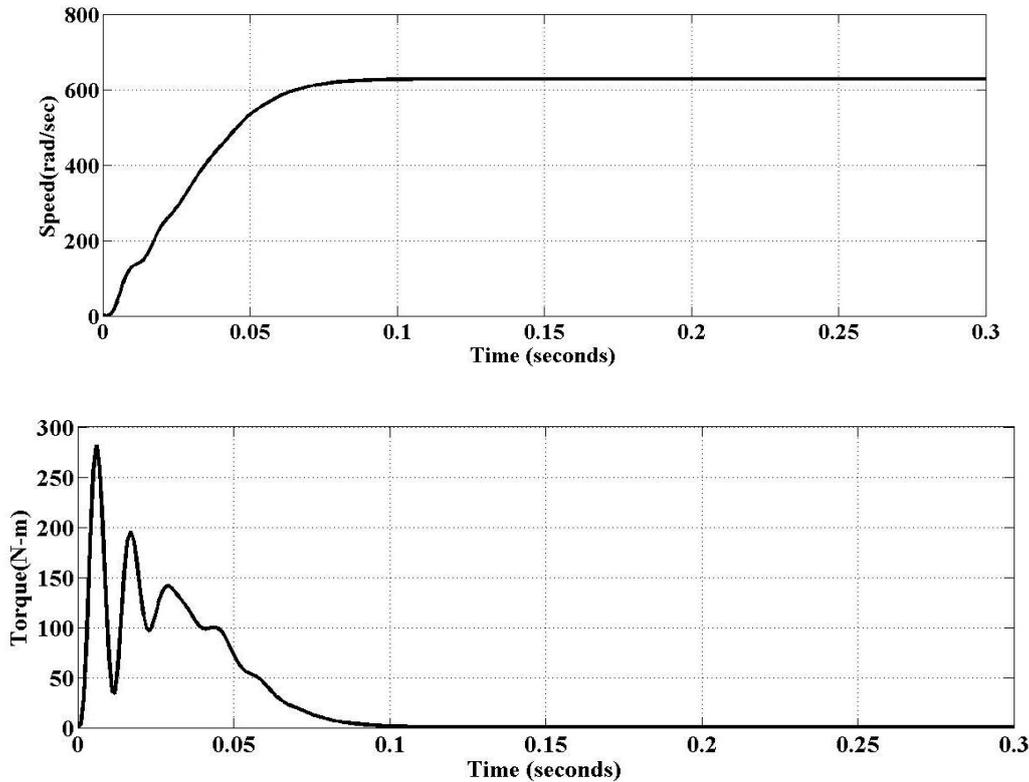


Figure 3: Simulation Results at no load condition

V. CONCLUSION

In this paper, a 30KW induction machine is modelled using MATLAB/SIMULINK. The input applied is 220V and frequency is 60Hz. Initially, machine is tested at no load condition. i.e. by keeping load torque, $T_L=0$. The three phase current, speed and torque go to steady state after some interval. Here at 0.1sec. As a value of speed increases, speed decreases.

APPENDIX

A.Machine Parameters

Rotor Resistance, $R_{rr} = 0.39\Omega$, Stator Resistance, $R_{ss} = 0.19\Omega$, Stator Inductance, Moment of Inertia, $J=0.0226$, $L_{sl}=0.21e-3H$, Rotor Inductance, $L_{rl} =0.6e-3H$, Magnetising Inductance, $L_m=0.4*e-3H$, Base Frequency, $f_{bb}=100Hz$, Number of Poles, $P =4$, $\omega_b =2*\pi*f_{bb}$, Stator Leakage Reactance, $X_{sl}= \omega_e * L_{sl}$, Rotor Leakage Reactance, $X_{rl} = \omega_e * L_{rl}$ Magnetizing Impedence, $X_m = \omega_e * L_m$, $X_m^*=1/ (1/X_{ls}+1/X_m+1/X_{lr})$

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