Transient Analysis of Three Phase Squirrel Cage Induction Machine using Matlab

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ABSTRACT

Three phase induction machine is one of most usable machine in industrial application because of its simple construction and other advantages such as reliable operation, low initial cost, easy operation and simple maintenance, high efficiency and having simple control gear for stating and speed control. The popularity of this motor has resulted into lot of research including the transient behavior of the machine. in this paper transient performance of three phase squirrel cage induction motor analyzed with dq0 axis based modeling in stationary reference frame, rotor reference frame and synchronously rotating reference frame. The proposed system has been developed and simulated by using MATLAB/SIMULINK.

Keywords – Induction motor, modeling, reference frame simulation, transient analysis

1. INTRODUCTION

When three phase induction motor are started and during the other transient operations of induction motor its draws large currents, which produced voltage drips, oscillatory torques and even generate the harmonics in the power systems. The dq axis model is more reliable and accurate to investigate such of these problems. The three reference frames are Stationary reference frame, Rotor reference frame, Synchronous reference frame. These reference frames are used to converting the input voltage (abc reference frame) to the dq reference frame, and output current (dq reference frame) to the abc reference frame. The transient dynamic behavior of three phase squirrel cage induction motor can be analyzed by using any one of the following three reference frames. And t is found that when,

if the stator voltage is unbalanced or discontinuous and the rotor voltages are balanced, the stationary reference frames is useful.if the rotor voltages are unbalanced or discontinuous and stator voltages are unbalanced or discontinuous and stator voltages are balanced, the rotor reference frames is used. And if stator and rotor all voltages are balanced and continuous, then synchronous reference frame is used.

The following relationships are used to transform the 'abc' to 'dq' reference frame.

$$\begin{bmatrix} V_{ds} \\ V_{qs} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 2\cos\theta & \cos\theta + \sqrt{3}\sin\theta \\ 2\sin\theta & \sin\theta - \sqrt{3}\cos\theta \end{bmatrix} \begin{bmatrix} V_{abs} \\ V_{bcs} \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} V`_{dr} \\ V`_{qr} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 2\cos\beta & \cos\beta + \sqrt{3}\sin\beta \\ 2\sin\beta & \sin\beta - \sqrt{3}\cos\beta \end{bmatrix} \begin{bmatrix} V`_{abr} \\ V`_{bcr} \end{bmatrix} \quad (2)$$

where, θ is the angular position of the reference frame while $\beta = \theta - \theta r$ is the difference between the position of the reference frame and the position of the rotor.

Also the following relationships are used to transform the 'dq' to 'abc' reference frame.

$$\begin{bmatrix} I_{as} \\ I_{bs} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ \frac{-\cos\theta+\sqrt{3}\sin\theta}{2} & \frac{-\sqrt{3}\cos\theta - \sin\theta}{2} \end{bmatrix} \begin{bmatrix} I_{qs} \\ I_{ds} \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} I`_{ar} \\ I`_{br} \end{bmatrix} = \begin{bmatrix} \cos\beta & \sin\beta \\ \frac{-\cos\beta+\sqrt{3}\sin\beta}{2} & \frac{-\sqrt{3}\cos\beta - \sin\beta}{2} \end{bmatrix} \begin{bmatrix} I`_{qr} \\ I`_{dr} \end{bmatrix} \quad (4)$$

$$I_{cs} = - I_{as} - I_{bs} \quad (5)$$

$$I'_{cr} = - I'_{ar} - I'_{br} \quad (6)$$

in this paper Matlab/Simulink based modeling is used for all the three reference frames as mentioned above for the analysis of dynamic behavior of the machine.

2. MATHEMATICAL MODELING

A three phase induction motor can be modeled with dqo axis transformation theory. In electrical engineering, direct-quadrature-zero (dqo) transformation is a mathematical transformation used to simplify the analysis of three phase circuits. In the case of balanced three phase

Circuits, application of the dqo transform reduces the three AC quantities to two DC quantities. It is often used in order to simplify the analysis of three phase synchronous machines. The dq0 transform first proposed in 1929 by R.H.park. in fact, the dqo transform is often referred to as Park's transformation. From dqo axis modeling.

$$[F_{dqo}] = [T_{dqo}]\,[F_{abc}] \tag{7}$$

Where

$$[T_{dqo}] = 2/3 \begin{bmatrix} \cos(\theta) & \cos(\theta-2\pi/3) & \cos(\theta+2\pi/3) \\ \sin(\theta) & \sin(\theta-2\pi/3) & \sin(\theta+2\pi/3) \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \tag{8}$$

The voltage balance equation for the dqo coils in arbitrary reference frame is:

$$[V^c] = [Z^c]\,[I^c] \tag{9}$$

Where $[V^c]$ and $[I^c]$ represents '4X1' column matrices of voltage and current and they are given as $[V^c_{ds}V^c_{qs}V^c_{ds}V^c_{qr}]^T$ and $[I^c_{ds}\ I^c_{qs}\ I^c_{dr}\ I^c_{qr}]^T$ respectively and, $(4\chi4)$ impedance matrices $[Z_c]$ is given as,

$$[Z_c] = \begin{bmatrix} R_s+L_sp & w_cL_s & L_mp & w_cL_m \\ -w_cL_s & R_r+L_sp & -w_cL_m & L_mp \\ L_mp & (w-w_r)L_m & R_r+L_rp & (w_c-w_r)L_r \\ -(w_c-w_r)L_m & L_mp & -(w_c-w_r)L_r & R_r+L_rp \end{bmatrix} \tag{10}$$

2.1 MODELING IN STATIONARY FRAME

Under the stationary reference frame the speed of the reference frame is zero, i.e. $w_c = 0$, which is substituted into voltage balance equation (9), hence the resulting model will be,

$$[V] = [Z]\,[I] \tag{11}$$

Where [V] and [I] represents '4X1' column matrices of voltage and current and they are given as $[V_{ds}V_{qs}V_{ds}V_{qr}]^T$ and $[I_{ds}\ I_{qs}\ I_{dr}\ I_{qr}]^T$ respectively and, (4X4) impedance matrices [Z] is given as,

$$[Z] = \begin{bmatrix} R_s+L_sp & 0 & L_mp & 0 \\ -w_cL_s & R_r+L_sp & -w_cL_m & L_mp \\ L_mp & (w-w_r)L_m & R_r+L_rp & (w_c-w_r)L_r \\ -(w_c-w_r)L_m & L_mp & -(w_c-w_r)L_r & R_r+L_rp \end{bmatrix} \tag{12}$$

and, the electromagnetic torque equation is given as

$$T_e = \frac{3}{2}\frac{p}{2} L_m(I_{ds}\, I_{qr} - I_{qs}I_{dr}) \tag{13}$$

If the motor terminals are directly connected to the bus bar and bus bar voltage are,

$$V_{as} = V_{max}\cos(w_st+\alpha)$$
$$V_{bs} = V_{max}\cos(w_st+\alpha-2\pi/3)$$
$$V_{cs} = V_{max}\cos(w_st+\alpha+2\pi/3) \tag{14}$$

Then using the park's transformation the terminal voltage become such as

$$V_{ds} = V_{max}\cos(w_st+\alpha)$$
$$V_{qs} = -V_{max}\sin(w_st+\alpha) \tag{15}$$

2.2 MODELING IN ROTOR FRAME

Under the rotor reference frame the speed of the rotor reference frame is $w_c=w_r$, and angular position is θ_c-θ_r, now the induction motor model in rotor reference frame is obtained by substituting r in superscript for rotor reference frame and $w_c= 0$ in equation (9). Hence the equation is given as;

$$[V^r] = [Z^r]\,[I^r] \tag{16}$$

Where $[V^r]$ and $[I^r]$ represents '4X1' column matrices of voltage and current and they are given as $[V^r_{ds}V^r_{qs}V^r_{ds}V^r_{qr}]^T$ and $[I^r_{ds}\ I^r_{qs}\ I^r_{dr}\ I^r_{qr}]^T$ respectively and, (4X4) impedance matrices $[Z^r]$ is given as,

$$[Z^r] = \begin{bmatrix} R_s+L_sp & w_rL_s & L_mp & w_rL_m \\ -w_rL_s & R_s+L_sp & -w_rL_m & L_mp \\ L_mp & 0 & R_r+L_rp & 0 \\ 0 & L_mp & 0 & R_r+L_rp \end{bmatrix} \tag{17}$$

And, the electromagnetic torque equation is given as

$$T_e = \frac{3}{2}\frac{p}{2} L_m(I^r_{ds}\, I^r_{qr} - I^r_{qs}I^r_{dr}) \tag{18}$$

And abc to dq0 variables transformation is obtained by substitute the θ_c=θ_r into equation (8), and defined as

$$[T^r_{abc}] = 2/3 \begin{bmatrix} \cos(\theta_r) & \cos(\theta_r-2\pi/3) & \cos(\theta_r+2\pi/3) \\ \sin(\theta_r) & \sin(\theta_r-2\pi/3) & \sin(\theta_r+2\pi/3) \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \tag{19}$$

Similarly if the motor terminals are directly connected to the bus bar and bus bar voltage are same as equation (14). Then using the Park's transformation, the terminal voltages become such as

$$V_{ds} = V_{max}\cos(sw_st+\alpha)$$
$$V_{qs} = -V_{max}\sin(sw_st+\alpha) \tag{20}$$

The dq voltage are therefore of slip frequency and d axis rotor current behaves as the phase a rotor current.

2.3 MODELING IN SYNCHRONOUS FRAME

Under the synchronous reference frame the speed of the reference frame is $w_c=w_s$, and angular position is $\theta_c=\theta_r= w_s t$, now the induction motor in synchronous reference frame is obtained by substituting e in superscript for synchronous reference frame and $w_c = w_s$ in equation (9). Hence the equation is given as

$$[V^e] = [Z^e]\,[I^e] \qquad (21)$$

Where $[V^e]$ and $[I^e]$ represents '4X1' column matrices of voltage and current and they are given as $[V^e_{ds} V^e_{qs} V^e_{ds} V^e_{qr}]^T$ and $[I^e_{ds}\ I^e_{qs}\ I^e_{dr}\ I^e_{qr}]^T$ respectively and, (4X4) impedance matrices $[Z^e]$ is given as

$$[Z^e] = \begin{bmatrix} R_s+L_s p & w_s L_s & L_m p & w_s L_m \\ -w_s L_s & R_s+L_s p & -w_s L_m & L_m p \\ L_m p & (w_s-w_r)L_m & R_r+L_r p & (w_s-w_r)L_r \\ -(w_s-w_r)L_m & L_m p & -(w_s-w_r)L_r & R_r+L_r p \end{bmatrix} \qquad (22)$$

And, the electromagnetic torque equation is given as

$$T_e = \frac{3}{2}\frac{p}{2} L_m (I^e_{ds} I^e_{qr} - I^e_{qs} I^e_{dr}) \qquad (23)$$

And abc to dq0 variables transformation is obtained by substitute the $\theta_c=\theta_r=w_s t$ into equation (8), and is defined as

$$[T^e_{abc}] = 2/3 \begin{bmatrix} \cos(\theta_s) & \cos(\theta_s - 2\pi/3) & \cos(\theta_s+2\pi/3) \\ \text{Sin}(\theta_s) & \sin(\theta_s - 2\pi/3) & \sin(\theta_s + 2\pi/3) \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \qquad (24)$$

Similarly if the motor terminals are directly connected to the bus bar and bus bar voltages are same as equation (14). Then using the Park's transformation the terminal voltage become such as,

$$V_{ds} = V_{max}\cos\alpha$$

$$V_{qs} = -V_{max}\sin\alpha \qquad (25)$$

This means the stator dq voltages are dc quantities and the mechanical motion is described by

$$Pw_r = (T_e - T_L)/J \qquad (26)$$

3. SIMULATION RESULT & DISCUSSION

All described reference model such as stationary reference model, rotor reference model and synchronous reference model has been tested on a three phase squirrel cage induction motor rated 3Hp, 460V, 60Hz and 4 Pole to analyze the dynamic behavior of machine. And the obtained simulated results are shown under these different operating reference condition, And three phase squirrel cage induction machine are having the following parameters as shown in Table.

Parameter of three phase induction machine

Power rating,	3Hp
Voltage (line to line),	460 V
Frequency	60Hz
Pole pair,	4
Stator resistance,	5.12Ω
Stator inductance,	0.0597(H)
Rotor resistance,	3.85(H)
Rotor inductance,	0.0597(H)
Magnetizing inductance,	0.2132(H)

3.1 STATIONARY REFERENCE FRAME

Under the stationary reference frame the d-axis are fixed and thus coincidence with the axis of the stator phase a winding. It means that at the same speed as it occurs over the stator, the stator mmf wave moves over this reference frame. When analyzed the transient behavior which involving the stator variable to use this stationary reference frame phase 'A' winding. Hence d-axis stator variable under stationary reference frame behave like the same as the stator phase 'A' variable of the motor.

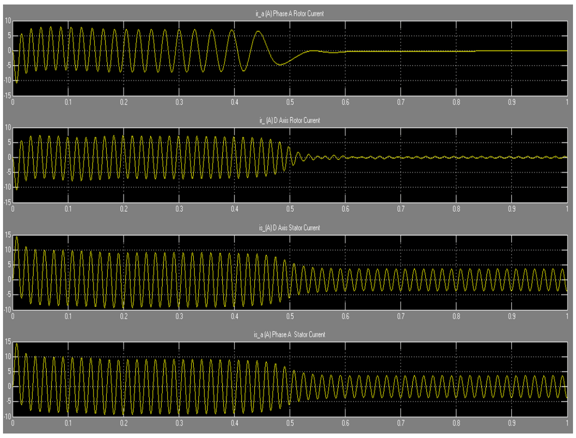

Fig. 1 shown the starting up current using stationary reference frame.

3.2 Rotor Reference frame

For the analysis under rotor reference frame, the d-axis of the reference frame is moves at the same speed as the rotor phase 'A' winding and coincident with its axis, under this reference frame it should be expected that the behavior of the phase 'A' current and d- axis current would be identical. Figure (2) shows how d axis rotor current and phase 'A' rotor current when the rotor is standstill at 60Hz are initial but gradually changes to slip frequency at normal running speed.

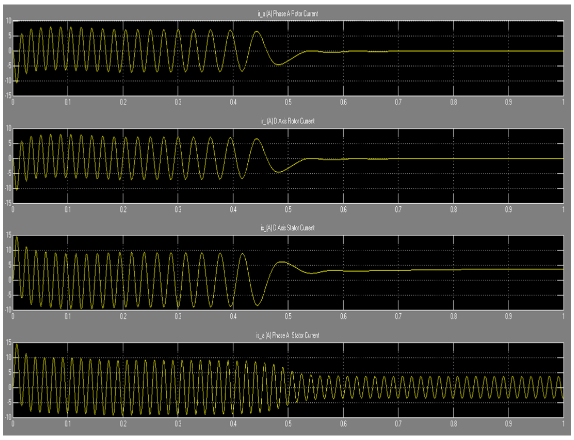

Fig.2 Shown the starting up current using rotor reference frame

3.2 SYNCHRONOUS REFERENCE FRAME

At the synchronous speed when reference frame is rotating, stator and rotor both are rotating at different speed relative to it. However, stator and rotor dq variables, space field mmf are constant when the stator and rotor speed rotating at the same speed as the reference speed. Whereas the steady state variables are in this reference frame are constant and do not varied sinusoidal with the time and actual variable are at 60 Hz and slip frequencies respectively.

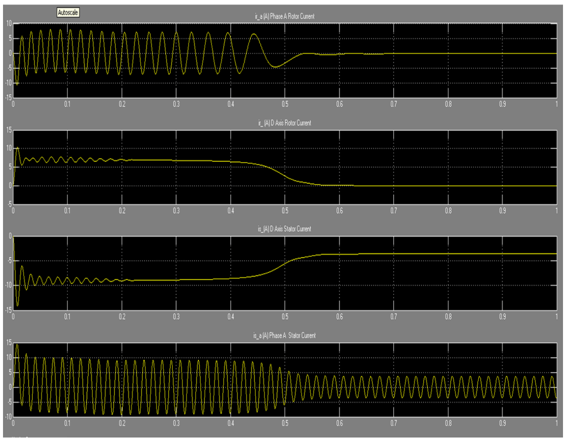

Fig.3 Shown the starting up current using rotor reference frame

4. CONCLUSIONS

In this paper Matlab/SIMULINK is used to analysis of transient performance of three phase induction motor by using stationary reference frame , rotor reference frame and synchronous reference frame and sufficient time span is included to study the complete performance characteristics of three phase squirrel cage induction motor. The simulated result has been concluded as in phase 'A' and d axis, the stator and rotor current following the different pattern under the different reference frame such as there is no difference between stator current (I_{as}) and d-axis stator current (I_{ds}), as shown in figure (1) under stationary reference frame. From figure (2) its shown that there is no difference between phase 'A' stator current (I_{as}) and d-axis stator current (I_{ds}) as shown in figure (2) under rotor reference frame. and there is no resemblance between phase 'A' stator current (I_{as}) and d-axis stator current (I_{ds})and phase 'A' rotor current (I_{as}) and d-axis rotor current (I_{ds}) as shown in figure (3) under synchronous reference frame. However, the solution of reference frame does not effects the speed rise, setting time, and maximum inrush current for the machine and phase 'A' rotor current not appears to be identical for three reference frame. From the figures of three reference frames its observed that the rotor current in phase 'A' does not appears to be identical. Hence rotor reference frame is very useful to look the transient effects on the rotor side of the machine.

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