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A Study on Influence of Induction Motor Model on Power System Stability

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1 INTRODUCTION

Induction motors are used as dynamic load in power system stability simulation[1]. The selection of the induction motor model affects the result of stability analysis significantly. So, it is important to assess the accuracy of the available models.

Induction motors are generally modeled in the frame synchronously rotating with system frequency. Different models of induction motors are available in different literatures[2]. These different models use different levels of approximations possibly resulting in the insufficient modeling of the behavior of induction motor. However, the comparative assessment of the accuracy of the responses of the different models[3] has not been done sufficiently yet.

In this paper, first, we develop induction motor models in a reference frame rotating in rotor speed. Secondly, the transient stability of a nine bus system will be evaluated for different motor models applied. The result of implementation of different models will be compared.

2 ANALYSIS OF INDUCTION MOTOR MODELS

2.1 Fifth, third and first order model in ω_e frame

The dynamics of induction motor can be represented by the set of five differential equations as shown in Equation 1. Here, $v_{qs}^e, v_{ds}^e, v_{qr}^{'e}, v_{dr}^{'e}$ represent the stator and rotor voltages, $\psi_{qs}^e, \psi_{ds}^e, \psi_{qr}^{'e}, \psi_{dr}^{'e}$ represent the stator and rotor fluxes, r_s, r_r are stator and rotor resistances, $i_{qs}^e, i_{ds}^e, i_{qr}^{'e}, i_{dr}^{'e}$ are stator and rotor currents, H is inertia constant and $\omega_r, \omega_b, \omega_e$ are the rotor speed, base frequency and supply frequency respectively. T_{em} is the electromagnetic torque and T_{mech} is the mechanical torque on the motor shaft.

The third order model can be obtained by neglecting the dynamics of the stator fluxes and the first order can be obtained by neglecting the dynamics of both the stator and rotor fluxes. It can be easily shown that this first order model is equivalent to the well-known model expressed by phasor quantities.

$$
\begin{aligned}
v_{qs}^e &= \frac{p}{\omega_b}\psi_{qs}^e + \frac{\omega_e}{\omega_b}\psi_{ds}^e + r_s i_{qs}^e \\
v_{ds}^e &= \frac{p}{\omega_b}\psi_{ds}^e - \frac{\omega_e}{\omega_b}\psi_{qs}^e + r_s i_{ds}^e \\
v_{qr}^{'e} &= \frac{p}{\omega_b}\psi_{qr}^{'e} + \left(\frac{\omega_e - \omega_r}{\omega_b}\right)\psi_{dr}^{'e} + r_r' i_{qr}^{'e} \\
v_{dr}^{'e} &= \frac{p}{\omega_b}\psi_{dr}^{'e} - \left(\frac{\omega_e - \omega_r}{\omega_b}\right)\psi_{qr}^{'e} + r_r' i_{dr}^{'e} \\
2H\, p\left(\frac{\omega_r}{\omega_b}\right) &= T_{em} - T_{mech}
\end{aligned}
\quad (1)
$$

$$where,\ p = \frac{d}{dt} : differential\ operator$$

The flux equation is given as

$$
\begin{bmatrix} \psi_{qs}^e \\ \psi_{ds}^e \\ \psi_{qr}^{'e} \\ \psi_{dr}^{'e} \end{bmatrix} =
\begin{bmatrix} x_{ls}+x_m & 0 & x_m & 0 \\ 0 & x_{ls}+x_m & 0 & x_m \\ x_m & 0 & x_{lr}'+x_m & 0 \\ 0 & x_m & 0 & x_{lr}'+x_m \end{bmatrix}
\begin{bmatrix} i_{qs}^e \\ i_{ds}^e \\ i_{qr}^{'e} \\ i_{dr}^{'e} \end{bmatrix} \quad (2)
$$

Here, x_{ls}, x_{lr}' and x_m are stator, rotor and mutual reactance respectively.

2.2 A problem in ω_e frame models

In transient/steady-state stability simulation framework, voltages and currents are shown by phasors for the purpose of reducing computational requirement. This phasor-based computation framework allows time step of 10 [ms] while instantaneous value-based computation requires time step less than 1 [ms].

In phasor-based framework, both slow and step changes in phasors are permitted. This means phasors can change discontinuously and then results in unbounded frequency at the moment of discontinuity. This may result in discontinuous change in induction motor state variables or fluxes. The authors consider that this is not a proper situation and is to be avoided if possible.

2.3 New ω_r frame models

2.3.1 Derivation

In the ω_r frame model, the d and q axes are rotating with the axis of ω_r or rotor speed just like synchronous machine model. We can write the induction motor equations in ω_r frame, by transforming the equations in ω_e frame by suitable angle. The transformation angle is the difference between the angles of ω_e and ω_r axis. The angle between their axes is changing with time. Let the instantaneous transformation angle be $(\delta_e - \delta_r)$. This is related to the frequency as

$$\frac{d}{dt}(\delta_e - \delta_r) = \frac{d\delta_e}{dt} - \frac{d\delta_r}{dt} = \omega_e - \omega_r \quad (3)$$

Note that ω_e and ω_r are variable. Using this transformation angle, we can make the transformation matrix to transform the induction motor equations from ω_e frame into ω_r frame. So,

$$T(\delta_e - \delta_r) = \begin{bmatrix} \cos(\delta_e - \delta_r) & -\sin(\delta_e - \delta_r) \\ \sin(\delta_e - \delta_r) & \cos(\delta_e - \delta_r) \end{bmatrix} \quad (4)$$

This discussion suggests that we need one more integrator to obtain δ_r. Now, the transformation from ω_e frame to ω_r frame can be performed as,

$$\begin{bmatrix} v_{qs}^r \\ v_{ds}^r \end{bmatrix} = T(\delta_e - \delta_r) \begin{bmatrix} v_{qs}^e \\ v_{ds}^e \end{bmatrix} \quad (5)$$

So our new induction motor equations in ω_r frame can be written as

$$v_{qs}^r = \frac{p}{\omega_b}\psi_{qs}^r + \frac{\omega_r}{\omega_b}\psi_{ds}^r + r_s i_{qs}^r$$

$$v_{ds}^r = \frac{p}{\omega_b}\psi_{ds}^r - \frac{\omega_r}{\omega_b}\psi_{qs}^r + r_s i_{ds}^r$$

$$v_{qr}^{'r} = \frac{p}{\omega_b}\psi_{qr}^{'r} + r_r^{'} i_{qr}^{'r}$$

$$v_{dr}^{'r} = \frac{p}{\omega_b}\psi_{dr}^{'r} + r_r^{'} i_{dr}^{'r} \quad (6)$$

The equation of motion of the rotor and the flux equations are same as that of ω_e frame model. The rotor angle for the coordinate transformation can be evaluated as

$$p\delta_r = \left(1 - \frac{\omega_r}{\omega_b}\right) \quad (7)$$

where the definitions of the symbols are same as those of ω_e frame model. The lower order models can be derived by neglecting the dynamics of the stator and rotor fluxes. The flux equation is similar to that of ω_e frame as in Equation 2, but the quantities would be in ω_r frame.

2.3.2 Discussion on computational requirement

While the steady state quantities are constant in ω_e frame, those are sinusoidal in ω_r frame as shown in Figure 2.3.1. Although the quantities are sinusoidal in ω_r frame, the computational requirement is not high because, in general, the slip frequency is below 1 [Hz]. The time step of 10 [ms], which is commonly used in stability simulations, can be used without the loss of accuracy.

3 STABILITY COMPARISONS

The stability limit or the maximum power transfer with the implementation of induction motor models has been evaluated in terms of loading levels. The maximum loading level (LL) is defined as the maximum percentage of bus load at which the rotor angle stability of the all the generators are maintained after the disturbance in the system. The motor ratio was fixed to 30% and 50% of the bus load. The results are tabulated in the Table 1. The maximum power transfer of lower order models is larger than that of higher order models. The result shows the optimistic characteristics of lower order models. In addition it is shown that static load model will result in optimistic result.

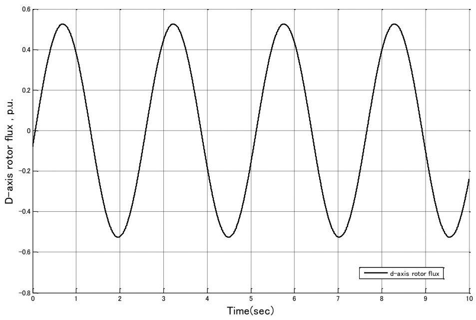

Figure 2.3.1 State variable (d-axis rotor flux) in ω_r frame

Table 1. Load Levels for stability limit

	Load Level	
Model	**30% Motor Load**	**50% Motor Load**
Fifth Order	1.073	0.750
Third Order	1.198	0.869
First Order	1.271	0.882
Static Loads	1.781	

Similarly, Table 2 shows the eigenvalues of the system that have poor damping and significant oscillatory frequency. The results presented are for 30% of motor loads and 100% load level. When the motor loads are present, the first order model implementation gives the most optimistic stability solution.

Table 2. Comparison of eigenvalues for different models

Model	slow mode	fast mode
Fifth order	-0.199±j2.441	-0.720±j8.340
Third order	-0.191±j2.445	-0.717±j8.340
First order	-0.2195±j2.935	-0.717±j8.353
Static	-0.188±j2.937	-0.706±j8.367

4 CONCLUSIONS

The results of this paper are summarized.

1. The induction motor can be modeled in rotor reference frame which eliminates the possible discontinuity of state variables due to step change in phasors.
2. The implementation of lower order models gives the more optimistic result of the stability assessment.

6 REFERENCES

[1]. C. Concordia and S. Ihara, “Load representation in power system stability studies,” *IEEE Trans. Power App. Syst., vol. PAS-101, pp. 969-977, 1982*

[2]. B.C. Lesieutre, P.W. Sauer, M.A. Pai, “ Development and comparative study of induction machine based dynamic P,Q load models”, *IEEE Transactions on Power Systems, Vol. 10, No. 1, February 1995*

[3]. Y. Kataoka, T. Omata, “ On input/output variables of load model for stability studies”, *IEEJ Trans. Power and energy, no. 1347, 1999*