CHAPTER 5

INDUCTION MOTOR MODEL

In this chapter, induction motor model is presented in detail. Method for aggregating a group of induction motors into one equivalent model is described.

5.1 General

It is well known that induction machines are widely used in many applications. Industrial plants may consist of several large induction motors, even in household appliances induction motors are also widely used (e.g. air-conditioners, refrigerators, etc.).

As mentioned above, it can be seen that most power system loads contain a substantial of induction motors which are well known that can have primarily influence on dynamic responses of power system loads. Therefore, it appears necessary to model induction motor loads in a reasonable way for stability studies of power systems.

There are many methods for representing the behavior of induction motors due to change in applied voltage and frequency (i.e. constant impedance, approximate steady state behavior) [10]. The methods depend on the degree of accuracy desired in the representation.

However, in practical power systems it is not easy to model induction motor loads because

(1) great number of motors are usually encountered

(2) large differences exist in the electrical and mechanical parameters

(3) the induction motors are scattered in the distribution network

(4) exact representation of each motor cannot be considered because it may require enormous computational efforts [4,12].

Therefore, in a real power system it appears necessary to model a diverse group of induction motors by one equivalent motor.

Methods proposed here for modelling induction motor loads are discussed in the following sections.

5.2 Steady state model

Steady state characteristic of a induction motor is represented by consumed active and reactive power as function of voltage and frequency.

Induction motor is modelled by the standard equivalent circuit shown in Figure 5.1

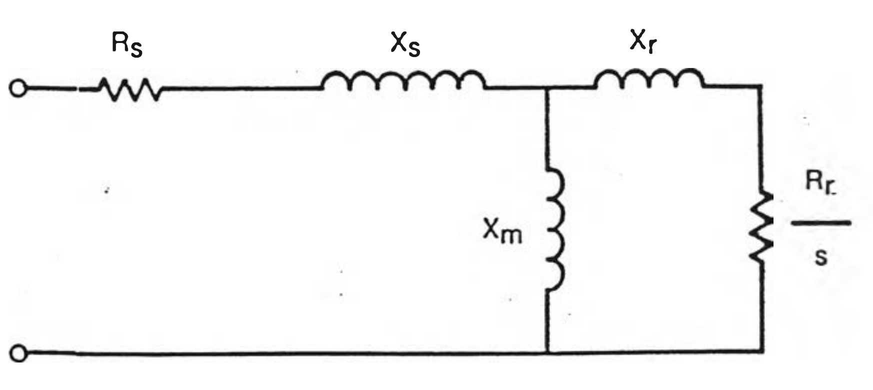

Figure 5.1 Induction motor equivalent circuit

The steady state characteristic is predicted by the following equation :

$$T_e = \frac{\frac{\omega_e}{\omega_b} X_M^2 r_r s |V_s|^2}{\left[r_s r_r + s\left(\frac{\omega_e}{\omega_b}\right)^2 (X_M^2 - X_{ss}X_{rr})\right]^2 + \left(\frac{\omega_e}{\omega_b}\right)^2 (r_r X_{ss} + s r_s X_{rr})^2}$$

This equation is solved in order to obtain induction motor slip at steady state condition by iteratively adjusting it until the electrical torque is equal to the mechanical load torque. The active and reactive power drawn by the motor are calculated by the following equations :

P = Re [(V**2/Z*)]

Q = Im [(V**2/Z*)]

The mathematical method for deriving steady state characteristic is described in detail in Appendix 1.

5.3 Dynamic model

To predict dynamic behavior of a induction motor, the inertia constant and load torque characteristic should be taken into account because these parameters have great effect on dynamic characteristic of induction motor.

In this work, the dynamic model of induction motor is derived by using the reduced-order model obtained by neglecting stator electric transients [22].

The voltage equations in terms of flux linkages expressed in the synchronously rotating reference frame are :

$$v_{qs} = Rs*Xrr/D*F_{qs} + w_e/w_b*F_{ds} - Rs*Xm/D*F_{qr}$$

$$v_{ds} = Rs*Xrr/D*F_{ds} - w_e/w_b*F_{qs} - Rs*Xm/D*F_{dr}$$

$$v_{qr} = Rr*Xss/D*F_{qr} + pF_{qr}/w_b - Rr*Xm/D*F_{qs} + (w_e - w_r)/w_b*F_{dr}$$

$$v_{dr} = Rr*Xss/D*F_{dr} + pF_{dr}/w_b - Rr*Xm/D*F_{ds} - (w_e - w_r)/w_b*F_{qr}$$

where

$$Xss = Xs + Xm$$

$$Xrr = Xr + Xm$$

$$D = Xss*Xrr - Xm**2$$

The meaning of the symbols used in the above equations are described in LIST OF PRINCIPAL SYMBOLS in this thesis.

The corresponding equations are :

$$v_{qs} = Rs*i_{qs} + w_e/w_b*F_{ds}$$

$$v_{ds} = Rs*i_{ds} - w_e/w_b*F_{qs}$$

$$v_{qr} = Rr*i_{qr} + (w_e - w_r)/w_b*F_{dr} + pF_{qr}/w_b$$

$$v_{dr} = Rr*i_{dr} - (w_e - w_r)/w_b*F_{qr} + pF_{dr}/w_b$$

The values of resistances and reactances are derived from the equivalent circuit in Figure 5.1.

The acceleration of the motor is represented by :

$$2*H*pw_r/w_b = Te - Tm$$

where

$$Te = Xm/D*(F_{qs}*F_{dr} - F_{qr}*F_{ds})$$

$$Tm = a + b*w_r + c*w_r**2$$

The active and reactive power are calculated as :

$$P = v_{ds}*i_{ds} + v_{qs}*i_{qs}$$

$$Q = v_{qs}*i_{ds} - v_{ds}*i_{qs}$$

These equations are solved by numerical and iterative method to derive active and reactive power drawn by the motor during system disturbances.

The method for solving these equations are presented in detail in Appendix 2.

5.4 Aggregate induction motor model

An important area of research in load modelling is the representation of induction motor groups by an aggregate model. As mentioned earlier, when load at a given bus include several induction motors, it is not convenient to model each motor individually. Thus, an aggregate motor model is necessary.

Several techniques for grouping induction motors to an aggregate model have been proposed [8,11-13,15-16]. Note that all aggregation methods are approximate in nature, therefore it is not necessary to use complex method. Instead, the method should be as simple as possible.

In this work, motor aggregation technique is developed. The method is based on motor rating weighted average. For this method, each parameter of the aggregate model is derived as the weighted average value of the respective parameter of individual motors in the group.

The equations used for this purpose are :

$$P_{mag} = \sum_{i=1}^{k} R_i * P_{mi} \;/\; R_{ag}$$

$$R_{ag} = \sum_{i=1}^{k} R_i$$

where P_m is each parameter of the induction motor model in per unit and R is the motor rating.

Motor parameters are those of the equivalent circuit shown in Figure 5.1 include inertia constant and load torque constants. The parameters are listed below :

Rs	stator resistance
Xs	stator reactance
Rr	rotor resistance
Xr	rotor reactance
Xm	magnetizing reactance
H	inertia constant
a,b,c	load torque constants

5.5 Motor parameters analysis

One of the most difficult tasks for load modelling is obtaining parameters for the model. For induction motor loads, in some cases only the power rating and number of units are known. It thus appeared necessary to estimate the motor parameters for use in the load model.

In order to investigate typical trends in parameters against motor ratings, individual motor information has been assembled from various manufacturers. The study is performed on 145 induction motors, range from 0.25 kW - 400 kW. The motors are low voltage three phase type, 50 Hz motors. Because the information does not directly give the values of motor parameters, therefore a method to evaluate motor parameters is required.

The method used here is similar to that used in ref.[15]. It is shown in Appendix 3.

Although individual motors of a given rating have different values of parameters, an attempt has been made to determine average values. Table 5.1 shows the average values of parameters derived from the mentioned method and manufacturer data.

Table 5.1

Average values of motor parameters

range from 0.25 - 400 kW.

kW	Rs	Xs	Rr	Xr	Xm	H
0.25	0.2512	0.1341	0.0443	0.1341	0.8338	0.0221
0.37	0.2048	0.1150	0.0658	0.1150	1.2480	0.0212
0.75	0.2004	0.1039	0.0424	0.1039	1.2640	0.0403
1.1	0.1865	0.1015	0.0457	0.1015	1.4174	0.0529
1.5	0.1785	0.0909	0.0401	0.0909	1.5686	0.0734
2.2	0.1498	0.0925	0.0410	0.0925	1.5799	0.0373
3.0	0.1432	0.0914	0.0473	0.0914	1.6270	0.0680
4.0	0.1087	0.0792	0.0449	0.0792	1.8496	0.0541
5.5	0.0971	0.0815	0.0351	0.0815	1.8671	0.1241
7.5	0.0895	0.0762	0.0369	0.0762	1.8321	0.0723
11.0	0.0905	0.0806	0.0334	0.0806	1.7705	0.1199
15.0	0.0803	0.0757	0.0319	0.0757	1.9066	0.0933
18.5	0.0725	0.0756	0.0259	0.0756	1.9825	0.1099
22.0	0.0727	0.0768	0.0219	0.0768	1.9351	0.1411
30.0	0.0706	0.0721	0.0172	0.0721	2.1211	0.1734
37.0	0.0609	0.0767	0.0206	0.0767	1.9988	0.1537
45.0	0.0613	0.0793	0.0221	0.0793	2.0032	0.1362
55.0	0.0531	0.0744	0.0205	0.0744	2.0013	0.2735
75.0	0.0511	0.0726	0.0169	0.0726	2.0709	0.3638
90.0	0.0505	0.0701	0.0160	0.0701	2.1968	0.3614
110.0	0.0507	0.0807	0.0164	0.0807	2.1394	0.5057
132.0	0.0468	0.0740	0.0155	0.0740	2.1577	0.4978
160.0	0.0440	0.0737	0.0130	0.0737	2.1837	0.4683
200.0	0.0421	0.0791	0.0126	0.0791	2.2672	0.5116
250.0	0.0425	0.0783	0.0141	0.0783	2.1797	0.4382
280.0	0.0376	0.0729	0.0124	0.0729	2.4205	0.5240
315.0	0.0343	0.0739	0.0118	0.0739	2.2506	0.3915
355.0	0.0330	0.0729	0.0104	0.0729	2.2189	0.5196
400.0	0.0344	0.0764	0.0115	0.0764	2.1806	0.4286

From Table 5.1, it can be seen that most parameters, except magnetizing reactance and inertia constant, tend to decrease as the power rating increase. Inertia constant varies over a wide range from about 0.02 - 0.5.

If the data of induction motors are not known, we may estimate by using the values from Table 5.1. However, note that the given value of inertia constants refer only to the motors, the total inertias (motor plus load) can vary over a wide range due to motor loads. Thus, it is difficult to estimate the value of inertia constants. However, inertia constants contribution of loads such as pumps, compressors, fans, spinning machines etc. are at least equal to that of the motors [11]. Therefore, we may assume that the inertias of motors and loads are equal.

5.6 Conclusions

Induction motor is modelled by reduced-order model which neglect stator transients. Aggregate motor model is developed for grouping several motors into one equivalent. The aggregation technique is based on motor rating weighted average. Finally, method is proposed to estimate motor parameters if the data is not available.