

COMPARISON OF AGGREGATION OF SMALL AND LARGE INDUCTION MOTORS FOR POWER SYSTEM STABILITY STUDY

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ABSTRACT

Aggregation of different sizes of induction motors (IM) connected to a power system has diverse precision on the identification of the aggregate model parameters. Earlier work on the aggregation accuracy of various motors sizes has not been extensively identified. Also, IM loads forms the highest component in power system load. Therefore, the paper proposes to compare the accuracy of the aggregate model parameters of a group of IM of different sizes and validate the results by comparing with the individual induction motor parameters. The simulations and the analysis are carried out using Matlab/Simulink-based software package. The performance of the developed model show that, small-scale induction motors gives better accuracy of the aggregate motor parameter when compared with large-scale motor parameters. It is found that the proposed small-scale aggregation model gives acceptably accurate results than the large-scale aggregation model and is good for power system stability analysis.

Keywords: Aggregate Model, Induction Motor, Parameter Accuracy, Matlab/Simulink.

1.0 INTRODUCTION

Induction motors are the main dynamic loads in an electric power system. The power system consists of many small sized and large sized induction motors consuming power in a power network. Therefore, for improved analysis of the accuracy of model parameters identification, it is crucial to aggregate a group of induction motors and compare with the results of the individual motors. In facts, load model in large power systems has received increasing concerns in recent years for system operation and control, Kostrev *et al.*, (2008) and Chinn (2006). This poses a threat if aggregation accuracy of induction motors parameters is not extensively analyzed, and more so if a power system is weak and prone to disturbance. Besides, different power system load models have diverse impact on the simulation result of power system dynamic loads. However, it is impractical to accurately represent each individual load due to the intense computation process involved. Appropriate dynamic load model aggregation reduces the computation time and provides a faster and efficient model derivation and parameters identification. The accuracy of these different sizes of induction motors is investigated and analyzed.

Different aggregation methods have in the past been proposed by Hakim and Berg (1976); Franklin and Morelato (1994); Lem and Alden (1994); Pillay *et al.*, (1997); Bing *et al.*, (2010). However, this paper discussed the method of induction motor aggregation as proposed by Karakas *et al.*, (2009) and Muriuki *et al.*, (2012). The goal of this paper is to represent and compare the accuracy of the aggregation of different sizes of induction motor model using a single equivalent motor model thereby reducing the computation time for large power system. The three-phase squirrel cage induction motors are connected separately to a common bus in a power system using their equivalent circuits when operating in the no-load and locked-rotor conditions. In the former operating conditions, it is assumed that the slips of all induction motors are equal to zero while for the latter the slip is equal to unity. The aggregation method is based on thevenin's theory of electrical network. The simulation is carried out using Matlab/Simulink. The comparison of the different sizes of induction motor aggregation is investigated using the IEEE 16 bus standard test system found in literature.

2.0 METHODOLOGY

2.1 Aggregation of Induction Motors

Simulation of induction motors is computationally feasible only if the group of individual three-phase single-cage-rotor induction motors are accurately aggregated as single equivalent motor model.

Aggregation of motors involves making some assumptions and therefore, this paper assumed the following:

- i) All the motors are of the same type and are connected in parallel and at the same bus with no other load types.
- ii) The output power for each sizes of motor is maintained for ease of comparison for the two sizes of IM while the same number of poles is maintained.
- iii) The equations used to obtain the aggregate model apply the equations proposed by Karakas *et al.*, (2009) see equation in (1) until (21) respectively.

Figure 1 Shows the equivalent circuit of the aggregate induction motor load, where R_s -stator resistance, X_s -stator reactance, R_r -rotor resistance, X_r -rotor reactance, X_m - magnetizing reactance and S -Slip of the induction motor respectively whose parameters of the aggregate model are identified.

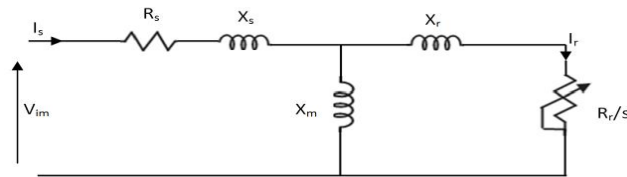


Figure 1: Equivalent circuit model of a three phase induction motor.

2.2 Dynamic Load Models

Numerous researches have shown that static load models are not suitable in describing the actual power system behaviour under most of the power system operating conditions. It is however, crucial to note that dynamic load models are the significant load in power system covering 60 % of the total power system load. Therefore, it is better to have dynamic load models which accurately represent the behavior of the load under most of the operating conditions. This is due to their innate behaviour of having inductance and capacitance that store some energy in the rotating parts (rotor) of the machines. Based on this reason, the induction motors are used as dynamic load that are compared to identify their suitability in aggregation. A dynamic load model is a model that expresses the active and reactive power at any instant of time as functions of the voltage magnitude and frequency at past instants of time and, usually, including the present instant. Normally, differential equations are used to represent such kind of loads. To describe the dynamic characteristic of the load, a non-linear dynamic load model with exponential recovery is considered in different types of dynamic load model as discussed in subtopic 2.2.1 and 2.2.2.

2.2.1 Differential model

The Differential model is presented a set of non-linear equations, where active and reactive powers have a nonlinear dependency on voltage Navarro (2002).

$$T_{Pr} \frac{dP_r}{dt} + P_r = P_0 \left(\frac{V}{V_0} \right)^{\alpha_s} - P_0 \left(\frac{V}{V_0} \right)^{\alpha_t} \quad (1)$$

$$P_T = P_r + P_0 \left(\frac{V}{V_0} \right)^{\alpha_t} \quad (2)$$

$$T_{qr} \frac{dQ_r}{dt} + Q_r = Q_0 \left(\frac{V}{V_0} \right)^{\beta_s} - Q_0 \left(\frac{V}{V_0} \right)^{\beta_t} \quad (3)$$

$$Q_T = Q_r + Q_0 \left(\frac{V}{V_0} \right)^{\beta_t} \quad (4)$$

Where α_t -transient active and load dependence, T_p -active load recovery time, α_s is the steady state active load-voltage dependence, V_0 and P_0 are the initial voltage and power consumption, P_r is the active power recovery and P_T is the total active power response.

2.2.2 Slip dynamic load model

The 2nd example of dynamic model is slip dynamic load model: the model is based on the effect of both static and dynamic load in the power system. The former dynamic model is commonly applied in the analysis of dynamic characteristics of power system load. In order to analyze the suitability and accuracy of the aggregated induction motors parameters Table 1 and Table 2 below classify small scale and large scale typical induction motor parameters.

Table 1: Typical Parameters for individual small induction motors.

HP	RS	Rr	XS	Xr	Xm
3	0.02	0.037	0.035	0.035	1.21
25	0.022	0.047	0.05	0.05	1.95
50	0.015	0.040	0.053	0.053	2.31
100	0.011	0.047	0.053	0.053	2.51

Table 2: Typical Parameters for individual large induction motors.

HP	RS	Rr	XS	Xr	Xm
500	0.0185	0.0132	0.0851	0.0851	3.8092
800	0.0148	0.0106	0.0808	0.0808	4.0702
1500	0.0118	0.0078	0.0797	0.0797	4.2026
2250	0.0092	0.0071	0.0718	0.0718	4.1388

2.3 Case Study: Test System Description

A Charles Gross 16 bus test system model was used in the analysis of the accuracy of aggregated small-scale and large-scale IM parameters. It consists of nine lines, three generators, and seven load points. The three generators are a steam plant located at Rogers, a hydrogenation plant at Russel Dam and a tie line to an external system connected at Lowry substation. The cities Grigsby, Feasterville, Philipsburg and Honnell represent the major load centers. The hydrogenation plant at Russel Dam and the steam plant at Rogers also take significant loads from the system. The parameters of the system used for analysis applied refer to Muriithi *et al.*, (2011). Bus 3 of the 16 bus was selected for analysis of the system as detailed below:

Total bus load = 10 Mw

Static load = 8.32 Mw

Dynamic load = (10-8.32) Mw = 1.68 Mw

1.68 Mw = $(1.68 \times 6 / 746)$ Hp = 2,250 Hp

3.0 SIMULATION RESULTS

The simulations were performed using Matlab/Simulink for obtaining and comparing the accuracy of the aggregate small-scale and large-scale induction motor parameters in a power system. The aggregate small-scale and large-scale induction motor parameters are shown in Table 3 and Table 4 respectively. By comparing these results with the typical motor parameters in table 2 and 3, it clearly shows that small aggregate motor parameters give better accuracy.

Table 3: Small-scale aggregate IM with typical data

HP	P(HP)	No of IM	Rs	Rr	Xs	Xr	Xm
2250	3	750	0.02	0.037	0.035	0.035	1.21
2250	25	90	0.0219	0.0472	0.0498	0.0498	1.95
2250	50	45	0.0150	0.0402	0.0532	0.0532	2.306
2250	100	23	0.011	0.0472	0.0532	0.0532	2.512

Table 4: Large-scale aggregate IM with typical data

HP	P(HP)	No of IM	Rs	Rr	Xs	Xr	Xm
2250	2250	1	0.0185	0.0132	0.0852	0.0852	3.809
2250	1500	2	0.0148	0.0106	0.0808	0.0808	4.07
2250	800	3	0.0118	0.0078	0.0797	0.0797	4.2026
2250	500	5	0.0090	0.0071	0.0718	0.0718	4.139

Figure 2 (a) and Figure 2(b) shows the result of the aggregate and individual active and reactive power of the small and large-scale induction motors. The results demonstrate that small motors have better accuracy in aggregation of the active and reactive powers, rather than the large scale IM. This is validated by the closeness of

the curves of the aggregate and the individual active and reactive power of the small motors. Similarly, Figure 3 (a) and Figure 3 (b) shows the response of the stator phase current for the aggregate and individual induction motors. It is seen that there are small discrepancies in time domain responses from the model developed. However, small-scale aggregate motors gives a good agreement compared with the results of large-scale aggregate motors. Figure 6 and Figure 7 shows an almost similar model characteristic for stator phase A current for both individual and aggregate motors thereby, validating the results.

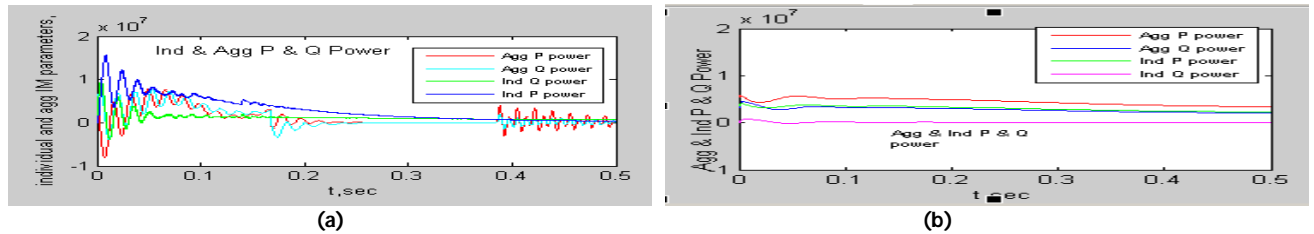


Figure 2: Active and reactive power of individual and aggregate induction motor at (a) large-scale, (b) small-scale.

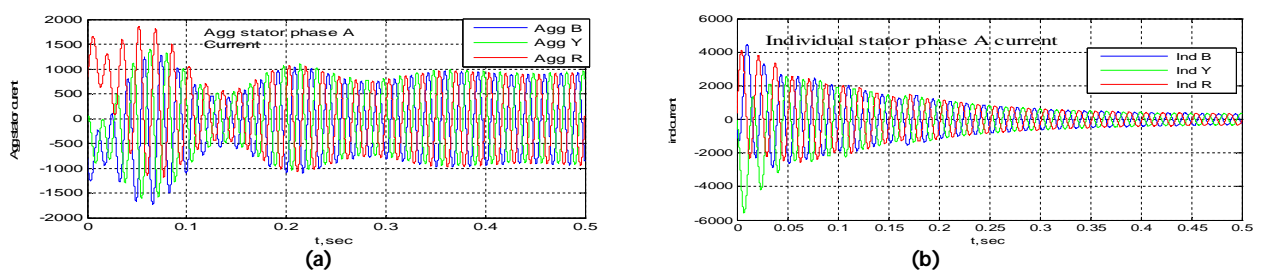


Figure 3: Responses of large-scale induction motor stator phase A current (a) aggregate, (b) individual.

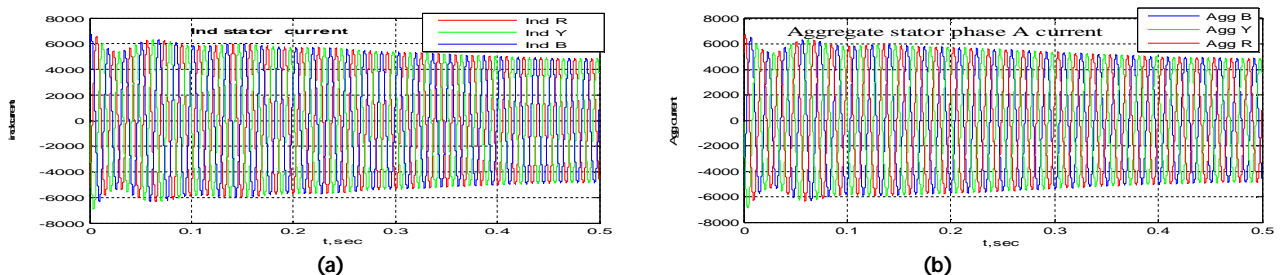


Figure 4: Responses of large-scale induction motor stator phase A current (a) individual, (b) aggregate.

4.0 CONCLUSION

This paper has presented the comparison of individual and the aggregate small and large-scale three-phase single-cage-induction motors connected at a common bus. A Matlab code was developed for aggregation of the motor parameters. The aggregation method based on no-load and locked-rotor gives better accuracy in identification of the aggregate motor stator and rotor parameters. The validity of the result has been proved by comparing the simulation results of the aggregate model of the small and large-scale motors with those of the individual induction motors. The accuracy of the aggregation of IM parameters depends on the sizes of the motor and the parameters to be identified. Therefore, depending on the parameters of the motor aggregated, the parameters of the aggregate small-scale induction motors closely resemble that of the individual induction motor parameters hence, gives better parameter accuracy which is crucial for power system analysis.

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