SUITABILITY OF AGGREGATION METHODS OF INDUCTION MOTOR MODELS FOR TRANSIENT STABILITY LOAD MODELING OF KENYA POWER TRANSMISSION AND DISTRIBUTION SYSTEM.

Kenya Power Company
Kinyua J. M*[1], C. M. Muriithi
P.O. Box 30099-00100, Nairobi Kenya.
[1]jmuriuki5@kplc.co.ke, cmaina77@yahoo.com

ABSTRACT

Current trend indicate that there has been increase on power outage frequency. This has partly been as a result of unstable power system with very small security margin of operation. Therefore, this paper focusses on the voltage stability of aggregation of multiple induction motors (IM) connected in parallel on the same bus of a power system into a single equivalent model using two methods of aggregations.This has been necessitated by the strong effects that the non linear loads have on power system characteristics and therefore erroneous modeling of these devices continues to be an area of greater uncertainty and may cause voltage instability. Though various methods of aggregations have been used, comparison on their suitablity and accuracy has not been extensively explored. Appropriate dynamic load model aggregation reduces the computation time and provides a faster and efficient model derivation and parameters identification that are most sensitive to load dynamics. The simulations and analysis are carried out using MATLAB/SIMULINK.The accuracy of these methods is compared to identify the most suitable parameters aggregation method of IM model. Their performance is validated by evaluating the results obtained from industrial and standard individual IM and the aggregation model on IEEE 16 Bus standard system found in literature. Further, the transient characteristics due to voltage disturbances of the aggregate IM and that of original IM group are simulated and compared to check the effectiveness of the aggrgation methods on power system. The results obtained are suitable and practical.

Key words: **Aggregation methods, induction motor, Power system voltage stability**.

1 INTRODUCTION

Different aggregation methods have been applied for induction motor load representation by several researchers [1]-[5] as a single equivalent model for ease and speed of power system analysis. However, comparison on the accuracy of these methods has not been meticulous. The modeling of a group of induction motors is paramount in the dynamic analysis of induction motor (IM) since they contribute a significant proportion of power system loads. This high percentage of induction motor loads in the power system causes delay during normal voltage recovery under fault conditions. It is however not practical to model every individual induction motors and especially large number of individual IM during the simulation studies since this can be highly time-consuming; therefore, aggregate models (single-unit equivalent models) are often employed. The accuracy of the results obtained with aggregate models depends in part on the assumptions made when deriving the aggregate motor and varies from method to method; grouping criterion is used to classify homogeneous motors [4]. Further, the accuracy of the results depends on how good the models are.

It is well known that load modeling on system dynamics is crucial; however it is still a big challenge. This complexity is brought about by the fact that load consists of various components with various characteristics, which nevertheless has to be represented as an equivalent single model. Further, it is the consumer of power who decides the order in which to connect their power consuming devices, thus making it even more intricate.

The goal of this paper is therefore to represent and compare two methodologies of aggregation of the nonlinear characteristic of induction motor loads from common bus. The two methods are: transformer-type equivalent and aggregation based on no-load and locked-rotor condition. These are achieved by Simulation of a group of induction motor model using a single equivalent motor model and analyze their suitability on parameter identification of aggregate load model. Matlab-based software is utilized in the simulations and analysis. The test results clearly demonstrates that, aggregation methods are of varying degrees of accuracy and are dependent on the assumptions made on derivation of the aggregate motors. However, in this research, it has been proven that, the transformer equivalent type model is of low accuracy in the analysis of parameter identification as compared to [2]. The result further, demonstrates that, the rate of convergence for the latter method is prompt compared to the latter. The efficiency of the aggregate and individual IM is estimated using the IEEE 16 bus standard system.

11 METHODOLOGY

A) THE AGGREGATION OF MULTIPLE INDUCTION MOTOR LOADS IN A POWER SYSTEM

Generally, large portion of power system loads are induction motors and their aggregation for parameter identifications and transient stability study is critical. The simulation of large group of IM takes time; therefore, in order to reduce the computation time, reduced order modeling is applied to represent a group of motors with one or more aggregate motors. There are different aggregation methods proposed in the literature [1]-[5] and their accuracy depends on the assumptions made.

In this paper, an aggregation method based on steady state theory of induction motor modeling [2] and a transformer-type equivalent circuit [4] is used to represent induction motors. Induction motors have been used in this research to obtain an aggregate motor model and their parameter identification. Aggregation without making some assumptions can prove to be an intricate venture and therefore, in this paper the following were assumptions made: All the motors are of the same type and are connected in parallel and at the same bus with no other load types. The output power for each sizes of motor is maintained for ease of comparison under the two aggregation methods of IM while the same number of poles is maintained.

Bus 3 of the 16 bus was selected for analysis of the system as detailed below:

Total bus load=10Mw
Static load=8.32Mw
Dynamic load=(10-8.32)Mw=1.68Mw
1.68Mw=(1.68*^6/746)Hp=2250Hp **(1)**

Individual and aggregate motors whose total load was 2250hp were analyzed and various parameters of the induction motor identified both under steady-state operation and under transient fault

1) **TRANSFORMER-TYPE EQUIVALENT CIRCUIT MODEL**

It is a common practice to represent IM in a conventional equivalent circuit model as shown in fig 1; however, a transformer-type equivalent circuit model shown in fig. 2 has been used. The equations used to obtain the aggregate motor model and their parameters can be found in [4].

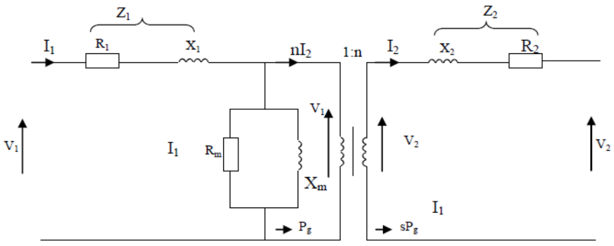


Fig. 1 Conventional equivalent circuit model

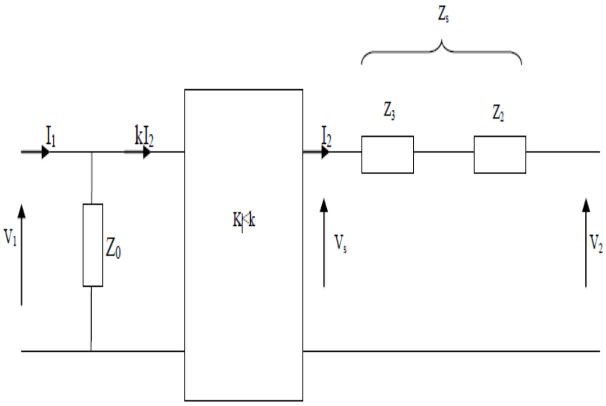


Fig. 2 Transformer-type equivalent circuit model

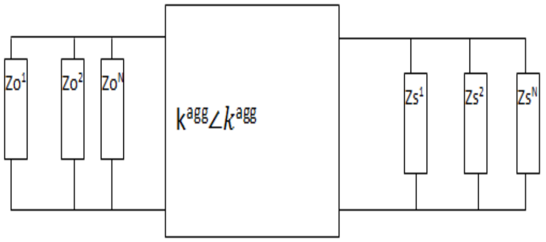


Fig. 3 Multimachine connected to the same bus

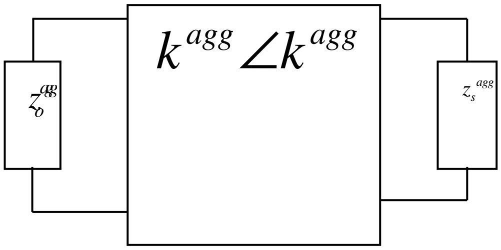


Fig 4 .The aggregate induction motor

In this paper k is taken as 0.98 and $\angle k = 0^{\circ}$ for the aggregate motor.

From fig .4, the following parameters can be obtained as shown below:

$$Z_O{}^{agg} = \frac{1}{\sum_{i=1}^{N} \frac{1}{[Z_1 + Z_M]^i}}, where Z_1 + Z_M = Z_O, Z_1 = R_1 + X_1, Z_M = R_C \,//\, X_M \qquad \textbf{(2)}$$

From fig 2 above, the equation below is derived

$$Z_S{}^{agg} = \frac{1}{\sum_{i=1}^{N} \frac{1}{Z_S{}^i}} where, Z_S = Z_2 + Z_3, \textbf{(3)}$$

Other derivations can be found from equations (3.3)-(3.9) in [4] respectively.

2) AGGREGATION OF A GROUP OF INDUCTION MOTOR BASED ON NO-LOAD AND LOCKED-ROTOR CONDITION.

This method is proposed by [6], where the parameters of the aggregate induction motor are determined from two operating conditions, i.e., no-load and locked-rotor conditions. However, the above method was first proposed by [7] and in this paper, the equivalent circuit parameters of the aggregation model are determined based on the same procedure. Fig.5 was been used for identification of model parameters of the aggregated IM. In the no-load operating conditions it is assumed that slips of all the induction motors are equal to zero while in the locked-rotor conditions the slips of all induction motors are equal to unity. The equations used to obtain the aggregate model can be found in [6] from (1)-(21) respectively. Fig .5 shows the equivalent circuits of the aggregate induction motor load, where R_S-stator resistance, X_S-stator reactance, Rr-rotor resistance, Xr-rotor reactance, Xm-magnetizing reactance and S- Slip of the induction motor respectively whose parameters of the aggregated model are identified.

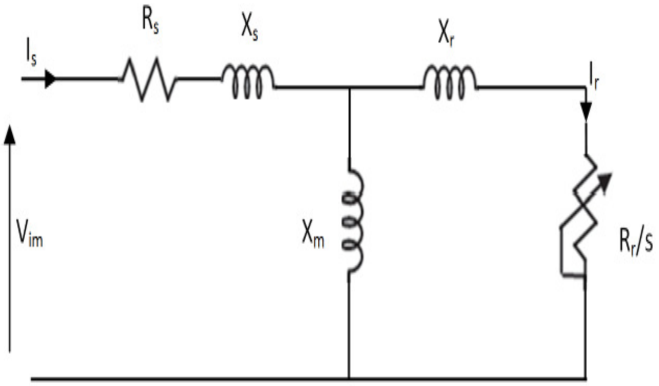


Fig. 5 Classical equivalent circuit model of an induction motor

111 GROUPING CRITERION

Generally, the above method is used to identify and group homogeneous motors. The inertia and open circuit time constant are often used to classify motors. In [7], the authors have developed a grouping criterion that may be expressed as:

$$G=a\times b\times H \quad \textbf{(4)}$$

$$a=Xm/R2 \quad \textbf{(5)}$$

$$b=(X1+X2)/R1+R2 \quad \textbf{(6)}$$

The group is homogeneous if $1 \le \frac{Gmax}{G\min} \le 2.5$ **(7)**

Using the above grouping criterion, the different sizes of motors are classified into different groups. Aggregation based on this method is then done for different motor groups separately to find aggregate motors from each group.

Based on [7], table 1 below shows the industrial load model parameters on individual induction motors.

Table .1Industrial per unit individual induction motor parameters

BUS	HP	R_S	Rr	X_S	Xr	Xm	H	RPM
3	3	0.02	0.04	0.03	0.03	1.21	0.71	1469
3	25	0.02	0.05	0.05	0.05	1.95	0.78	1435
3	50	0.02	0.04	0.05	0.05	2.31	0.79	1465
3	100	0.01	0.05	0.05	0.05	2.51	1.06	1485

Table. 2. Typical Parameters for individual small induction motors

HP	RS	Rr	XS	Xr	Xm	H	RPM
3	0.02	0.037	0.035	0.035	1.21	0.707	1760
25	0.022	0.047	0.05	0.05	1.95	0.528	1695
50	0.0153	0.0402	0.053	0.053	2.31	0.79	1750
100	0.011	0.047	0.053	0.053	2.51	1.06	1705

Table.3. Typical Parameters for individual large induction motors

HP	RS	Rr	XS	Xr	Xm	H
1000	0.0158	0.0104	0.0851	0.0851	7.63	0.711
500	0.0185	0.0132	0.0851	0.0851	3.81	0.527
250	0.0241	0.0141	0.0864	0.0864	3.03	0.659
500	0.0185	0.0132	0.0851	0.0851	3.81	0.527

1 Non Linear Model of Aggregated Power System

This model is used for analysis of large disturbance. The aggregated multi-machine power system can be represented by a set of first order nonlinear differential equations as in [9].

Normally, nonlinear equations are solved iteratively using the Runge Kutta Merson integration technique with typical step length of one Ms, additionally, the transient stability analysis of the multi-machine power system are performed using the nonlinear transient simulation program. From the simulation study it is possible to analyze voltage stability of the aggregated nonlinear model such as induction motor load

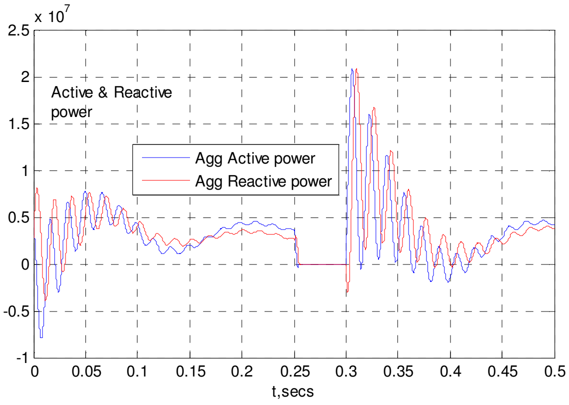
2 Linearized Model of Aggregated Power System

This model is used to analyze small signal stability of the power system. The signal of the multi-machine system in the matrix form is derived from the equations of the individual machines in the system after being linearized and combined to represent a multi-machine, multi-load system.

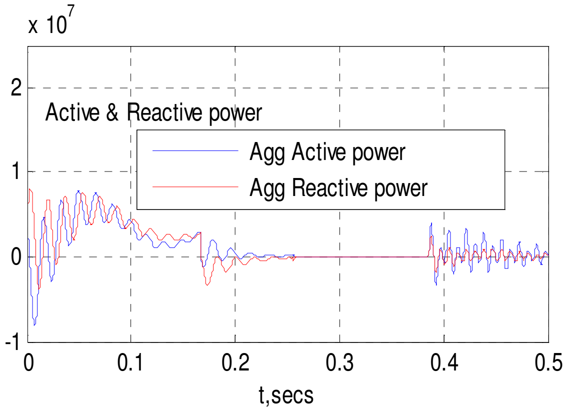
1V. DISCUSSION AND RECOMMEDATION

In this paper, an IEEE-16 bus standard network was used to show suitability and accuracy of aggregation methods in identification of motor parameters for the two methods of motors aggregations in a power system. Induction motors connected in parallel on bus **3** were considered for a case study. From the analysis of the two methods of aggregation it demonstrates that aggregation of IM based on two special operating conditions yields comparatively better results of the aggregated parameters; see table 4 and 5 in the appendix respectively, as opposed to the transformer-type equivalent method of aggregation as in table 6 and 7 respectively. Also noted is that, when the rotor is not turning the slip is 100% and at no-load, any increase in mechanical load will result in slip increase.

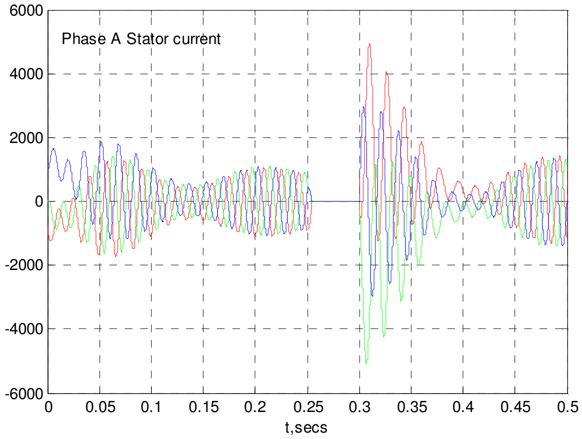
Figs 6 and 7 demonstrate the effect of steady-state and transient operation on aggregated induction motors. The aggregate model closely resembles that of the four individual motors. Figs 8 and 9 show the result of the Steady_state and transient operation of the individual induction motors. It is also noted that, under short-circuit fault, the induction motor loads draws high reactive power and this may cause the generator to lose its ability to act as constant voltage source because of the field current limits. This will cause the induction motor to demand more current to maintain the load thereby causing the terminal voltage to decrease and may even cause the motors to stall. This is clearly shown in figures 7(a) and 7(b) respectively.The graphs clearly draw a close similarity of the result obtained from the aggregation model to that obtained from the individual motors. For improved and accurate operation of the power system, it is crucial to aggregate the dynamic load that constituent the major load in a power system. By so doing, the frequency of the power system outage is reduced and this translate into low operational cost thereby optimizing on the power system operation.



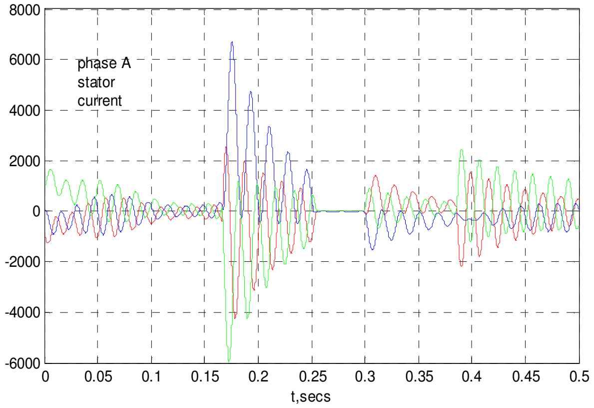
6(a): Active & reactive power response



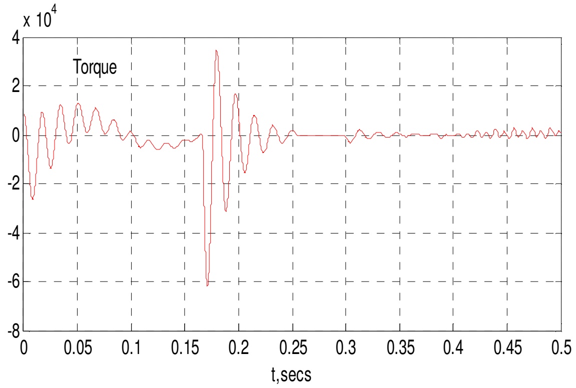
7(a): Aggregate active & reactive power responses

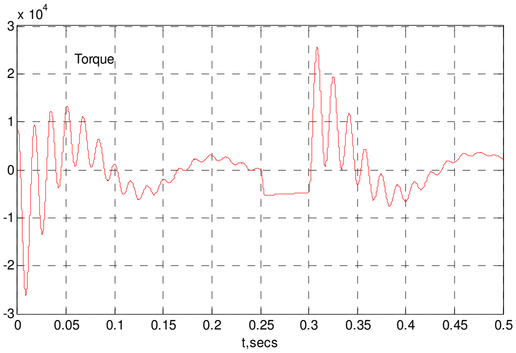


6(b): Aggregation of stator phase A current



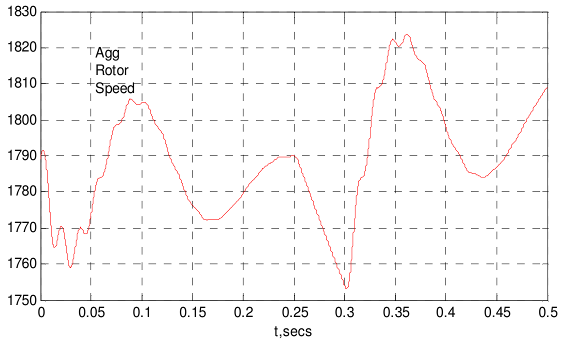
7(b) : Aggregate stator phase A current





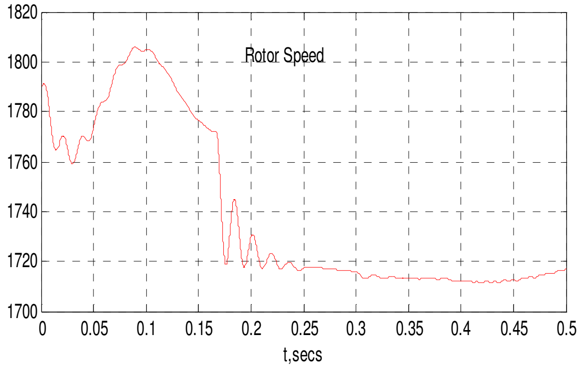
6(c): Torque aggregation

7(c): Torque aggregation



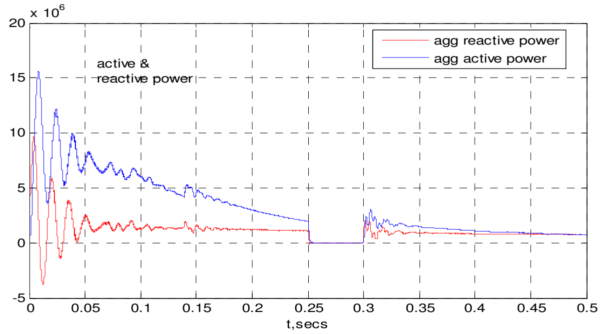
6(d) Aggregate rotor speed

Fig. 6. Steady-state operation of the aggregate IM

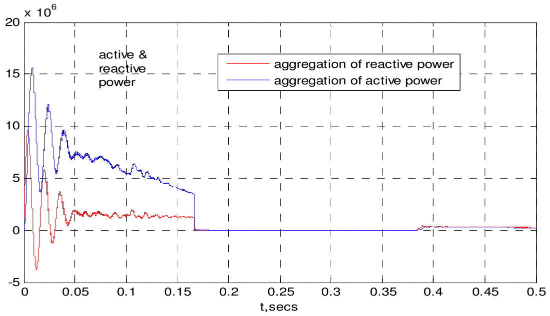


7(d): Aggregate rotor speed

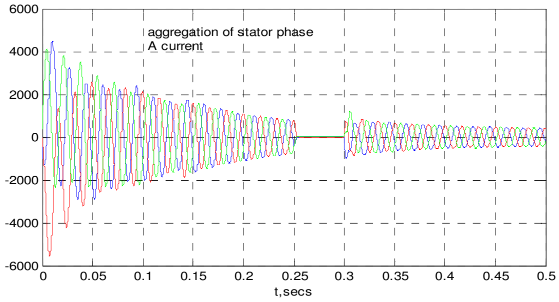
Fig. 7. Switching transient responses



8(a): Summation of the active & reactive power responses

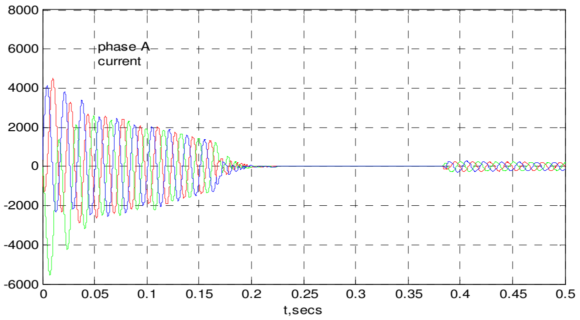


9(a): Summation of active & reactive power responses



8(b): Summation of the stator phase A current

Fig.8. Steady_state operation of the individual induction motors



9(b): Summation of the stator phase A current

Fig.9. Switching transient responses of individual induction motor

V CONCLUSION

It was found out that the transformer-type equivalent method of aggregation is inferior in identification of some of the aggregated motor parameters of a power system. This method was compared to aggregation of multiple induction motors based no-load and locked-rotor conditions which yielded better results that are comparable to individual motor parameters. This validated the latter method of aggregation employed.

The objective of this paper has been achieved. It has also been realized that unless a suitable method of aggregation is selected, the results is bound to generate some errors. This does not resonate well with system control operators and power system engineers whose responsibilities is to ensure that the power system is run with minimal disturbances. It was also proved that, method based on special operating conditions has good potential to be used in modeling of large motors in any complex power system because of its high accuracy. Therefore, for better analyses of power system, aggregation of IM is crucial for parameters identification and sensitivity to various power system operating conditions. Minimal disturbances to power system will translate into improved transmission and distribution efficiency thereby contributing to improved revenue.

REFERENCES

[1] M.M. Abdel Hakim and G.J.Berg “Dynamic Single Unit Representation of Induction Motor Groups”, IEEE Trans.On Power.Appar.Syst. Vol.PAS-95, (1976), PP.155-165.

[2] D.C Franklin and A. Morelato, “Improving Dynamic Aggregation of Induction Motor Models ’’, IEEE/PES 1994 Winter Meet., New York, Jan.30-Feb.3, (1994)

[3] T.Y.J.Lem and R.T.H. Alden, “Comparison of Experimental and Aggregate Induction Motor Responses,’’IEEE Trans.Power Syst., Vol.9, No.4, Pp.1895-1900, Nov. (1994)

[4] E.Pillay, S.M.A. Sabur and M.M.Haq, “A Model for Induction Motor Aggregation for Power System Studies’’, Electric Power Systems Research, Pp.225-228, Nov (1996).

[5] Zhao Bing, Tang Yong, Zhang Wenchao, “Model Representations of Induction Motor Group in Power System Stability,’’ 2010 International Conference on Computer Application and System Modeling (ICCASM 2010)

[6] Arif Karakas, Fangxing Li and Sarina Athikari, “Aggregation of Multiple Induction Motors Using MATLAB-Based Software Package” (2009)

[7] T. Uchida, H. Kai, T. Funabashi, T. “A Method for Aggregation of A Group of Induction Motor Load,’’ Power System Technology, Proceedings. Powercon (2000). International Conference, Vol 3, Pp 1683-1688

[8] M. Akbaba and S.Q. Fakhro, ‘New Model for Single-Unit Representation of Induction Motor Loads, Including Skin Effect, For Power System Transient Stability Studies,’’ Lee *Proc.-B,* 139 (6) (Nov. 1992)

[9] Abdalla, O.H.; Bahgat, M.E.; Serag, A.M.; El-Sharkawi “Dynamic Load Modeling and Aggregation in Power System Simulation Studies”, Power System Conference, (2008). MEPCON 2008. 12th International Middle-East,

APPENDIX

A) TABULATION OF RESULTS USING THE TWO METHODS OF AGGREGATION IN A POWER SYSTEM

1) AGGREGATION OF IM BASED ON NO-LOAD AND LOCKED-ROTOR CONDITION

Table 4. Aggregated IM parameters of different sizes of an industrial consumer

P_{agg}	R_{1agg}	R_2agg	X_{1agg}	X_{2agg}	XM_{agg}	V p.u	$SLIP_{agg}$	RPM_{ag}g
2250	0.02	0.04	0.03	0.03	1.21	1	0.027	1751
2250	0.02	0.05	0.05	0.05	1.95	1	0.0129	1777
2250	0.02	0.04	0.05	0.05	2.31	1	0.0073	1787
2250	0.01	0.05	0.05	0.05	2.51	1	0.0078	1786

Table.5. Typical aggregated IM parameters

P_{agg}	R_{1agg}	R_2agg	X_{1agg}	X_{2agg}	XM_{agg}	V p.u	$SLIP_{agg}$	RPM_{agg}
2250	0.02	0.037	0.035	0.035	1.21	1	0.0248	1755
2250	0.022	0.047	0.050	0.050	1.95	1	0.0121	1778
2250	0.013	0.0402	0.0530	0.0530	2.31	1	0.0074	1787
2250	0.011	0.047	0.053	0.053	2.51	1	0.0074	1787

2) TRANSFORMER-TYPE EQUIVALENT CIRCUIT METHOD OF AGGREGATION

Table 6. Aggregation of IM parameters of an industrial consumer

P_{agg}	R_{1agg}	R_2agg	X_{1agg}	X_{2agg}	XM_{agg}	V p.u
2250	0.02	2	0.03	0.03	1.47	1
2250	0.02	2.5773	0.05	0.05	2.45	1
2250	0.02	4.253	0.05	0.05	2.45	1
2250	0.01	5.3191	0.05	0.05	2.451	1

Table .7. Typical induction motor parameters aggregation

P_{agg}	R_{1agg}	R_2agg	X_{1agg}	X_{2agg}	XM_{agg}	V p.u
2250	0.02	1.85	0.035	0.035	1.715	1
2250	0.022	2.427	0.05	0.05	2.45	1
2250	0.0153	4.2766	0.053	0.053	2.597	1
2300	0.011	5	0.053	0.053	2.597	1