INDUCTION MOTOR LOAD FLOW SIMULATION WITH DIGSILENT POWERFACTORY

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Abstract— currently there is a growing interest in load modeling. This has gained momentum globally as an area of research by power industry engineers and academic researchers. The interests have been in the simulation of voltage stability and planning by utilizing static loads to represent the relationship between power and voltage. As, most load of the power systems are dynamic, there is need to diversify the study to capture dynamic load characteristics from the measured voltage disturbance.

It is a reality that, load representation that contributes significantly to voltage instability of the power system has received relatively less attention and continues to be an area of greater ambiguity. Therefore, there is a need for studies in power system load modeling and analyze their characteristics both under steady state and dynamic performance.

The paper proposes to solve the load flow equations of a power system with DigSilent induction motor (IM) models whose active and reactive power are estimated at each iteration. Simulations were carried out to demonstrate the effects of small and large faults in the system on the induction motor loads. In addition, the dynamic behavior of the IM with reference to various parameters was investigated. The results include system responses to sudden load changes and 3-phase faults. The simulation results indicate that the effect of the load model and their aggregation on system performance is reasonable and practical. It was also found that, representing the system loads by a single dynamic equivalent load reflects the actual stability of the power system. However, representing these loads by constant impedance load gives false indication of the system stability under dynamic behavior.

Keywords- Aggregation models, DigSilent induction motor load, load modeling, load flow, voltage stability

1 INTRODUCTION

Load flow calculations are used to analyze and investigate systems under steady-state and short-circuit free conditions therefore; it provides a foundation for power system voltage stability analysis. The load flow calculates the active and reactive power flows for all branches and the voltage magnitudes and phase for all nodes. Dynamic load models, as well as the phenomena of voltage instability, are of growing importance to the studies of power system dynamic [1]. Failure to represent the loads accurately leads to simulation results that do not agree with the actual response of the load and may affect the assessment of the power system security margin. A growing concern has been in the area of the dynamic behavior of the aggregate induction motor load which has continued to attract academic researchers and power system engineers in the studies of power system stability, planning and parameter identifications that have most effects on load dynamics. In the conventional load flow study, the active and reactive powers of the load buses are generally given [2].

Static load models are known to be inaccurate because they are static and time invariant and are therefore not sufficiently accurate to describe the load behaviors under various operating conditions. The uncertainty regarding load composition and the sufficiency of these static loads have been questioned in some publications [3]. However, the load behavior is mostly dynamic with the active and reactive powers being changed at any instant of time [4] and it is for this reason that dynamic load models are considered.

To solve load flow equations with IM loads, the motor active power is assumed to be fairly constant [5]. This assumption is valid when the motors are operated in the vicinity of small changes of the supply voltage, not below the stalling point while running a constant load [6].

This paper investigates modeling and aggregation of composite loads. The load flow equations will be solved by DIGSILENT PowerFactory induction motor models where Newton Raphson technique will be used to calculate the problem iteratively until it converges for a solution to be found. Additionally, the load flow algorithm has been modified to include the non linear characteristics of an aggregated induction motor load and DIGSILENT IM that calculates the active and reactive power in each iteration. The static component representing the aggregation o f the distributed static loads is achieved throughout transferring these loads to a boundary bus while conserving the phasor voltage and complex power at the motor buses as well as the boundary bus. The dynamic component, which represents the aggregation of IM loads distributed in the system, is obtained by in-cooperating the modified feeder parameters into the motor circuit of the corresponding motor. Simulation results ar e provided to demonstrate the accuracy of the aggregation of the IM load and model parameter identification that closely matches that of individual IM load.

11. METHODOLOGY

A) Power System Modeling

In order to investigate the dynamics of an industrial power system, a multi-machine model of the whole system is desirable. Such a model should include the dynamic interactions between mechanical and reactive modes of the machines in the system, in addition to accounting for the load variations and adequate models for these loads [7]. Normally, non linear models of the power systems are necessary for simulating the system responses due to large disturbances while linearized models are convenient in case of dynamic studies associated with small disturbances. It is important to precisely represent loads for accuracy of analysis of power system stability.

B) Industrial Load Aggregation

Industrial loads consist of 60% induction motor load which is a significant portion of the load that can have severe effects on the power system dynamics if not well controlled and can lead to voltage instability and even voltage collapse if not addressed at the opportune time. The individual power system load component which comprises dynamic induction motors as well as static loads have to be aggregated into one dynamic equivalent load model to reduce the system order during the power system dynamic studies. In this paper transformer type equivalent circuit is used to represent an induction motor [6]. The equations and circuit used to obtain an aggregate IM load parameters can be found in [8].The accuracy of the results obtained from the aggregate motors depends in part on the assumptions made in the derivation of the aggregate motor and varies from method to method [9].

C) 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 in the form below:

$$\dot{X}_2=X_2 \quad (1)$$

$$\dot{X}_2=C_6X_3+C_2X_2+(C_3V_{d1}+c_4V_{q1})X3+C_5X_3^2 \quad (2)$$

$$\dot{X}_3=C_6X_3+C_7X_4+C_8V_{d2}+C_9V_{q1} \quad (3)$$

$$\dot{X}_4=C_{10}X_2+C_{11} \quad (4)$$

$$\dot{X}_5=X_6 \quad (5)$$

$$\dot{X}_6=C1_2T_{L2}+C_{13}X_6+(C_{14}V_{d2}+C_{15}V_{q2})X_7+C_{16}X_7^2 \quad (6)$$

Where:

$$X= [ɗg\omega_{rg}\,É_{qg}\;E_{fd}\;ɗ_m\;\omega_{rm}\;É_{qm}]^T$$

and the C'S are constant coefficients in terms of the system parameters and the operating point. 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.

D) 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. Below are the system equations:

$$\dot{X}=Ax+Bu \quad (7)$$

$$Y_0=Cx+Du \quad (8)$$

The above two general equations are used to simulate the response of the system to small disturbances such as sudden change of load. Furthermore, Eigenanalysis can be used to analyze small signal stability.

The eigenvalue analysis allows for the computation of modal sensitivities with respect to generator or voltage controllers, reactive power compensating devices etc.

E) Case Study

In this paper, load flow simulation of an industrial induction motor load is carried out using DigSilent PowerFactory software package. Data was collected by measurement -based approach which involved placing the power quality meter at load buses for which the load models were developed. Data collected involved that of measured voltage disturbance. Below is a model of data collected from Bamburi Cement Company per unit motor parameters. See table 2 below.

MOTOR HP	Rs	Rr	Xs	Xr	Xm	H
2.82	0.02	0.04	0.03	0.03	1.21	0.71
10.06	0.02	0.04	0.05	0.04	1.45	0.75
20.12	0.02	0.05	0.05	0.05	1.95	0.78
100.58	0.01	0.05	0.05	0.05	2.51	1.06
177.01	0.02	0.01	0.09	0.09	3.03	1.06

Table 2: Individual industrial induction motor parameters

F) Stability Analysis Using Digsilent Powerfactory

PoweFactory analyzes the dynamic behaviour of both small and large power systems in the time domain using the transient simulation functions that are available in the software. It is therefore, possible to model complex system such as large industrial loads taking into account electrical and mechanical parameters.

For modeling a variety of machines and controller units, as well as the electrical and mechanical components of power plants, etc., ***Power Factor***y' global library provides a large number of predefined models. This library includes models of generators, motors, controllers, motor driven machines, dynamic loads and passive network elements. As an example, this library contains the IEEE standard models of power plant controllers. Furthermore, the user can model specific controllers and develop block diagrams of power plants with a large degree of freedom. Therefore, this software is a power tool for analysis and estimation of power system parameters that are most sensitive to dynamic loads.fig. 1 shows the equivalent circuit of the composite load model used in the simulations.

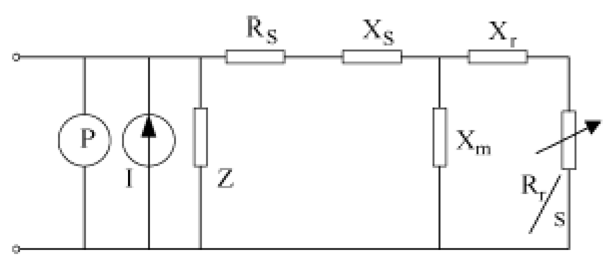

Fig 1 Equivalent circuit of the composite load model

The following parameters of the induction motor load will be identified, namely:

RS-stator resistance, XS-stator reactance, Rr-rotor resistance, XR-rotor reactance, XM- magnetizing reactance

And S- Slip of the induction motor respectively.

G) Results and Discussion

Based on [8] and using equations 4,11,13,15 and 19 respectively, the aggregated parameters of the industrial induction motor loads are achieved.

Digsilent has been used to analyze two types of power system disturbance namely, small and large disturbances.

Case 1: The original detailed model of the reactive power is shown in fig 2a with its equivalent dynamic load model

Case2: The aggregated dynamic equivalent load models for active power and its detailed load are shown in fig.2b.

Case3: load represented by constant impedance load model

1. **Small disturbance fault**

The effects of the detailed and aggregated load model on the simulated performance of the power system are modeled in the linearized form. The following small fault study has been conducted on the test system:

- An increase of 5% torque in the generator mechanical input torque.

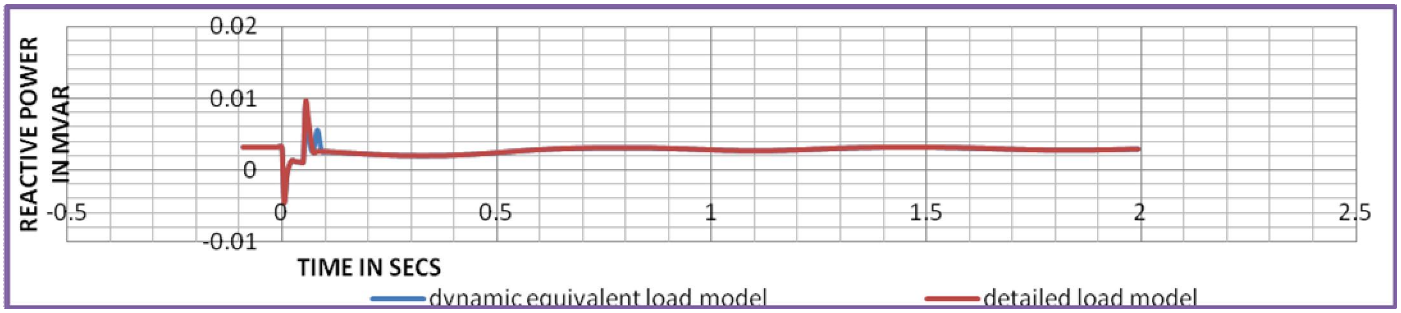

Fig. 2a

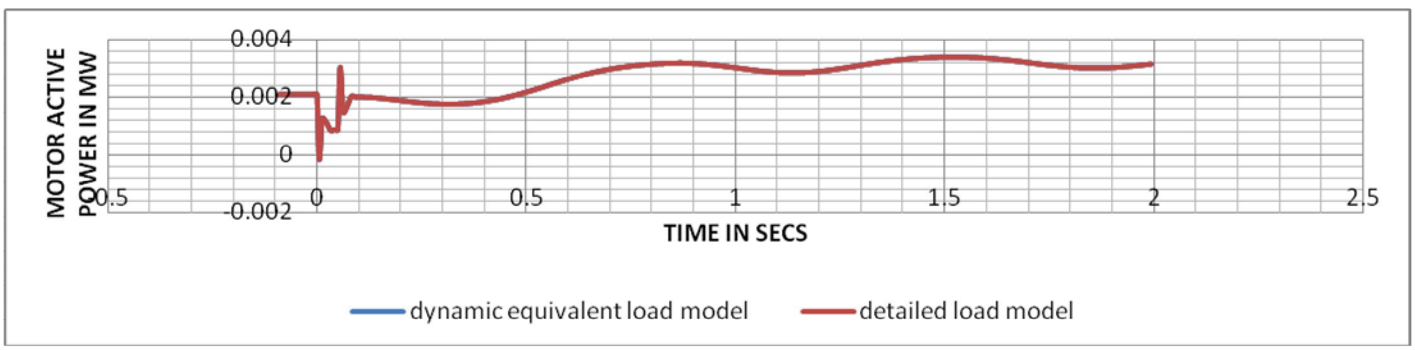

Fig.2b

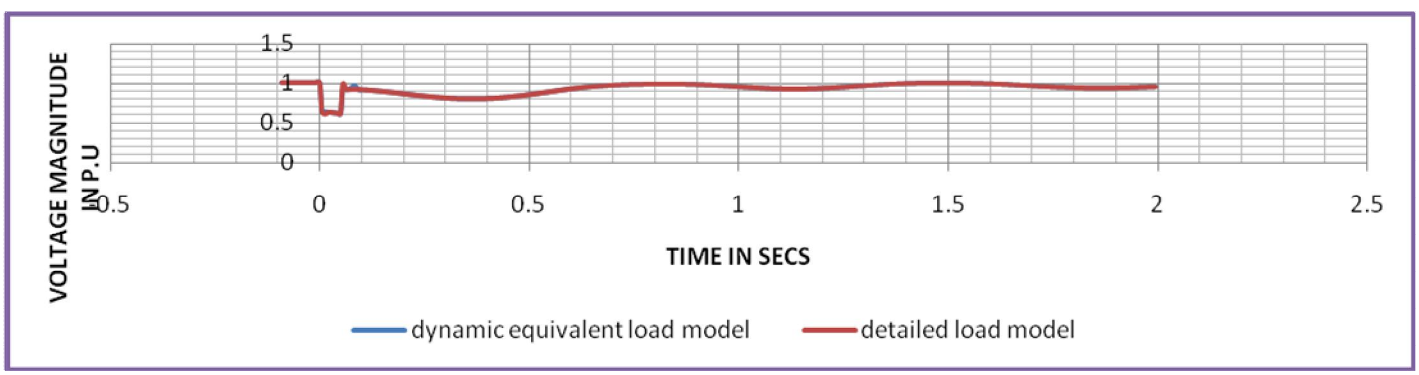

Fig.2c

Fig 2 Motor responses associated with small change in generator load torque

11 Large disturbance faults

A nonlinear model was used to study large transient disturbance. The simulations were done of nonlinear model for purposes of comparison between original detailed load and the dynamic equivalent load model of an IM for analysis of large transient disturbance of a power system.

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A 3-phase fault applied on transmission line 2 and cleared after 50Ms. Figures 3 shows the asynchronous generator responses associated with large disturbances.

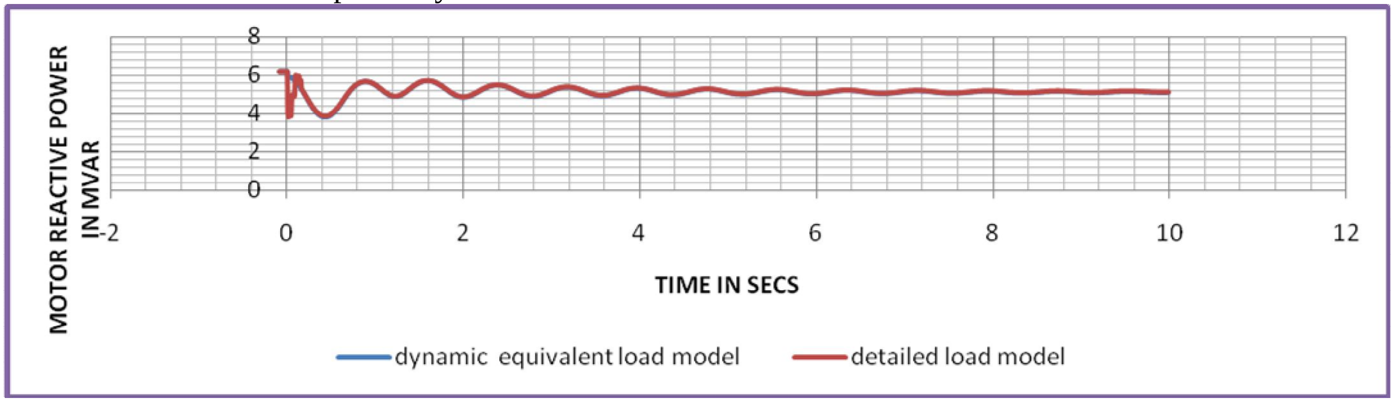

Fig.3a

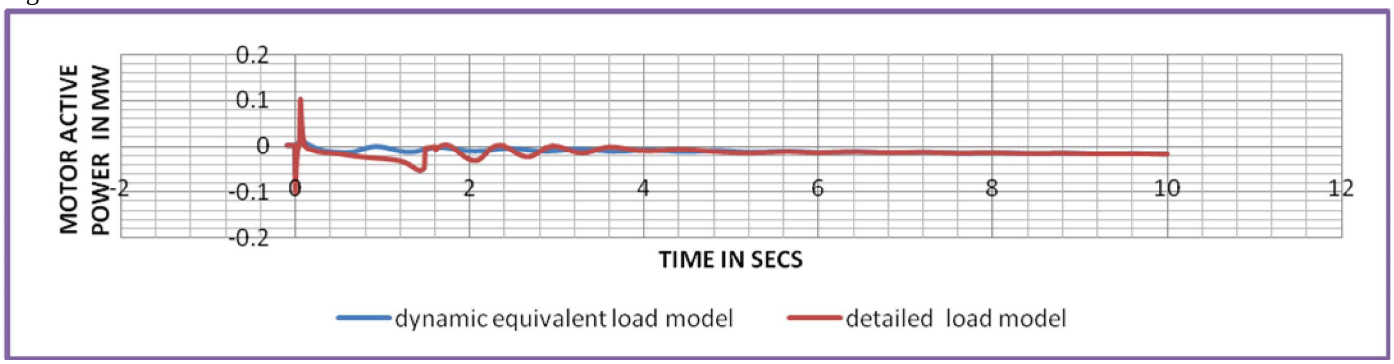

Fig.3b

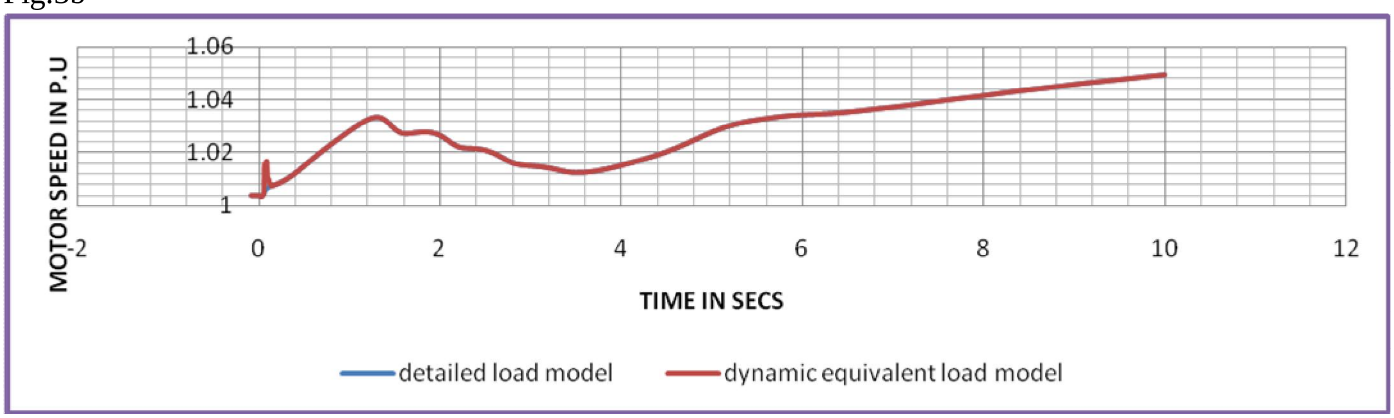

Fig. 3c

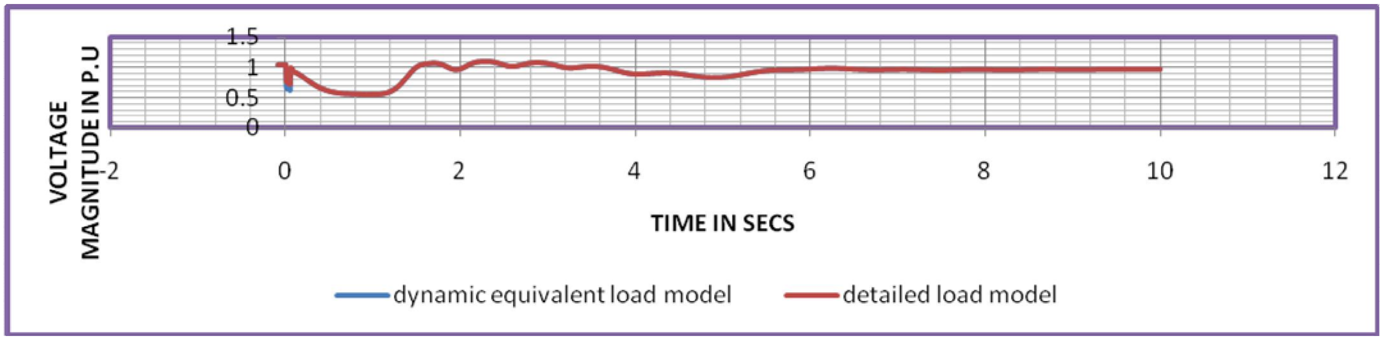

Fig. 3d

Fig 3 Motor Reponses associated with a 3-phase Short circuit along the transmission line

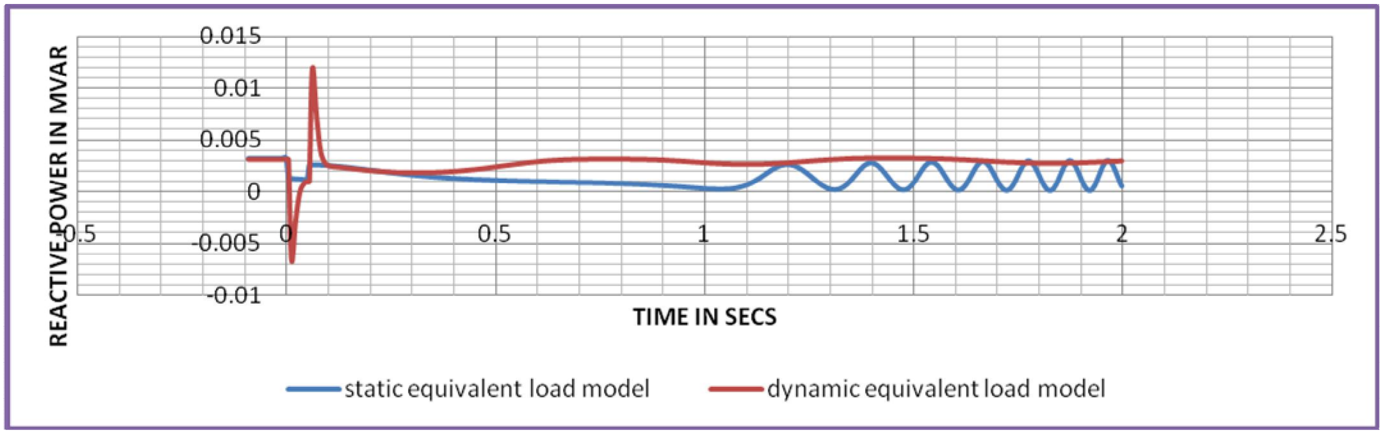

Fig. 4a

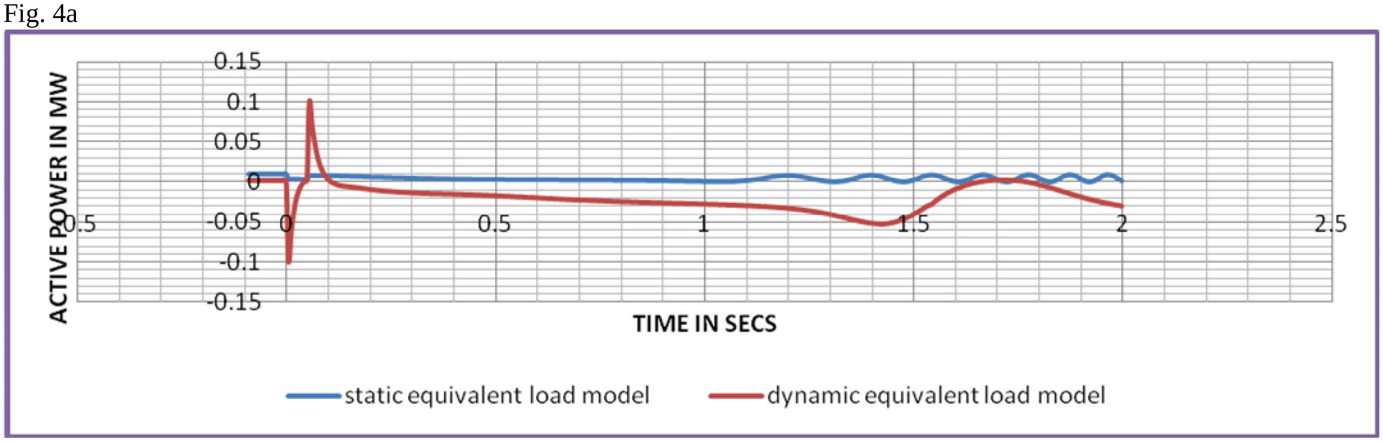

Fig. 4b

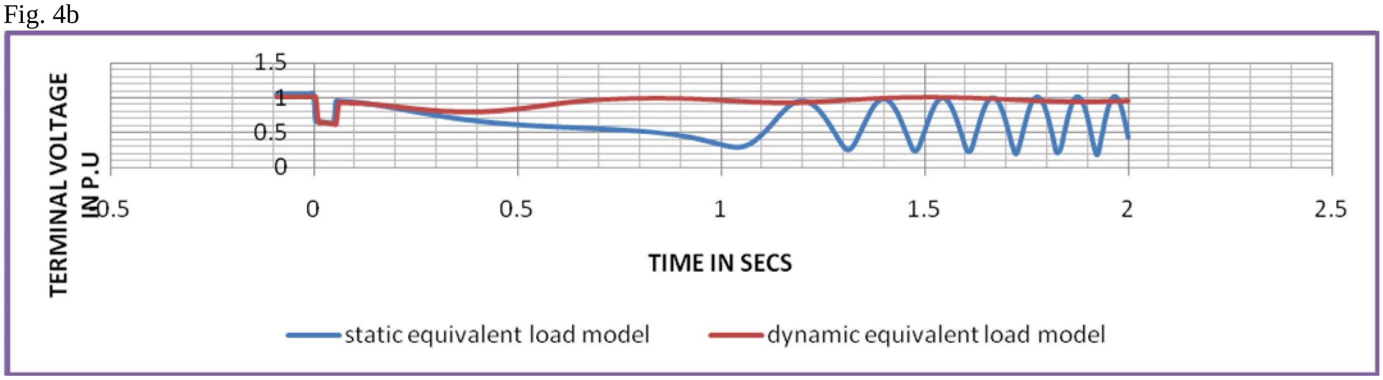

Fig. 4c

Fig .4 Effects of constant impedance loads on static loads under dynamic simulation

H) Simulation results

Fig. 2

Figures.2 shows the IM responses associated with small disturbance.

The simulation result demonstrates the close concurrence amid the aggregated dynamic equivalent load model and the original detailed load connected to the same bus as different cases. The simulation results therefore, demonstrate the effectiveness of the aggregation model.

Fig 3

Figures 3 shows Motor Reponses associated with a 3-phase short circuit along the transmission line. The simulation result portrays a near match relation between the aggregated dynamic load and the original detailed load. The results similarly, indicate that under voltage disturbance, active and reactive load have most effects on load dynamics.

Fig4

Figures.4 shows that static loads are inadequate to represent the actual power system behavior under dynamic simulation. The results re-confirm that static loads are inadequate in the representation of the dynamic loads by the constant impedance model and therefore give false indication of the voltage stability of the power system under fault.

Conclusion

The responses of detailed and aggregated industrial loads has been simulated and their effects analyzed by simulation of small and large disturbances. The simulation in each of the four cases demonstrates the effect of load model and aggregation on the system performance. Loads represented by single dynamic equivalent displayed actual stability limits of the power system. It was however, different for loads represented by an equivalent constant impedance model whose results were not appropriate for analysis of voltage stability under dynamic behavior. It has therefore been shown that PowerFactory DigSilent software which has not been so pronounced in power system application is a powerful tool in the analysis of load flow. Further, static loads are inadequate to represent the actual power system behavior under dynamic simulation and may produce imprecise results and lead to inappropriate system performances.

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