POWERFACTORY LOAD FLOW SENSITIVITY ANALYSIS OF AN INDUCTION MOTOR LOAD MODEL

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Abstract**—**PowerFacotry Load flow sensitivity is a method used to obtain certain relationship between dependent and independent variables using differential relationship among physical measure in systems. Voltage sensitivity analysis is based on the linearization of the system around the operational point resulting from a load flow calculation. Inappropriate load representation has been a major setback causing inaccurate simulation results of the dynamic load. Further, induction motor loads comprise of 60% power system loads whose understanding under various dynamics is crucial for system stability. Static loads are known to be imprecise in dynamic load simulation and therefore yield false information on the system stability. This paper presents a dynamic load model whose parameters are varied to investigate their effects on both active and reactive load dynamics. Load modeling using field measurement data from power quality meter of an industrial consumer and that of standard motor models are analyzed to assess their effects on sensitivity of the system stability. Load flow sensitivity is analyzed to perform a voltage sensitivity analysis based on the linearization of the system around the operational point that results from a load flow calculation. The efficiency of the system is **estimated using the IEEE 9 bus system. The result indicates that load** model parameters have different sensitivity values under voltage disturbance. The results acquired are thus acceptable and rational.

Key words: Composite load model, Field measurements, Load flow sensitivity, Induction motor parameters.

I. INTRODUCTION

Sensitivity analysis is a method of identifying which among the parameters of the composite load model measured are easy to identify from the currently selected inputs and outputs. Load demand has continued to rise over the years and it is crucial to know the loads performance under various load dynamics. About 60% of power system loads consists of induction motor loads and significantly affects the system dynamics. It has further, been recognized that high percentage of induction motor loads in the system avert the normal voltage recovery following the fault [1]. Besides, using different load models in power system may produce contradicting simulation results [2]. Load modeling is still a complex field that still has uncertainty attached to it. The difficulty lies in the fact that load consists of various components with diverse and dynamic characteristics. Generally, there are two load modelling approaches [3]: The component-based and the measurement-based approaches: the former requires reliable data, which are not easy to get and also prior knowledge of load characteristics and load class data is essential.

Component load model does not accurately represent the steady state reactive power versus voltage responses as well as the transient response of the active and reactive power because of the complex nonlinear characteristics of the load components. Measurement-based load model has attracted many researchers as a method of data collection because it portrays the real system load dynamics and represents the load characteristics precisely. Further, the identified load parameters could be easily modified or updated when new measurement data are obtained from digital fault recorders.

In this paper, sensitivity analysis of industrial induction motor load is investigated by PowerFactory load flow sensitivity using standard IEEE 9 bus system to perform a voltage sensitivity analysis based on the linearization of the system around the operational point that resulted from a load flow calculation to facilitate identification of parameters that are most affected by active and reactive load dynamics.

11 MATERIALS AND METHODS

A) COMPOSITE LOAD MODELING

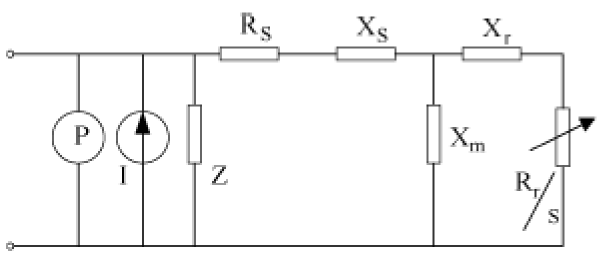

Fig.1. Equivalent circuit of the composite load model

The schematic structure of the composite load model is shown in fig .1 above whereby the static part is represented by a ZIP model while the dynamic part is represented by an induction motor respectively. The model consists of a static part modeled as ZIP and a dynamic Part, modeled as an equivalent circuit of the third-order motor dynamics. With this structure the 14 parameters of the induction motor load model can be found from equations in [4].

Z, I and P represents the constant impendance, constant current and constant power. Rs is the stator winding resistance; Xs is the stator leakage reactance; Xr is the rotor leakage reactance; Xm is the magnetizing reactance; Rr is the rotor reactance and S is the motor slip respectively.

B) TRAJECTORY SENSITIVITY METHOD

Trajectory sensitivity method calculates the sensitivity of the power system dynamics with respect to the parameters. This method is deferent from the static sensitivity calculation, which gives only a numerical value at the steady state, trajectory sensitivity calculation produces the sensitivities along the system evolving trajectory [5]. With respect to load equations (1)-(3) in [5], the perturbation method is used to derive the trajectory sensitivities of an industrial load using differential algebraic equations with continuous dynamics. The general form of the load characteristics can be found from [4] -[5] respectively. Further, it is crucial to note that the trajectory sensitivities are affected by the initial values and trajectories because they are based on linearization of the originally nonlinear dynamic system. Analysis of an industrial induction motor load indicates that Rs, Rr and Xr have the most effects on the active and reactive dynamics while trajectory sensitivities with respect to other parameters are unobservable.

C) LOAD FLOW SENSITIVITY ANALYSIS OF AN INDUSTRIAL INDUCTION MOTOR USING DIGSLENT POWERFACTORY

PowerFactory load flow sensitivity performs a voltage sensitivity analysis based on the linearization of the system around the operational point that results from a load flow calculation. Linearizing the load flow equations around the actual operating point leads to the following equation system:

$$\begin{bmatrix} JP\theta & JPv \\ JQ\theta & JQv \end{bmatrix} \begin{bmatrix} \partial\theta \\ \partial v \end{bmatrix} = \begin{bmatrix} \partial P \\ \partial Q \end{bmatrix} \qquad (1)$$

The equation system in (1) shows that changes in the voltage magnitude and angle due to small changes in the active and reactive power can be directly calculated from the load bus Jacobian matrix. For example if P is set to 0 (constant), the sensitivities of the type dv/dQ are calculated from

(1) according to:

$$\partial v = 1/jQv\partial Q = SvQ\partial Q \quad (2)$$

Where $$jQv = -\frac{jQv}{jpv} jpV + jQV \quad (3)$$

As can be seen from (2), the variation of voltage magnitude at each busbar can be described by a linear combination of small reactive power variations according to:

$$\partial V_i = \frac{Si}{\partial Q_1} + - - + Si_n \partial Q_n \quad (4)$$

Here the diagonal elements $Si1$ of S represent the voltage variation at bus i due to a variation of reactive power at the same point. The non-diagonal elementsSij describe the voltage

variation at busbar $i$due to the variation in

reactive power at a different point on the network.

Positive dv/dQ sensitivity indicates stable

operation. High sensitivity means that even small changes in reactive power cause large changes in the voltage magnitude; therefore the more stable the system, the lower the sensitivity (high voltage sensitivities are indicative of weak areas of the network.

D) APPLYING THE IEEE TYPICAL LOAD PARAMETERS

In the year 1995, IEEE task force on load representation for dynamic performances proposed some typical induction motor data for large scale simulation [6]. It was found out that amongst the seven types of motors, type 6 is the weighted aggregate of residential and industry motors whose parameters are shown in table 1 below.

Table 1: induction motor parameters of IEEE type 6

Rs	**Xs**	**Xm**	**Rr**	**Xr**	**A**	**B**	**H**
0.035	**0.094**	**2.8**	**0.048**	**0.163**	**1**	**0**	**0.93**

D) **Grouping criterion**

It is fundamental to identify and group homogeneous motors for enhanced accuracy of the aggregated model parameters. In this paper, inertia and open circuit time constant are used to classify motors [7] as articulated in equations 4.1, 4.2, 4.3 and 4.4 correspondingly

E) AGGREGATION METHOD

Based on [8], the aggregated parameters of the industrial induction motor loads are achieved. In this paper, the assumption made was that, the mechanical output power of the aggregate motor is assumed to be equal to the total mechanical output power delivered by the individual motors.

$$\boldsymbol{HP^{agg} = \sum_{i=1}^{N} (HP)^i} \quad \textbf{(5)}$$

Four IM were used in the analysis of the model aggregation using transformer-type equivalent circuit model.

F) CASE STUDY

In this paper, sensitivity analysis of an industrial induction motor load is carried out using DigSilent PowerFactory sensitivity 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. Table 2 shows a model of data collected from an industrial consumer in per unit motor parameters.

Table 2: Individual industrial induction motor parameters and aggregated one

MOTOR HP	Rs	Rr	Xs	Xr	Xm	H	RPM
2.82	**0.02**	**0.04**	**0.03**	**0.03**	**1.21**	**0.71**	**1469**
10.06	**0.02**	**0.04**	**0.05**	**0.04**	**1.45**	**0.75**	**2900**
20.12	**0.02**	**0.05**	**0.05**	**0.05**	**1.95**	**0.78**	**1460**
100	**0.01**	**0.05**	**0.05**	**0.05**	**2.51**	**1.06**	**1485**
133	**0.01**	**0.04**	**0.02**	**0.02**	**0.9**	**0.7**	**1490**

G) TEST SYSTEM

The figure.2 below shows the topology of the IEEE 9 bus test system which comprises of three synchronous generators in parallel with three static loads connected to an infinite bus. The generators supplies a load area composed of four industrial induction motors and three static loads on the load buses. The data of the system components are given in table 2.

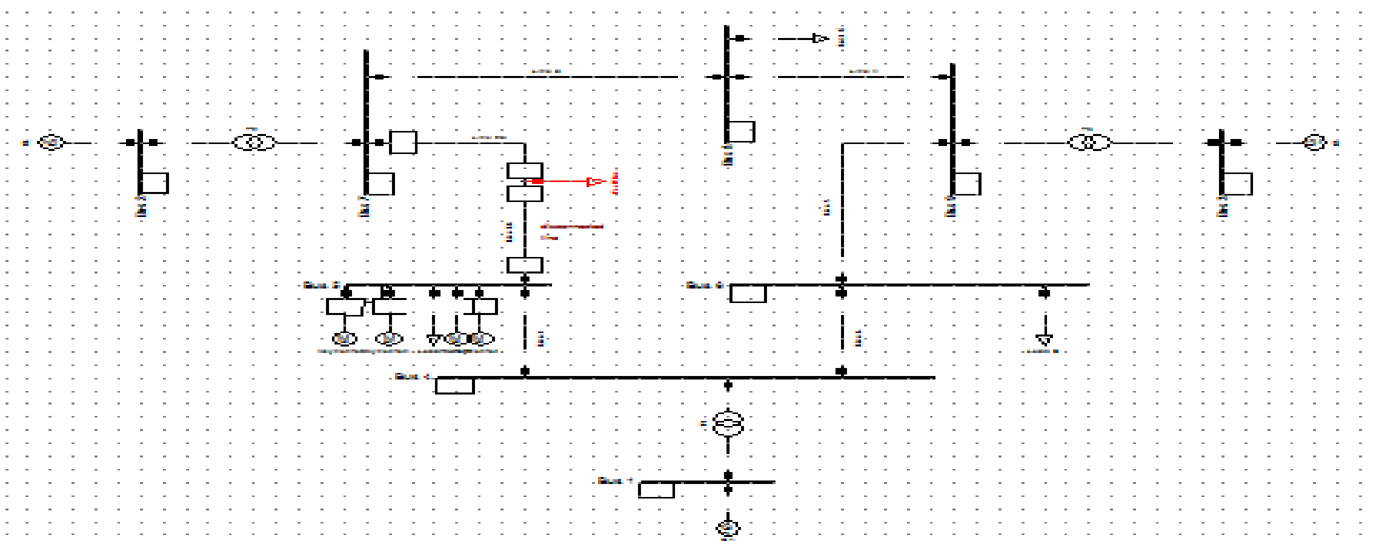

Fig .2: IEEE nine bus system

H) RESULTS AND DISCUSSION

A fault was created on line 2a of bus 7 and both measurements and the simulated load dynamics of the composite load model are shown in fig 3-5 respectively. **Fig 3** shows that the model with measurement closely matches that of the IEEE model and therefore gives an inaccurate description on the reactive load dynamics thereby giving false indication of the power system stability. **Fig 4** gives satisfactory performance of both models on describing the active load dynamics although some errors were noted due to delay in dynamics recovery

Fig 5 shows the load model with IEEE type 6 motor under voltage disturbance. Further, DIGSILENT load flow sensitivity of the four industrial induction motors were analyzed, the results indicates that, not all parameters are sensitive or observable from the measured voltage disturbance. **Fig. 6** Portrays a scenario whereby Rs and Rr have the most effects on active load dynamics and are therefore, said to be more sensitive to voltage disturbance. Similarly, **fig 7** confirms that Rs and Xr have almost similar effects on describing the reactive load dynamics.

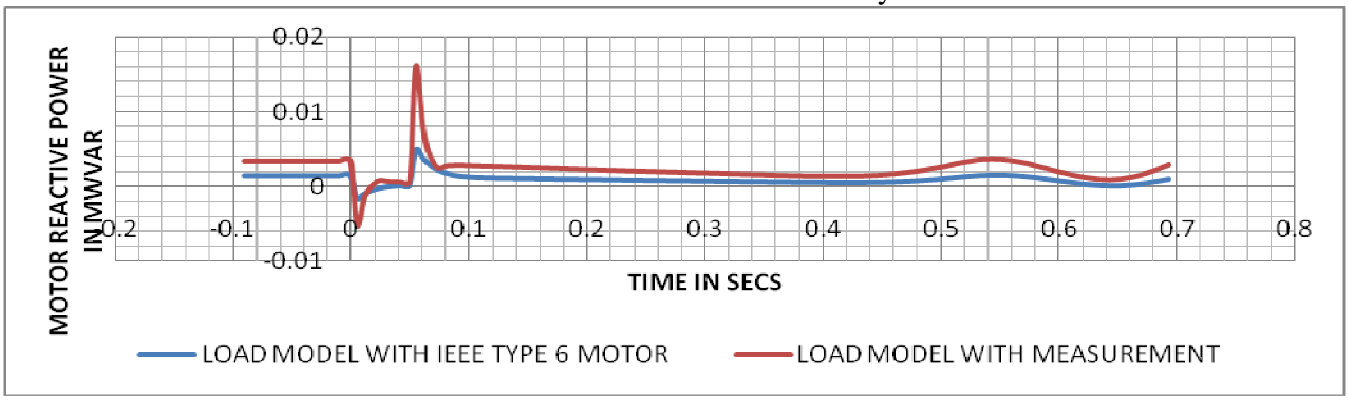

Fig. 3 Industrial reactive load model and load model with measurement

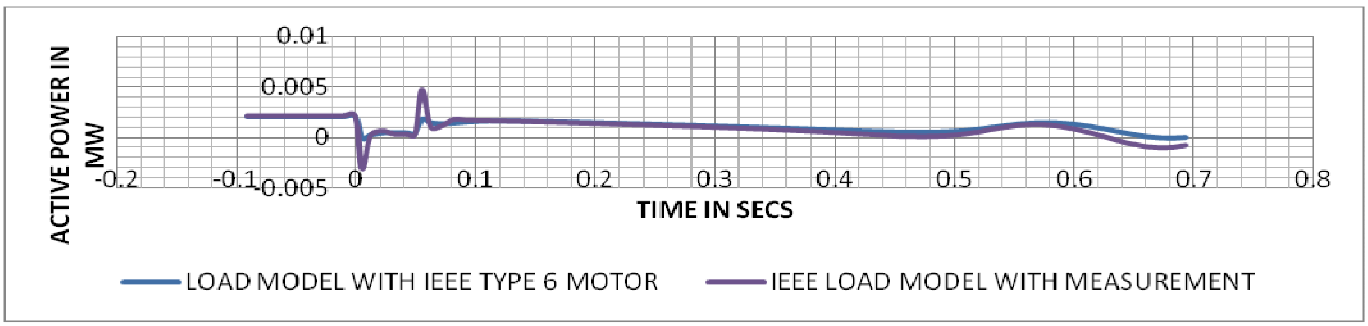

Fig. 4 Industrial active load model and load model with measurement

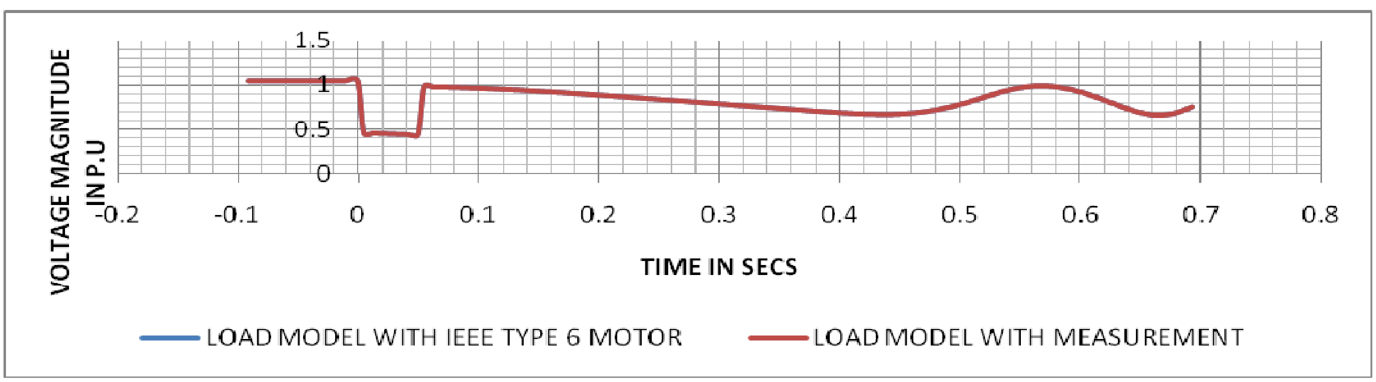

Fig 5 Industrial bus voltage under fault

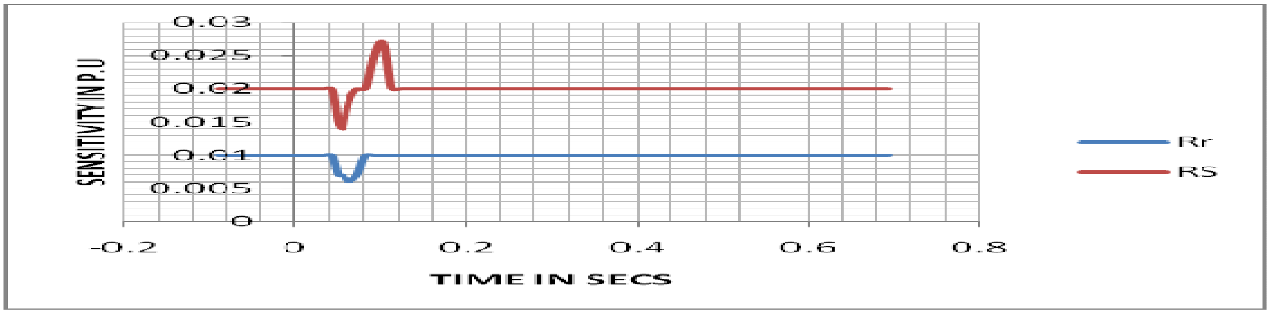

Fig 6 PowerFactory load flow sensitivity of active power with respect to Rr and Rs

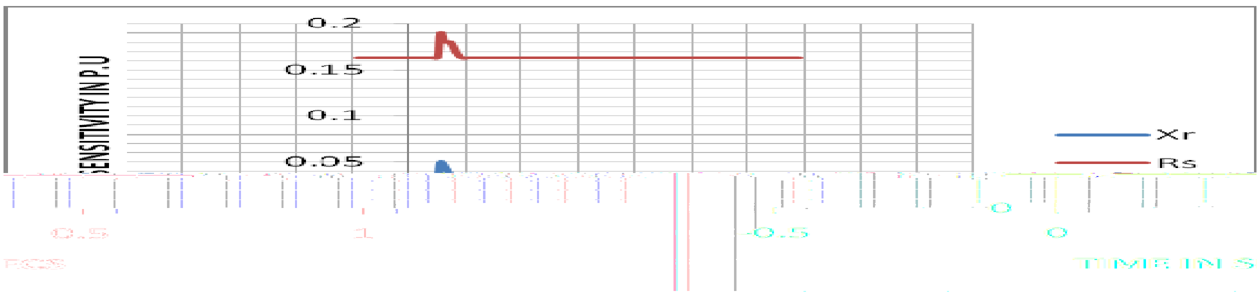

Fig.7 PowerFactory load flow sensitivity of reactive power with respect to Xr and Rs

H) CONCLUSION

It has been shown that PowerFactory DigSilent software is a powerful tool in the sensitivity analysis of IM parameters and that not all parameters of the industrial induction motors are sensitive to voltage disturbance. The PowerFactory load flow sensitivity of various parameters has been verified by use of IEEE- 9 bus standard system whose network was extended by insertion of four industrial motors on bus 5 of diverse sizes and their response under fault investigated. The results evidently demonstrate that active and reactive load dynamics are most sensitive and thus identifiable from the measured voltage disturbance. However, the sensitivity analysis shows that some parameters are of low sensitivity. This does not mean that they are lesser important only that they are not easily identifiable and plays a significant role in voltage sensitivity analysis. When there is a short-circuit fault, IM loads absorbs a greater amount of reactive power. This high reactive power demand by the loads may cause the generator to lose their ability to act as a constant voltage source because of the field current limits. For such a case the generator behaves like a voltage source behind the synchronous reactance and its voltage reduces. This is clearly demonstrated by fig 3 and fig 4 respectively where the reactive power reaches the peak within a short time. The results achieved are satisfactory.

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