MODELLING OF THE INDUSTRIAL LOAD OF BAMBURI CEMENT COMPANY FOR POWER SYSTEM STUDIES

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ABSTRACT

In the recent past, much attention has been given to models for generation and transmission equipment. The representation of the loads has received comparatively less attention and continues to be an area of greater uncertainty. There is therefore a need for studies into the development of power system load modelling techniques. Accurate modelling of loads continues to be a difficult task due to several factors, for example, lack of precise information for the composition of the load and changing load composition with time delays. Electric analysts and their management require evidence of the benefits of improved load representation in order to justify the effort and expense of collecting and processing load data, as well as to modify computer program load models. This paper seeks to develop an aggregation model that will be used to aggregate the industrial load of Bamburi Cement Company. The effect of power factor improvement at the load on voltage stability will also be analyzed.

Keywords: **Load modelling, voltage stability.**

1. INTRODUCTION

In Bamburi Cement Company, a significant portion of power system load is comprised of induction motors.

The simulation of these individual induction motors for system studies can be time consuming. In order to reduce the computation time, reduced order modelling is used to represent a group of motors with one or more aggregate motors. Simulation studies become computationally feasible only if these induction motors can be aggregated in a single equivalent model.

Usually, induction motors are represented by the conventional equivalent circuit model. However, an alternative type of equivalent circuit called the transformer-type equivalent circuit [1] will be used for modelling.

Voltage stability continues to be an area of great concern in many power systems world-wide. Many systems have become vulnerable to situations of uncontrollable system voltages owing to a continual growth in load, lack of a corresponding growth in generation and transmission inefficiencies. In its most severe form, voltage instability can result in localized or even cascading system blackouts. To deal with this serious issue, many utilities have mandated the study of voltage stability as a normal component in system planning and operation. While acceptable methods of voltage stability analysis have emerged in recent years, and comprehensive tools have been developed, the issue of load modelling remains a challenge [2] and continual study on the same is beneficial.

2. AGGREGATION OF THE INDUSTRIAL LOAD

Using the aggregation model developed in [1] the induction motors from Bamburi Cement Company are aggregated. A simplified diagram is shown in figure 1:

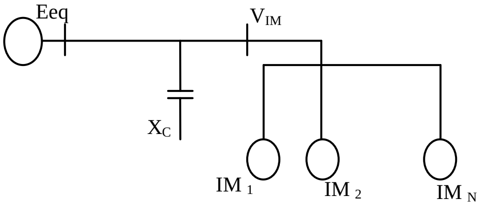
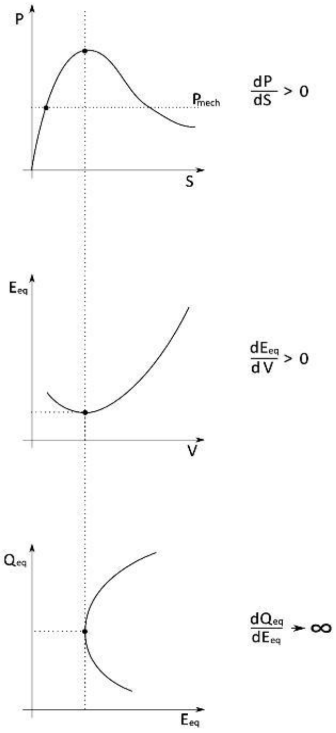


Figure 1: A simplified aggregation diagram.

3. STABILITY CRITERION

For an induction motor operating individually and in a system, the stability criterion graphs of Power against Slip, E_{eq} against V drawn and Q_{eq} against E_{eq} are as shown below [5,6,7]:



Graph 1: Stability Criterion Graphs.

The aggregate load connected to the system can be represented by the following circuit diagram.

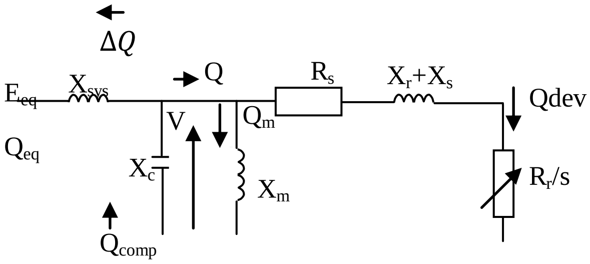


Figure 3: Aggregate Load Connected to the System.

Where

$$S_{crit} = \frac{Rmot}{Xmot} \qquad 1$$

$P_e = P_{mech}$ at the operating slip

$$V_{crit} = \sqrt{2 \times Pe \times (Xs + Xr)} \qquad 2$$

$$Q_{dev} = \frac{Pe \times s}{Scrit} \qquad 3$$

$$Q_m = \frac{Vnom^{\ 2}}{Xm} \qquad 4$$

$$Q_{comp} = Q_m + \frac{Pe \times s}{Scrit} - P_e \times \tan\theta \qquad 5$$

$$X_{comp} = \frac{Vnom^{\ 2}}{Qcomp} \qquad 6$$

$$X_{eq} = \frac{Xm \times Xcomp}{Xcomp - Xm} \qquad 7$$

As the voltage varies from 1p.u. to V_{crit},

$$\mathrm{Q} = \frac{V^2}{\mathrm{Xeq}} + \frac{Pe \times s}{Scrit} \qquad 8$$

$$\Delta\mathrm{Q} = (\mathrm{Pe}^2 + Q^2) \times \frac{Xsys}{V2} \qquad 9$$

$$\mathrm{Eeq} = \sqrt{(V + \frac{QXsys}{V})^2 + (\frac{Pmec\,h \times Xsys}{V})^2} \qquad 10$$

$$\mathrm{Qeq} = \mathrm{Q} + \Delta\mathrm{Q} \qquad 11$$

According to [3], the complex apparent power drawn by induction motor can be expressed as function of voltage and slip as follows:

$$S_m = V_m I_m^* \qquad 12$$

$$I_m = \frac{V_m}{R_{mot} + \mathrm{j}\, X_{mot}} \qquad 13$$

$$R_{mot} = R_S + \frac{X_m^2 (\frac{R_r}{s})}{(\frac{R_r}{s})^2 + (X_m + X_r)^2} \qquad 14$$

$$X_{mot} = X_S + \frac{X_m^2 \left(\frac{R_r}{s}\right) + X_m X_r (X_m + X_r)}{(\frac{R_r}{s})^2 + (X_m + X_r)^2} \qquad 15$$

The motor reactive power and active power consumptions are given by:

$$Q_m = \frac{V_m^2 X_{mot}}{(R_{mot})^2 + (X_{mot})^2} \qquad 16$$

$$P_m = \frac{V_m^2 R_{mot}}{(R_{mot})^2 + (X_{mot})^2} \qquad 17$$

The voltage is varied from the maximum value to the critical voltage below which the induction motor draws excessive reactive power. Graphs of Power against Slip are drawn, and at different voltages, the operating slip is obtained.

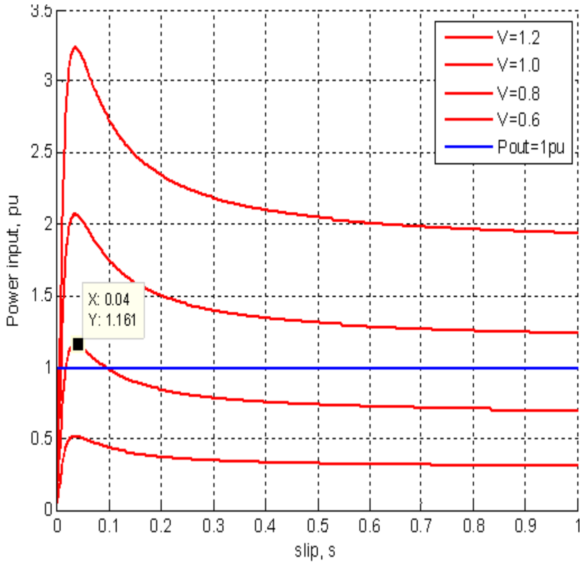
4. RESULTS

The aggregated parameters of the industrial load are as follows:

Table 1: Aggregated Parameters – Industrial Load

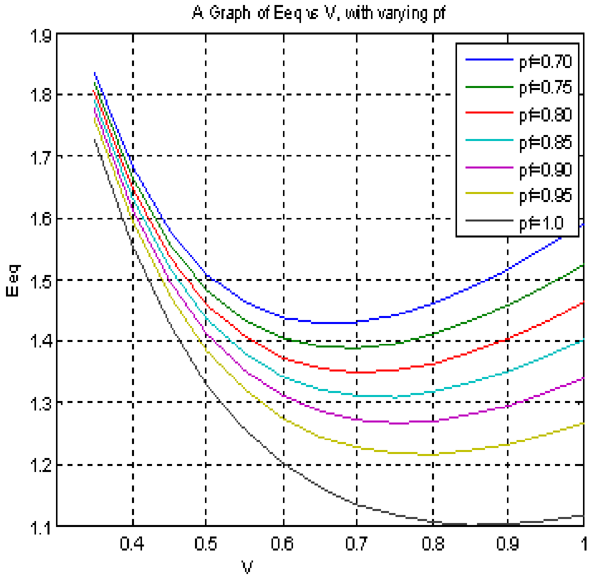
Parameters	**Rs**	**Rr**	**Xs**	**Xr**	**Xm**	**HP_agg**
Aggregated Values	0.0474	0.0037	0.1515	0.0026	29.6565	11669

Using these parameters and substituting them in equations 14, 15 and 17, the Power vs. Slip curves are obtained as shown below:

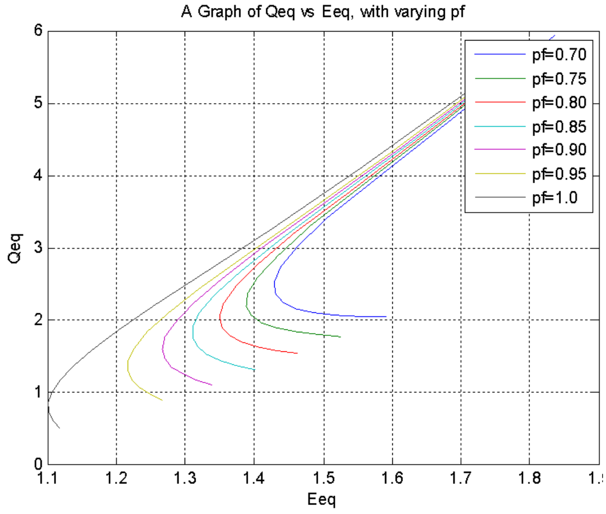


Graph 2: Power vs. Slip curves

Since Pmech is equal to Pe at the operating slip, the stability criterion graphs are obtained using equations 1 – 11 as follows:



Graph 3: Eeq vs. V, with varying power factors.



Graph 4: Qeq vs. Eeq.

5. CONCLUSION

All electric equipment require "vars" – which describes the reactive or magnetizing power required by the inductive characteristics of electrical equipment. These inductive characteristics are more pronounced in motors and transformers, and therefore, can be quite significant in industrial facilities [4].

The flow of reactive power through the power system will result in energy losses on both the utility and the industrial facility. Utilities charge for this reactive power in the form of a penalty, or KVA demand charge, to justify the cost for lost energy and the additional conductor and transformer capacity required to carry the reactive power. In addition to energy losses, reactive power flow can also cause excessive voltage drop, which may have to be corrected by either the application of shunt capacitors, or other more expensive equipment, such as load-tap changing transformers, synchronous motors, and synchronous condensers. Therefore, on one hand, power utility companies are justified in their introduction of power surcharges requiring industries to operate at a favourable power factor (usually above 0.85).

However, on the other hand, as the power factor is improved, the security margin of the industrial load decreases and the loads become more unstable as shown in Graph 3.

$$\text{Security Margin} = \frac{Eeqo - Eeqcrit}{Eeqcrit} \qquad 18$$

Table 2: A Table showing the variation of stability with increase in power factor

pf	**0.70**	**0.75**	**0.80**	**0.85**	**0.90**	**0.95**	**1.0**
Security Margin (%)	23.07	9.71	8.89	6.87	5.51	4.09	2.27

As the power factor is improved at the loads, the stability decreases.

In mitigation to this, utility companies should consider supplying reactive power in addition to real power. The reactive power used for power factor correction should be injected at other places in the system other than at the loads to maintain voltage stability.

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