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Simulation of Voltage Stability Analysis in Induction Machine

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Abstract

A steady state analysis is applied to study the voltage collapse problem. The modal analysis method is used to investigate the stability of the power system. Q-V curves are used to confirm the obtained results by modal analysis method and to predict the stability margin or distance to voltage collapse based on reactive power load demand. The load characteristics are considered in this research. Different voltage dependent loads are proposed in order to be used instead of the constant load model. The effect of induction machine load is considered in this study. The load is connected to several selected buses.

Index Terms-- PV and QV diagram, Eigen value & Eigen vector, Participation factor and Load Flow.

I. INTRODUCTION

Voltage collapse problem has been one of the major problems facing the electric power utilities in many countries. The problem is also a main concern in power system operation and planning. It can be characterized by a continuous decrease of the system voltage. In the initial stage the decrease of the system voltage starts gradually and then decreases rapidly. Stressed power system; i.e. high active power loading in the system. In bulk transmission network to avoid the cost of building new lines and generation facilities. When a bulk transmission network is operated close to the voltage instability limit, it becomes difficult to control the reactive power margin for that system. As a result the system stability becomes one of the major concerns and an appropriate way must be found to monitor the system and avoid system collapse. One of the major reasons of voltage collapse is the heavy loading of the power system, which is comprised of long transmission lines. The system appears unable to supply the reactive power demand. Producing the demanded reactive power through synchronous generators, synchronous condensers or static capacitors can overtake the problem [1]. Another solution is to build transmission lines to the weakest nodes. Voltage collapse may occur due to a major disturbance in the system such as generators outage or lines outage.

In many algorithms have been proposed in the literature for voltage stability analysis. Most of the utilities have a tendency to depend regularly on conventional load flows for such analysis. Some of the proposed methods are concerned with voltage instability analysis under small perturbations in system load parameters.

II. POWER FLOW PROBLEM

The solution of power flow predicts what the electrical state of the network will be when it is subject to a specified loading condition. The result of the power flow is the voltage magnitude and the angle at each of the system nodes. These bus voltage magnitudes and angles are defined as the system state variables [2]. That is because they allow all other system quantities to be computed such as real and reactive power flows, current flows, voltage drops, power losses etc., Power flow solution is closely associated with voltage stability analysis. It is an essential tool for voltage stability evaluation. Much of the research on voltage stability deals with the power-flow computation method. The power-flow problem solves the complex matrix equation

$$I = YV = \frac{S^*}{V^*} \tag{1}$$

$$S = P + jQ \tag{2}$$

The Newton-Raphson method is the most general and reliable algorithm to solve the power-flow problem. It involves iterations based on successive linearization using the first term of Taylor expansion of the equation to be solved. From Equation (1), we can write the equation for node k (bus k) as

$$I_k = \sum_{w=1}^{n} YK_m V_m \tag{3}$$

$$P_k - jQ_k = V_k * I_k = V_k * \sum_{m=0}^{n} Y_{km} V_w \tag{4}$$

$$Vk = Vk\,e^{j\theta k}, Vw = Vw\,e^{j\theta m}, Ykw = Ykw\,e^{jkm} \tag{5}$$

$$V_k = V_k e^{j\theta k}\,,\; V_w = V_w e^{j\theta m}, Y_{kw} = Y_{kw} e^{jkm} \tag{6}$$

$$P_k + jQ_k = \sum_{m=1}^{n} Y_{kw} V_k V_m \cos(\theta_k - \theta_m - \gamma_{kw}) + j\sum_{m=1}^{n} Y_{km} V_k V_m \sin(\theta_k - \theta_m - \gamma_{kw}) \tag{7}$$

$$\Delta Pk = P_k^{j\,ch} - P_k$$

$$\Delta Qk = Q_k^{jch} - Q_k$$

$$\begin{pmatrix} \Delta P \\ \Delta Q \end{pmatrix} = j \begin{pmatrix} \Delta \theta \\ \Delta V \end{pmatrix} \tag{8}$$

$$Y_{km} = g_{km} + jB_{km} \tag{9}$$

III. PERFORMANCE EIGEN VALUE ANALYSIS METHOD

It can predict voltage collapse in complex power system networks. It involves mainly the computing of the smallest Eigen values and associated eigenvectors of the reduced Jacobin matrix obtained from the load flow solution [3]. The Eigen values are associated with a mode of voltage and reactive power variation, which can provide a relative measure of proximity to voltage instability. Then, the participation factor can be used effectively to find out the weakest nodes or buses in the system

A. Effect of Load Modeling

It is important to have an analytical method to predict the voltage collapse in the power system, particularly with a complex and large one. The modal analysis or Eigen value analysis can be used effectively as a powerful analytical tool to verify both proximity and mechanism of voltage instability [4]. It involves the calculation of a small number of Eigen values and related eigenvectors of a reduced Jacobin matrix. The stability margin or distance to voltage collapse can be estimated by generating the Q-V curves for that particular bus the steady state induction machine load model is considered in this study.

$$\frac{\partial P_k}{\partial \theta_w} = V_k V_m (G_{kw} \sin\theta_{kw} - B_{kw} \cos\theta_{kw}) \tag{10}$$

$$V_w \frac{\partial P_k}{\partial \theta_w} = V_k V_m (G_{kw} \cos \theta_{kw} - B_{kw} \sin \theta_{kw}) \quad (11)$$

$$\frac{\partial Q_k}{\partial \theta_m} = -V_m \frac{\partial P_k}{\partial V_m} \quad (12)$$

$$V_m \frac{\partial Q_k}{\partial V_m} = \frac{\partial P_k}{\partial \theta_m} \quad (13)$$

$$\frac{\partial P_k}{\partial \theta_k} = -Q_k - B_{kk} V_k^2 \quad (14)$$

$$V_k \frac{\partial P_k}{\partial V_k} = P_k + G_{kk} V_k^2 \quad (15)$$

$$\frac{\partial Q_k}{\partial \theta_k} = P_k - G_{kk} V_k^2 \quad (16)$$

$$V_k \frac{\partial Q_k}{\partial V_k} = Q_k - B_{kk} V_k^2 \quad (17)$$

Then

$$J = \begin{bmatrix} \frac{\partial P_k}{\partial \theta} & \frac{\partial P_k}{\partial V} \\ \frac{\partial Q_k}{\partial \theta} & \frac{\partial Q_k}{\partial V} \end{bmatrix} \quad (18)$$

TABLE .1. MACHINE PARAMETER

Hp	Volts	Rpm	Torque (N.m)	I (A)	rs (ohm)	X_{1S} (ohm)	X_m (ohm)	X_{1r} (ohm)	rr (ohm)	J $Kg.m^2$
500	2300	1773	1980	93.6	0.262	1.206	54.02	1.206	1.187	11.06
2250	2300	1786	8900	421.2	0.029	0.226	13.04	0.226	0.022	63.87

B. Modal Analysis & Q – V Curve

The modal analysis mainly depends on the power-flow Jacobin matrix. The voltage-reactive power curves are generated by series of power flow simulation. They plot the voltage at a test bus or critical bus versus reactive power at the same bus. The bus is considered to be a PV bus, where the reactive output power is plotted versus scheduled voltage. Most of the time these curves are termed Q–V curves rather than V–Q curves. Scheduling reactive load rather than voltage produces Q–V curves. These curves are a more general method of assessing voltage stability [5]. They are used by utilities as a workhorse for voltage stability analysis to determine the proximity to voltage collapse and to establish system design criteria based on Q and V margins determined from the curves. Operators may use the curves to check whether the voltage stability of the system can be maintained or not and take suitable control actions. The sensitivity and variation of bus voltages with respect to the reactive power injection can be observed clearly. The main drawback with Q–V curves is that it is generally not known previously at which buses the curves should be generated. In normal operating condition, an operator will attempt to correct the low voltage condition by increasing the terminal voltage.

C. Effect of Load Modeling

The load representation can play an important factor in the power system stability. The load characteristics can be divided into two categories, static characteristics and dynamic characteristics. The effect of the static characteristics is discussed in this section. Recently, the load representation has become more important in power system stability studies. In the previous analysis, the load was represented by considering the active power and reactive power. Both were represented by combination of constant impedance (resistance or reactance), constant current and constant power (active or reactive) elements. This kind of load modeling has been used in many of the power system steady state analyses. The effect of the static load modeling on voltage stability is presented in this section. A voltage dependent load model is proposed. The new load model is used instead of the constant load used previously. A significant change in the stability limit or distance to voltage collapse should be noticed clearly [6, 7].

D. Voltage Dependent Loads

Voltage dependency of reactive power affects the steady state stability of power system. This effect primarily appears on voltages, which in turn affect the active power. It is well known that the stability improves and the system becomes voltage stable by installing static reactive power compensators or synchronous condensers. The active and reactive proposed static load model for a particular load bus in this study is an exponent function bus voltage as shown in the following equations:

$$P_k = P_0 \frac{V_k^{np}}{V_0} \tag{19}$$

$$Q_k = Q_0 \frac{V_k^{nq}}{V_0} \tag{20}$$

Then the load flow equation (2.6) at load bus k can be written as

$$0 = P_0 \frac{V_k^{np}}{V_0} + \sum_{m=1}^{n} Y_{km} V_k V_m \cos(\theta_k - \theta_m - \gamma_{kw}) \tag{21}$$

$$0 = Q_0 \frac{V_k^{nq}}{V_0} + \sum_{m=1}^{n} Y_{km} V_k V_m \sin(\theta_k - \theta_m - \gamma_{kw}) \tag{22}$$

E. Effect of Induction Motor Load

Induction machine motor is one of the most popular loads in the power system. About 50-70% of all generated power is consumed by electric motors with about 90% of this being used by induction motors. Therefore, it is considered an important part of the power system load and a significant attention regarding this type of load has been taken for both dynamic and steady state analysis. In this research, the induction machine load is considered using the steady state model analysis.

IV. PROBLEM FORMULATION

The Modal analysis method has been successfully applied to two different electric power systems. The Q-V cures are generated for selected buses in order to monitor the voltage stability margin. Different voltage dependent load and Induction machine load models are simulated. A power flow program based on Mat lab is developed to,

A. Analyses with constant impedance Load

The modal analysis method is applied to the three suggested test systems. The voltage profile of the buses is presented from the load flow simulation. Then, the minimum Eigen value of the reduced Jacobin matrix is calculated. After that, computing the participating factors identifies the weakest load buses, which are subject to voltage collapse.

B. Analysis considering effect of induction machine load

The modal analysis including the induction machine load is performed for the three suggested test systems. The induction machine load can be connected to any bus in the tested system. In this study two-induction machine loads with different ratings have been selected for the analysis. The machines data are shown in Table 1.

The voltage profile of the buses is presented from the load flow solution. Then, the minimum Eigen value of the reduced Jacobin matrix is calculated. After that, computing the participating factors identifies the weakest load buses, which are subject to voltage collapse [8, 9].

C. The IEEE 14 Bus System

Table.2 shows the voltage profiles of all buses of the IEEE 14 Bus system as obtained from the load flow including induction machine load model 1 & 2.

TABLE. 2. VOLTAGE PROFILES OF IEEE 14 BUS SYSTEM

BUS NO	CONSTANT LOAD MODEL	IMPEDANCE LOAD MODEL 1	IMPEDANCE LOAD MODEL 2
1	1.060	1.060	1.060
2	1.040	1.040	1.040
3	1.010	1.010	1.010
4	0.979	0.983	0.983

5	0.983	0.986	0.987
6	1.070	1.070	1.070
7	1.046	1.049	1.050
8	1.080	1.080	1.080
9	1.050	1.055	1.056
10	1.049	1.053	1.053
11	1.056	1.058	1.058
12	1.024	1.027	1.027
13	1.044	1.049	1.050
14	1.029	1.050	1.053

The result shows the effect of both induction machine load and the constant load. It can be seen that all the bus voltages are within the acceptable level. In general, the lowest voltage compared to the other buses can be noticed at bus number 4 in all cases. Table.3 shows the Eigen values of all buses of the IEEE 14 Bus system as obtained from the load flow including induction machine load model 1 & 2.

TABLE .3. EIGEN VALUES OF IEEE 14 BUS SYSTEM

S.No	CONSTANT LOAD MODEL	IMPEDANCE LOAD MODEL 1	IMPEDANCE LOAD MODEL 2
1	62.5497	62.7566	62.7774
2	40.0075	40.1996	40.2196
3	21.5587	21.6384	21.6466
4	18.7197	18.8205	18.8311
5	15.7882	15.8638	15.8714
6	11.1479	11.2021	11.2077
7	2.7811	2.8274	2.8321
8	5.4925	5.5355	5.5399
9	7.5246	7.6189	7.6290

Table .3. shows the participation factors of all buses of the IEEE 14 Bus system as obtained from the load flow including induction machine load model 1 & 2.

TABLE. 4. PARTICIPATION FACTORS OF IEEE 14 BUS SYSTEM

BUS NO	CONSTANT LOAD MODEL	IMPEDANCE LOAD MODEL 1	IMPEDANCE LOAD MODEL 2
4	0.0091	0.0092	0.0092
5	0.0045	0.0046	0.0046

7	0.0691	0.0704	0.0706
9	0.1912	0.1939	0.1942
10	0.2319	0.2376	0.2382
11	0.1095	0.1136	0.1140
12	0.0225	0.0226	0.0226
13	0.0351	0.0346	0.0345
14	0.3270	0.3135	0.3121

D. The IEEE 30 Bus System

Table.5. shows the voltage profiles of all buses of the IEEE 30 Bus system as obtained from the load flow including induction machine loads at bus 30.

TABLE .5 VOLTAGE PROFILES OF IEEE 30 BUS SYSTEM

BUS NO	CONSTANT LOAD MODEL	IMPEDANCE LOAD MODEL 1	IMPEDANCE LOAD MODEL 2
1	1.060	1.060	1.060
2	1.043	1.043	1.043
3	1.019	1.020	1.020
4	1.010	1.011	1.011
5	1.010	1.010	1.010
6	1.009	1.010	1.011
7	1.001	1.002	1.002
8	1.010	1.010	1.010
9	1.048	1.049	1.049
10	1.040	1.040	1.041
11	1.082	1.082	1.082
12	1.054	1.055	1.055
13	1.071	1.071	1.071
14	1.038	1.039	1.039
15	1.033	1.034	1.034
16	1.041	1.042	1.042
17	1.035	1.035	1.036
18	1.023	1.024	1.024
19	1.020	1.021	1.021
20	1.024	1.025	1.025
21	1.025	1.027	1.027
22	1.025	1.027	1.027
23	1.018	1.020	1.020
24	1.006	1.010	1.011
25	0.983	0.991	0.993
26	0.964	0.973	0.975
27	0.977	0.988	0.991

28	1.008	1.011	1.011
29	0.956	0.979	0.984
30	0.944	0.979	0.986

The result shows the effect of both induction machines load and the constant load. It can be seen that all the bus voltages are within the acceptable level except buses 29 and 30. In general, the lowest voltage compared to the other buses can be noticed at bus number 30 in all cases [10]. Table.6 shows the Eigen values of all buses of the IEEE 30 Bus system as obtained from the load flow including induction machine load model 1 & 2.

TABLE .6. EIGEN VALUES OF IEEE 30 BUS SYSTEM

S.NO	CONSTANT LOAD MODEL	IMPEDANCE LOAD MODEL 1	IMPEDANCE LOAD MODEL 2
1	110.2056	110.3383	110.3615
2	100.6465	100.7790	100.8104
3	65.9541	66.0366	66.0507
4	59.5431	59.5990	59.6125
5	37.8188	37.8559	37.8646
6	35.3863	35.4126	35.4185
7	23.4238	23.4500	23.4558
8	23.0739	23.1397	23.1521
9	19.1258	19.1603	19.1676
10	19.7817	19.7989	19.8026
11	18.0785	18.1123	18.1192
12	16.3753	16.4800	16.5022
13	13.7279	13.7888	13.8023
14	13.6334	13.6568	13.6612
15	11.0447	11.0704	11.0750
16	0.5060	0.5211	0.5240
17	1.0238	1.0355	1.0380
18	1.7267	1.7555	1.7618
19	8.7857	8.7949	8.7970
20	7.4360	3.5873	3.5887
21	3.5808	4.0554	4.0564
22	4.0507	7.5141	7.5303
23	6.0207	5.4839	5.4898
24	5.4527	6.1933	6.2299

Table.7 shows the participation factors of all buses of the IEEE 30 Bus system as obtained from the load flow including induction machine load model 1 & 2.The simulation results of voltage profile and participation factor of IEEE 14 & 30 bus systems are presented as shown in the Fig. 1 to 4 respectively.

TABLE .7 PARTICIPATION FACTORS OF IEEE 30 BUS SYSTEM

S.NO	CONSTANT LOAD MODEL	IMPEDANCE LOAD MODEL 1	IMPEDANCE LOAD MODEL 2
1	0.0004	0.0004	0.0004
2	0.0005	0.0005	0.0005
3	0.0005	0.0006	0.0006
4	0.0002	0.0002	0.0002
5	0.0037	0.0040	0.0041
6	0.0121	0.0130	0.0132
7	0.0037	0.0041	0.0041
8	0.0081	0.0088	0.0090
9	0.0111	0.0120	0.0122
10	0.0079	0.0087	0.0088
11	0.0115	0.0125	0.0127
12	0.0165	0.0181	0.0184
13	0.0179	0.0196	0.0200
14	0.0172	0.0189	0.0192
15	0.0176	0.0189	0.0191
16	0.0189	0.0203	0.0206
17	0.0238	0.0255	0.0258
18	0.0395	0.0414	0.0419
19	0.1055	0.1070	0.1073
20	0.1729	0.1770	0.1778
21	0.1028	0.1015	0.1013
22	0.0025	0.0026	0.0026
23	0.1934	0.1858	0.1842
24	0.2118	0.1988	0.1961

V. CONCLUSION

In this paper, the voltage collapse problem is studied. The Modal analysis technique is applied to investigate the stability of two well-known power systems. The method computes the smallest Eigen value and the associated Eigen vectors of the reduced Jacobin matrix using the steady state system model. The magnitude of the smallest Eigen value gives us a measure of how close the system is to the voltage collapse. Then, the participating factor can be used to identify the weakest node or bus in the system associated to the minimum Eigen value.

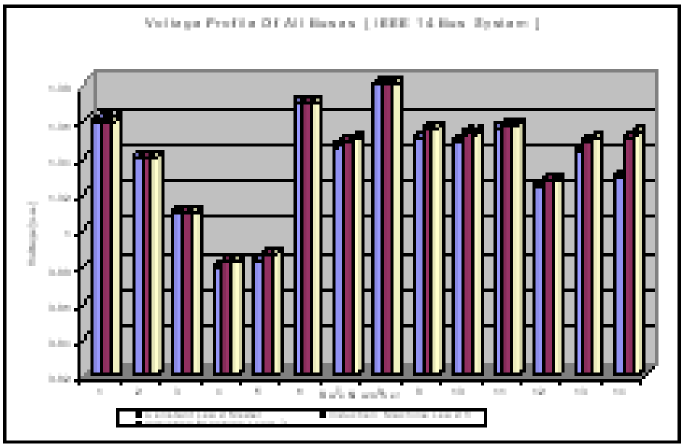

Fig.1. Voltage profile of IEEE 14 bus system

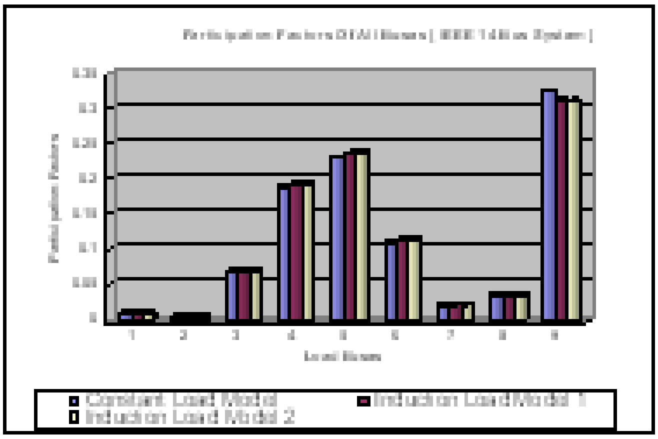

Fig. 2. Participation factor of IEEE 14 bus system

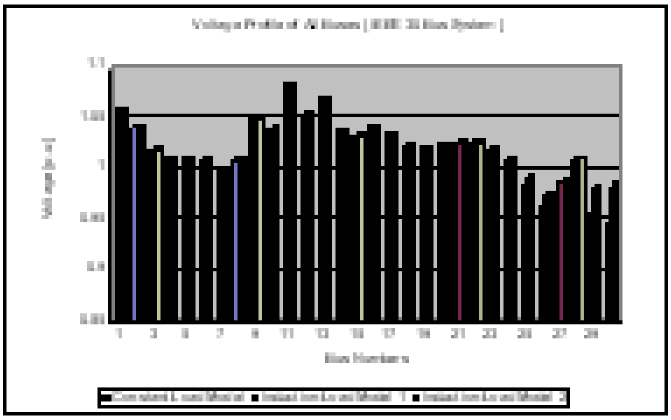

Fig. 3. Voltage profile of IEEE 30 bus system

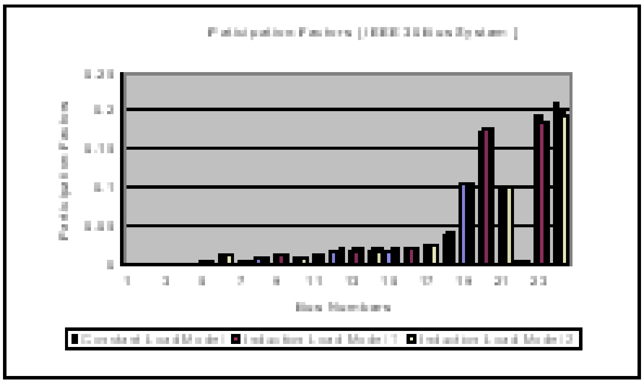

Fig. 4. Participation factor of IEEE 30 bus system

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