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Voltage Dependency of Reactive Power Affects the Stability of Power System

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***Abstract*- Normally, stability was often regarded as a problem of generators and their controls, while the effect of loads was considered as a secondary factor. The load representation can play an important factor in the power system stability. The effects of load characteristics on power system stability have been studied. Many of research results showed that the load characteristics affect the behavior of the power system. The effect of the dynamic load modelling on voltage stability is presented in this paper. A voltage dependent load model is studied. A significant change in the stability limit or distance to voltage collapse should be noticed clearly. Simulations were carried out to investigate the effect of dynamic load on power system stability is carried out using Western System Coordinate Council (WSCC) 9-bus test system. The results were presented and discussed.**

***Keywords:* Dynamic load, voltage dependent load, power system stability, WSCC 9-bus test system, Matlab (Simulink)**

I INTRODUCTION

In the past, voltage stability was investigated as static. However, most of power system consists of a huge number of dynamic systems connected in different manner and its dynamic behavior has great influence on the voltage stability analysis. For that reason, in order to get more sensible result it is essential to take the full dynamic system model into account. Dynamic phenomena causing voltage instability, occurring in electric power systems subjected to strong load demands, lead to a progressive decreasing of the voltage magnitude at one or more buses, resulting sometimes in network islanding, thus leading to local or global blackouts. Oscillatory instability and voltage instability are two major problems. Consequently, dynamic voltage stability poses a primary threat to system security and reliability.

The effect of loads was considered as a secondary factor. The load representation can play an important factor in the power system stability. The effects of load characteristics on power system stability have been studied. Many of research results showed that the load characteristics affect the behavior of the power system.

The load characteristics can be divided into two categories; static characteristics and dynamic characteristics. The effect of the static characteristics is discussed in chapter 3. Recently, the load representation has become more important in power system stability studies [1-3]. In the previous analysis, the load was represented by considering the active power and reactive power and both were represented by a combination of constant impedance (resistance or reactance),constant current and constant power (active or reactive) elements. This kind of load modelling has been used in many of the power system steady state analyses. However the load may be modeled as a function of voltage and frequency depending on the type of study. On the other hand, there is no single load model that leads to conservative design for all system configurations [4].

Dynamic load models whose active power P and reactive power Q vary as functions of positive-sequence voltage. Negative- and zero-sequence currents are not simulated. The effect of the dynamic load modelling on voltage stability is presented in this section. A voltage dependent load model is studied. A significant change in the stability limit or distance to voltage collapse should be noticed clearly.

The singular value decomposition technique was applied to the multi-input multi-output (MIMO) transfer function of the test system in order to carry out the identification of the weak bus in the power system [5, 6]. The MIMO system is defined takes into account the critical nodal voltages as outputs and possible control variables as the input. The proposed technique takes the advantages of the classical static voltage stability analysis and the modern multi-variable feedback control theory. The singular values and singular vectors are calculated for frequencies corresponding to the critical system modes. The output singular vectors shows at which bus the voltage magnitude is the most critical. Using the magnitudes of the input singular vectors the most suitable inputs for countermeasures can be selected. Based on the results

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presented on [6], the effect of the dynamic load modelling on voltage stability is presented in this paper. A voltage dependent load model is studied. Simulations were carried out to investigate the effect of dynamic load on power system stability is carried out using Western System Coordinate Council (WSCC) 9-bus test system.

II Voltage Dependent Load.

Voltage dependency of reactive power affects the stability of power system. This effect primarily appears on voltages, which in turn affects 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 [7]. The active and reactive dynamic load model for a particular load bus is an exponent function of the per unit bus voltage as shown in the following equations:

$$P_k = P_0 * \left(\frac{V}{V_0} \right)^{np} * (1 + T_{p1} * s) / (1 + T_{P2} * s) \tag{1}$$

$$Q_k = Q_0 * \left(\frac{V}{V_0} \right)^{nq} * (1 + T_{q1} * s) / (1 + T_{q2} * s) \tag{2}$$

Where:

V_0 is the initial positive sequence voltage.

P_0 and Q_0 are the initial active and reactive powers at the initial voltage V_0.

V is the positive-sequence voltage.

n_p and n_q are exponents (usually between 1 and 3) controlling the nature of the load.

T_{p1} and T_{p2} are time constants controlling the dynamics of the active power P.

T_{q1} and T_{q2} are time constants controlling the dynamics of the reactive power Q.

Then the load flow equation is given by:

$$P_k + jO_k = \sum_{m=1}^{n} Y_{km} V_m V_m \cos(\theta_k - \theta_m - \gamma_{km}) + j \sum_{m=1}^{n} Y_{km} V_m V_m \sin(\theta_k - \theta_m - \gamma_{km}) \tag{3}$$

In order to include the effect of loading, the load flow in Equation (3) at load bus k can be written as:

$$0 = P_0 * \left(\frac{V}{V_0} \right)^{np} * (1 + T_{P1} s) / (1 + T_{P2} s) + \sum_{m=1}^{n} Y_{km} V_m V_m \cos(\theta_k - \theta_m - \gamma_{km}) \tag{4}$$

$$0 = Q_0 * \left(\frac{V}{V_0} \right)^{nq} * (1 + T_{q1} s) / (1 + T_{q2} s) + \sum_{m=1}^{n} Y_{km} V_m V_m \sin(\theta_k - \theta_m - \gamma_{km}) \tag{5}$$

To use the singular value decomposition technique on power system analysis a linearised relation between the active and reactive powers at nodes versus the voltage magnitudes and node angles has to be found, which is established by power flow Jacobian matrix as:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_{P\theta} & J_{PV} \\ J_{Q\theta} & J_{QV} \end{bmatrix} \begin{bmatrix} \Delta \theta \\ \Delta V \end{bmatrix} = [J] \begin{bmatrix} \Delta \theta \\ \Delta V \end{bmatrix} \tag{6}$$

The Jacobian matrix *J*, in equation 6, thus contains the first derivatives of the active power part *F*, and the reactive power part *G*, of the power system flow equations with respect to voltage magnitudes *V* and node angle θ .

If the singular value decomposition [8] is applied to the Jacobian matrix *J*, the obtained matrix decomposition can be written as:

$$J = UST^T \tag{7}$$

The minimum singular value, $\sigma_n(J)$ is a measure of how close to singularity the power system flow Jacobian matrix is. If the minimum singular value is equal to zero, the studied matrix is singular and no power flow solution exists. The singularity of the Jacobian matrix corresponds to that the inverse of the matrix does not exist. This can be interpreted as an infinite sensitivity of the power flow solution to small perturbations in the parameters values. At the point where $\sigma_n(J)=0$ several branches of equilibria may come together and the studied system will experience a qualitative change in the structure of the solutions due to a small change in parameter values. This point called a static bifurcation point of the power system [7].

III Test system description

The detailed model of WSCC 3-machines, 9-bus test system shown in Figure 1 is used to demonstrate the singular value decomposition methods applied to the MIMO system to identify the weakest bus. The test system connected in a loop configuration, consists essentially of nine buses (B1 to B9) interconnected through transmission lines (L1, L2, L3), three power plants and three loads connected at buses B5, B6, and B8 respectively. The corresponding power system dynamic model consists of generators described by 6th order model, governors, static exciters, Power System Stabilizer (PSS) and non-linear voltage and frequency dependent loads. The detailed generator, controller and load model can be found in [6-7, 10].

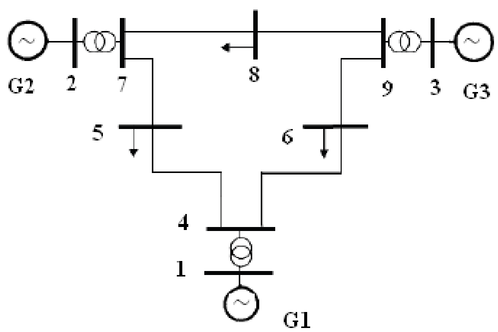

Fig. 1 WSSC 3-machine, 9-bus test system [10]

IV Analysis considering the effect of load characteristics.

In the following, the singular value decomposition including load characteristics were applied to the reduced Jacobian matrix which is corresponding to the transfer matrix of the MIMO system in order to determine the maximum singular value and the critical modes of oscillations were identified [5, 6]. After that, the magnitudes of the output and input singular vectors that relates the critical buses and the most suitable control action were calculated. Different voltage dependent load models can be implemented by changing the np and nq values in Equations (1) and (2). The singular value is performed from the two critical modes of frequencies. Equation 6 and Equation 7 will update the load equations in the load flow. Then, the nonlinear equations will be solved to obtain a new load flow solutions. A load flow Matlab based program is developed to include the dynamic load model.

Finally, the effects of dynamic load model on these modes were studied. Results presented and discussed. The results are shown in Figure 2 to Figure 6.

Exciter mode

The simulation results shown in Figure 2 show the output singular vectors that correspond to the maximum singular value at the exciter mode for different load characteristics (np = nq = 1, 2 and 3 respectively). In general, the result shows that, the buses 5, 6 and 8 have the highest singular value to the critical mode, which is similar as obtained before. The largest output singular value at bus # 8 indicates a high contribution of this bus to the voltage collapse. There is a slight change in the magnitude of the output singular vector but this change does not change the position of the critical mode.

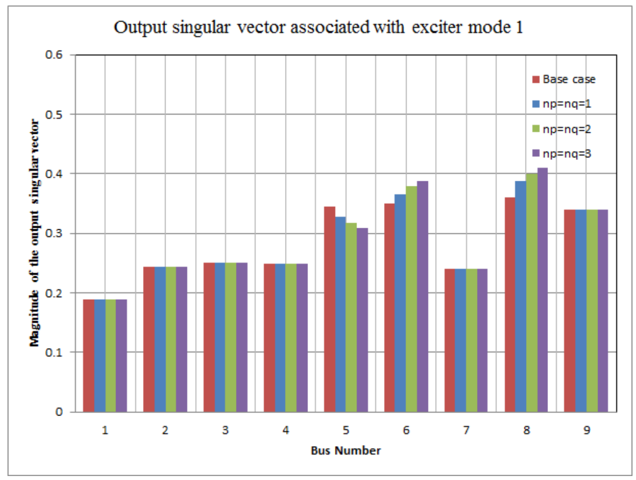

Fig. 2 Plot mode of magnitude of the output singular vector vs bus number at different load characteristics

In Figure 3, the magnitude of the input singular vector associated with this mode is presented. The simulation results show that there is also a slight change in the magnitude of the input singular vector due to the load characteristics and still the input numbers 16, 17 and 18 are the most suitable signals for this mode.

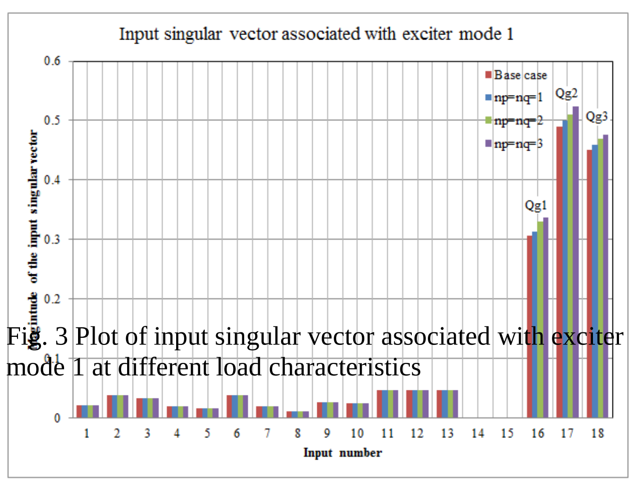

Fig. 3 Plot of input singular vector associated with exciter mode 1 at different load characteristics

Inter-area mode

The effect of load model on the magnitude of the output singular vector associated with the inter-area mode is given in Figure 4. Also, there is a slight change in the magnitude of the output singular vector due to the change in load characteristics. There is no change in the critical mode position due to load changes and bus # 8 is the most critical bus.

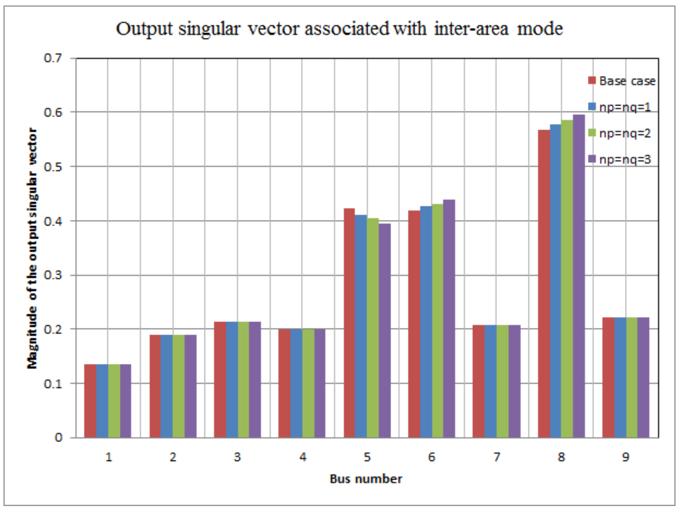

Fig. 4 Plot of magnitude of the output singular vector vs bus number with different load characteristics

Figure 5 shows the magnitude of the input singular vector due to changes in the load model. From the results, there is no change in the position of the input signal that is suitable for dynamic stability analysis. Although, there is a slight change in the magnitude of the input signal but this does not change the position of critical nodes.

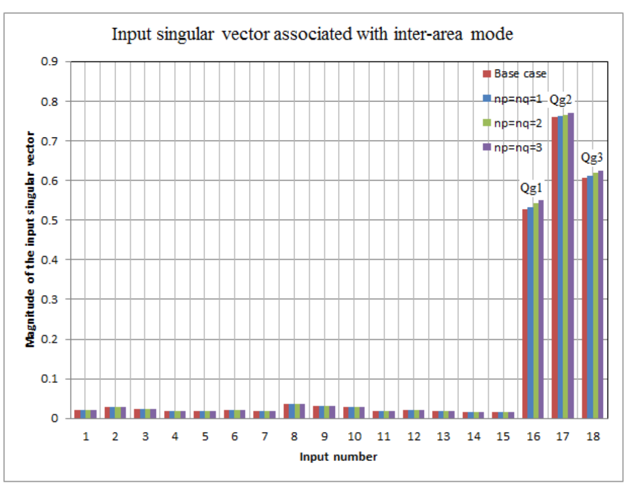

Fig. 5 Plot of magnitude input singular vector vs input number with different load characteristics

The simulation results shown in Figure 6 show the voltage profiles of all buses of the test system as obtained from the load flow considering different load characteristics. The result shows four types of nonlinear loads, including the base case and three different voltage dependent loads (np = nq = 1, 2 and 3 respectively). The simulation results show that all the bus voltages are within the acceptable level (± 10). Also, it can be noticed that the lowest voltage in all cases compared to the other buses is at bus # 8.

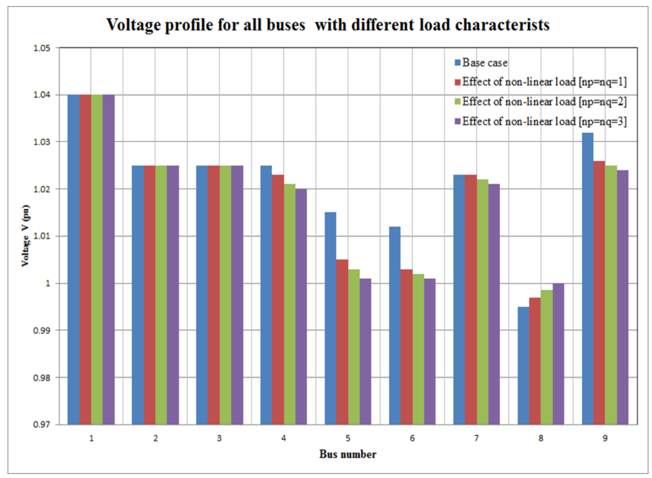

Fig. 6 Voltage profiles of all buses of the test system at different load models

V Conclusions

The effect of the dynamic load on critical modes and voltage stability margin were also studied. The results shows that there is an effect of the dynamic load model on the critical mode and voltage stability margin but these effects did not change the position of the critical mode (weakest buses) and their associated control signals. In addition, a noticeable change in the voltage level appeared clearly. The method is highly accurate and suitable dynamic stability analysis; it can also be applied to large power systems.

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