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An Analytical approach for Dynamic Voltage Stability Analysis in Power Systems

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Abstract: - In this paper present an analytical approach for power system dynamic voltage stability analysis using the multi-input multi-output (MIMO) as transfer function. Based on the modal analysis and singular value analysis the dynamic voltage stability is presented. Our model takes in consideration the advantages of the classical static voltage stability using the traditional multi-variable feedback control theory.

Key-Words: - Dynamic voltage stability, Singular value analysis, power system dynamics

1 Introduction

Nowadays a large number of researches and studies were performed in the area of voltage stability. Most of them calculate the voltage stability problem using static analysis methods based on the study of the reduced (V-Q) Jacobian matrix, and by performing modal analysis [1-6]. Thus, the bus, branch and generator participation factors on the static voltage stability can be obtained. Moreover, the stability margin and the shortest distance to instability can also be determined [6]. A power system is a typical large dynamic system and its dynamic behavior has great influence on the voltage stability. The latest blackouts have shown that voltage stability is very closely associated with issues of frequency and angle stability [7, 8]. Therefore, in order to get more realistic results it is necessary to take the full dynamic system model into consideration. Some researches have been performed on the dynamic voltage stability analysis [1,5,6,9]. The general structure of the system model used is similar to that for transient stability analysis. The overall system equations comprise a set of first-order differential equations plus the algebraic equations (DAEs) [6]. However, for voltage stability analysis, special attention should be paid to issues of voltage and reactive power control and load behavior.

In [9], the objective of dynamic voltage stability is achieved by minimizing oscillations of the state and network variables. Then, a parameter optimization technique is applied for limiting the magnitude of oscillations.

In [10], the voltage stability is decoupled from the angle dynamics. The authors are assuming that all electromechanical oscillations are stable. By neglecting the power-angle dynamics, the voltage response of the unregulated power system can be approximated by the eigenvalues of the Voltage Stability Matrix [10].

However, in large power systems, the dynamic voltage stability is associated with different modes of oscillations. Although there is extensive literature on voltage stability, very few deal with this issue.

In this paper, an analytical approach for the assessment of dynamic voltage stability is described. The method takes the advantages of modern multi-variable control theory. Based on the MIMO transfer function, interactions between properly defined input and output variables affecting dynamic voltage stability can be analyzed at different frequencies.

This paper is organized as follows: Following the introduction, the control analysis of dynamic and static voltage is described in section 2. Then in section 3, the proposed dynamic voltage stability modeling is introduced. The analysis for dynamic voltage stability solution is discussed in section 4. Finally, a brief conclusion is deduced.

2 Control Analysis of Dynamic and Static Voltages

In this section we calculated the mathematical model for the dynamic and static voltage stability study of a power system comprises a set of first order differential equations and a set of algebraic equations [1,6]

$$x= f(x,y) \qquad (1)$$
$$0=g(x,y) \qquad (2)$$

where:

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x is the state vector of the system
y vector containing bus voltages

Equations (1) and (2) are usually solved in the time domain by means of the numerical integration and power flow analysis methods [5, 6].

The steady state equilibrium values (x_0, y_0) of the dynamic system can be evaluated by setting the derivative in Equation (1) to zero. Through linearization about (x_0, y_0), Equations (1) and (2) are expressed as follows [1, 5]:

$$\frac{d\Delta x}{dt} = A\Delta x + B\Delta y \tag{3}$$

$$0 = C\Delta x + D\Delta y \tag{4}$$

Further, by eliminating Δy, the linearized state equation can be written as [1, 5].

The static bifurcation will occur when det (D) = 0. For the dynamic bifurcation phenomenon, it is always assumed that det (D) ≠ 0 and that D^{-1} exists [1,5].

By analyzing the eigenvalues of $\widetilde{A}$, dynamic voltage stability analysis can be performed.

In addition the static voltage stability analysis is described which is based on the modal analysis of the power flow Jacobian matrix, as given in Equation (5) [6]:

$$\begin{bmatrix} \Delta P_{PQ,PV} \\ \Delta Q_{PQ} \end{bmatrix} = \begin{bmatrix} J_{P\vartheta} & J_{PV} \\ J_{Q\vartheta} & J_{QV} \end{bmatrix} \mathrm{x} \begin{bmatrix} \Delta\vartheta \\ \Delta V_{PQ} \end{bmatrix} \tag{5}$$

where:

$\Delta P_{PQ,PV}$ the incremental change in bus real power

ΔQ_{PQ} the incremental change in bus reactive power

$\Delta\vartheta$ incremental change in bus voltage angle

ΔV incremental change in bus voltage magnitude

The elements of the Jacobian matrix represent the sensitivities between nodal power and bus voltage changes [6]. Power system voltage stability is largely affected by the reactive power. Keeping real power as constant at each operating point, the Q-V analysis can be carried out. Assuming $\Delta P_{PQ,PV} = 0$, it follows from Equation (5) [4, 6]:

$$\Delta Q_{PQ} = \left[J_{QV} - J_{Q\theta}.J_{P\vartheta}{}^{-1}.J_{PV} \right] \mathrm{x}\ \Delta V_{PQ} =$$

$$= J_R.\Delta V_{PQ} \tag{6}$$

and

$$\Delta V_{PQ} = J_R{}^{-1}.\Delta Q_{PQ} \tag{7}$$

Based on the $J_R{}^{-1}$, which is the reduced V-Q Jacobian matrix, the Q-V modal analysis can be performed. Therefore, the bus, branch and generator participation factors are obtained. Moreover, the stability margin and the shortest distance to instability will be determined [4- 6].

As discussed in [2, 3, 11], the application of singular value analysis to $J_R{}^{-1}$ also allows the static voltage stability analysis. In order to prevent voltage collapse, different measures can be applied [5, 6]. The reactive power compensation, under-voltage load shedding and the control of transformer tap-changers are the most important control features for enhancing the static voltage stability [5, 6, 9].

Furthermore, with the development of power electronics, FACTS (Flexible AC Transmission Systems) devices, i.e. SVC (Static Var Compensation), are also recognized as important tools for the dynamic voltage stability control.

3 A novel approach for Dynamic Voltage

In this paper, we suggest to carry out voltage dynamic stability analysis based on the MIMO transfer function, which is widely used in control engineering.

For this analysis, a detailed dynamic power system model including generators, governors, static exciters, power system stabilizers (PSS) and nonlinear voltage and frequency dependent loads is necessary. Furthermore, dynamic loads may also be included. In general, the dynamic models described by Equations (1) and (2) must consider all relevant issues affecting voltage stability.

As the first step, variables that affect dynamic voltage stability must be selected as input variables to the MIMO system. These are usually the real and reactive power controls of selected generators and loads. Some other variables, such as the tap-changer position and the SVC control signals, can also be included as inputs. The voltage magnitudes at the most critical nodes are considered as output signals. Since the number of input and output variables can usually be constrained to a small range, large power systems can also be analyzed using the proposed method.

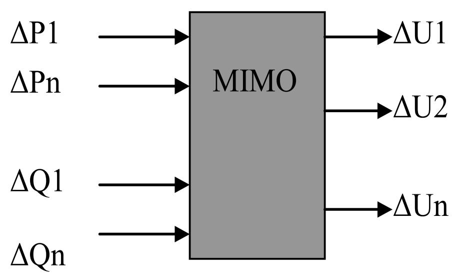

Fig.1**: Dynamic voltage stability modeling**

In this study, a MIMO system transfer function matrix is employed by using all the generation and load controls as the input signals.

4 Analytical Results

Based on the above model the MIMO system transfer function matrix is calculated by using all the generation and load controls as the input signals. On the other side the set of output signals is extended to all bus voltages due to the small size of the power system. Based on the above figure.1, the transfer function matrix is calculated below.

$$[\Delta U_1 ... \Delta U_n]^T =$$

$$J_V(s).[\Delta P_1 .. \Delta P_n \mid \Delta Q_1 ... \Delta Q_n]^T \qquad (8)$$

Each sub transfer function in the $J_V(s)$ can be calculated using the numerical methods to the power dynamic model.

5 Conclusion

In this paper suggests the application of singular value analysis using a MIMO model for power system dynamic voltage stability studies. Due the limitation of inputs and outputs this method is also applied for large systems. Finally, the calculation of the transfer function numerical methods based on a dynamic system model can be used. For the future work simulation works will be prepared.

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