IEEE Transactions on Power Systems, Vol. PWRS-1, No. 1, February 1986

EFFICIENT EIGENVALUE AND FREQUENCY RESPONSE METHODS APPLIED TO POWER SYSTEM SMALL-SIGNAL STABILITY STUDIES

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Abstract - Frequency response and eigenvalue techniques are fundamental tools in the analysis of small signal stability of multimachine power systems. This paper describes two highly efficient algorithms which are expected to enhance the practical application of these techniques. One algorithm calculates exact eigenvalues and eigenvectors for a large power system, while the other produces the frequency response of the transfer functions between any two variables in the system. This paper also presents alternative computing procedures for the AESOPS eigenvalue estimation algorithm which are simpler and at least as efficient as those described in [1].

I. INTRODUCTION

Low damped electromechanical oscillations have become a common phenomenon in modern electric power systems. The damping of these oscillations, which in some circumstances may even be negative, is dependent on the system structure, its operating conditions, and the effects of automatic-controller action. An efficient way to combat these problems is through the installation of additional signals to the generator excitation systems, which need be properly tuned. This area of work has received continuous attention in recent years, leading to the development of methods and computer programs to determine the source of these problems and obtain solutions by means of control [2].

Among the present requirements in this field, there is the need for simple, reliable and efficient algorithms for the computation of eigenvalues and frequency response of transfer functions for large power systems. This paper describes two efficient algorithms for the calculation of eigenvalues, eigenvectors and the frequency response of transfer functions between any two specified variables in a multimachine system. These algorithms exploit the sparse nature of the power system Jacobian matrix and therefore produce fast solutions at low computational cost. The power system Jacobian matrix formulation caters for various models of generators and associated controllers, induction motors, non-linear loads of different characteristics, and static VAR compensators.

The first successful attempt to calculate the dominant eigenvalues of large power systems has been the AESOPS program [1], which has quite complex computing procedures. This paper presents alternative computing procedures for the AESOPS algorithm which are simpler and at least as efficient as those described in [1].

This paper was sponsored by the IEEE Power Engineering Society for presentation at the IEEE Power Industry Computer Application Conference, San Francisco, California, May 6-10, 1985. Manuscript was published in the 1985 PICA Conference Record.

The notations adopted in the paper are defined as used.

II. THE POWER SYSTEM JACOBIAN MATRIX

The power system stability problem can be represented by a set of differential equations together with a set of algebraic equations, to be solved simultaneously with each other. Equation (1) shows the Jacobian matrix of the entire set of equations, evaluated at an operating point ($\underline{x}_o$, $\underline{y}_o$):

$$\begin{bmatrix} \Delta\dot{\underline{x}} \\ \underline{0} \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \cdot \begin{bmatrix} \Delta\underline{x} \\ \Delta\underline{y} \end{bmatrix} \qquad (1)$$

The power system state matrix can be obtained by eliminating the equations for the algebraic variables in the Jacobian matrix:

$$\Delta\dot{\underline{x}} = (J_1 - J_2 J_4^{-1} J_3)\,\Delta\underline{x} = A\,\Delta\underline{x} \qquad (2)$$

The symbol A is used to represent the system state matrix, whose eigenvalues determine the singular point stability of the non-linear system.

The most reliable method to date for the computation of the full set of eigenvalues of an assymetrical matrix is the QR method developed by Francis [3], which does not exploit the sparsity of the given matrix. Research work has been quite intensive on methods which produce full eigensolutions by exploiting the sparse nature of assymetrical state matrices. These methods will, unfortunately, not have application in the analysis of low-damped electromechanical oscillations, since the associated state matrices are themselves not sparse.

Consider, to illustrate this nonsparsity, the case where every generator in the system is represented by the state vector $\Delta(E_d', E_q', \omega, \delta, V_{fd})$, where the state ΔV_{fd} is associated with a first order model of an excitation control system. Reference 4 discusses this particular example, and shows that, even as the number of generators in the system approaches infinity, the ratio of non-zero elements of the state matrix does not fall below 48 percent. Research efforts should, therefore, be directed towards methods of eigenvalue calculation which do not require the explicit formation of the power system state matrix. The eigenvalue calculation algorithm, presented in this paper, is applied to the power system Jacobian matrix, which is very sparse.

The Jacobian matrix formulation used in this work is an improved version of that developed by Vorley [5] for solving the power system transient stability problem via the "simultaneous solution" approach [6]. It caters for various models of synchronous generators and associated controllers, induction motors, non-linear loads of different characteristics and static VAR compensators. Models for HVDC links and associated controls can also be easily incorporated.

0885-8950/86/0001-0217$01.00