NEW METHODS FOR FAST SMALL-SIGNAL STABILITY ASSESSMENT OF LARGE SCALE POWER SYSTEMS

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Abstract *- This paper describes new matrix transformations suited to the efficient calculation of critical eigenvalues of large scale power system dynamic models. The key advantage of these methods is their ability to converge to the critical eigenvalues (unstable or low damped) of the system almost independently of the given initial estimate. Matrix transforms such as inverse iteration and S-matrix can be thought as special cases of the described method. These transforms can also be used to inhibit convergence to a known eigenvalue, yielding better overall efficiency when finding several eigenvalues.*

Keywords *- Small-signal stability, low damped oscillations, large scale systems, sparse eigenanalysis, matrix transforms.*

I. INTRODUCTION

Fast stability assessment is still a major concern for engineers engaged in large scale power systems operation. There is a need for the development of efficient real-time stability functions to be included in modern EMS.

Efficient methods for the small-signal stability analysis of large scale power systems were developed in the last decade [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]. Most of these methods are based in the use of the *augmented system equations* [2, 5, 6, 7, 8], exploiting the Jacobian matrix sparsity, and rely on iterative methods to obtain one or a few eigenvalues at a time [2, 4, 5, 10].

The major drawback of these methods is the difficulty to ensure that all unstable or low damped eigenvalues of the system have been found. One way to overcome this problem is the use of the **S**-matrix [3], a special matrix transform which maps the eigenvalues in the left half-plane to the circle of unitary radius. The unstable eigenvalues are therefore the eigenvalues of greater modulus and could then be calculated by a plain power method [11, 12] applied to **S**. Unfortunately the power method converges slowly due to the closeness of the moduli of the eigenvalues of **S** to one.

This paper describes new matrix transforms that overcome this problem, yielding a better convergence rate:

- inverse iteration applied to the **S**-matrix [13];
- power method applied to a Möbius [14] (i.e., linear fractional) transform of the **A** matrix;
- an efficient and highly effective method to inhibit convergence to already known eigenpairs [13]. This technique harnesses the convergence properties of partial eigensolution methods.

The Möbius transform allows the choice of three parameters, which can be used to modify the mapping properties. For instance, one can enhance convergence of eigenvalues within a certain region in the complex plane while simultaneously inhibiting convergence on another pre-specified region.

All methods rely on the flexibility in handling separately regions of spectrum by making use of iterations of conveniently chosen functions of the state matrix **A**.

The efficient implementation of these methods is obtained by expressing the basic step of each of these matrix transforms as the solution of a single linear system, with practically the same computational cost of an inverse iteration step [13].

The eigenvalue mapping properties of these matrix transforms are exemplified through a small test system. Results on the large scale Brazilian Interconnected System are then presented.

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II. ITERATIVE EIGENVALUE COMPUTATION

Power Method

The basic idea that underlies almost every partial eigenvalue computation method is that the sequence **x**, **Ax**, ..., $\mathbf{A}^k\mathbf{x}$ converges to the eigenvector $\mathbf{q}_1$ associated with the eigenvalue of largest modulus (λ_1) of matrix **A**, provided that $|\lambda_1| > |\lambda_2| \geq \ldots \geq |\lambda_n|$ [11, 12]. The convergence of this method is linear and depends on the ratio

$$\frac{|\lambda_1|}{|\lambda_2|} \tag{1}$$

This method is not suitable for direct application to the small-signal stability analysis, since the modes of interest in this problem are not those with largest moduli in the state matrix **A**.

The inverse iteration method [11, 12] has been successfully applied to the small-signal stability analysis [2, 5]. This method uses the matrix transform

$$\mathbf{M}_1 = f_1(\mathbf{A}) = (\mathbf{A} - q\mathbf{I})^{-1} \tag{2}$$

where q is a complex shift, in place of the matrix **A**, in the power sequence. The eigenvalues of **A** closest to q will be mapped to the eigenvalues of largest moduli in $\mathbf{M}_1$ and thus the convergence will be driven to these eigenvalues and respective eigenvectors.

The **S**-matrix method proposed in [3] may be generalized to the matrix transform [13]

$$\mathbf{M}_2 = f_2(\mathbf{A}) = (\mathbf{A} + \bar{h}\mathbf{I})(\mathbf{A} - h\mathbf{I})^{-1} \tag{3}$$

where h is a complex number.

Although its initial application with the Lanczos method [3], this matrix transform could also be used with the power method to converge to the eigenvalue of largest modulus in $\mathbf{M}_2$.