COMPUTING DOMINANT POLES OF POWER SYSTEM TRANSFER FUNCTIONS

Nelson Martins[1] Senior Member
Leonardo T. G. Lima[2] Member
Herminio J. C. P. Pinto[1] Member

1 CEPEL, Caixa Postal 2754, CEP 20.001-970, Rio de Janeiro, RJ, BRAZIL, Fax. +55-21-260-1340, e-mail: pacdyn@acsi.cepel.br
2 UNIVERSIDADE FEDERAL FLUMINENSE, Dept. of Electrical Engineering, R. Passo da Pátria 156, Niterói, RJ, CEP 24.210, BRAZIL

Abstract *- This paper describes the first algorithm to efficiently compute the dominant poles of any specified high order transfer function. As the method is closely related to Rayleigh iterations (generalized Rayleigh quotient), it retains the numerical properties of global and ultimately cubic convergence. The results presented are limited to the study of low frequency oscillations in electrical power systems, but the algorithm is completely general.*

Keywords *- Small-signal stability, poorly damped oscillations, transfer function, dominant poles, transfer function residues, participation factors, large scale systems, sparse eigenanalysis.*

I. INTRODUCTION

Practical Needs

Linear systems [1] and feedback control [2] are the key to power system small-signal stability analysis and control [3]. The state-space description of the dynamic system underlies all practical computational methods, but the transfer function concept is fundamental to the understanding and engineering design of system stability analysis and control.

Practical eigensolution problems involve state matrices whose dimensions may range from a few thousand to one million [4]. Power system eigenanalysis applications have reached the order of 20,000 state variables [5,6].

The frequencies of power system electromechanical oscillations range from zero to 2 Hz. The cluster of eigenvalues in this narrow frequency band impairs examination of the (usually few) eigenvalues of practical concern. The development of partial eigensolution algorithms incorporating the transfer function idea is highly desirable for several reasons, including these:

- many system eigenvalues naturally disappear due to pole-zero cancellation in the specified transfer function. This should dramatically improve convergence to the effective transfer function poles, which are the dominant ones for the high-order, original transfer function.
- as such algorithms only produce eigenvalues which are dominant in the transfer functions of interest, the user is freed from the repetitive task of verifying if the converged eigenvalue is one of interest to the analysis in hand. Root-Locus plots, for instance, could be rapid and automatically obtained for large systems.
- model reduction is an important issue to the control systems field [2] and its applications in power system dynamics [5,7,8,9,10,11]. Highly reduced power system transfer function models prove effective for controller design [5]. Once the dominant transfer function poles have been found, the calculation of its residues can be efficiently carried out [12]. From this information, one can build a reduced transfer function model whose accuracy can be varied at will depending on the number of dominant poles considered.

95 WM 191-7 PWRS A paper recommended and approved by the IEEE Power System Engineering Committee of the IEEE Power Engineering Society for presentation at the 1995 IEEE/PES Winter Meeting, January 29, to February 2, 1995, New York, NY. Manuscript submitted August 1, 1994; made available for printing January 4, 1995.

The concept of pole dominance, as utilized in this paper, is now described. A transfer function $G(s)$ can be expressed in a parallel form [1, 13], as a sum of residues over a first-order pole:

$$G(s) = \sum_{j=1}^{n} \frac{R_j}{s - \lambda_j} \qquad (1)$$

$G(s)$ can be effectively approximated by the sum of only the m terms, $m < n$, which have residue magnitudes $|R_j|$ above some given value. This reduced sum of m terms determine the so called *effective* transfer function behavior [13].

A large residue magnitude $|R_j|$ implies dominance, i.e., good observability and controllability of the pole λ_j in the transfer function $G(s)$. The peaks of the Bode Magnitude plots occur at frequencies which are close to the imaginary parts of the dominant poles of $G(s)$.

Previous Efforts

The original AESOPS algorithm [14] is a heuristically based one-at-a-time eigenvalue method designed to selectively compute only the electromechanical modes of oscillation of large power systems. It is derived from the linearized equation of motion of a chosen generator, to which a complex frequency disturbance in the mechanical torque is applied. At every iteration, a corrected value for this complex frequency disturbance is applied until the system becomes resonant. This iterative process is almost always convergent and the converged complex frequency value corresponds to an electromechanical eigenvalue which is dominant at the torque-angle loop of the disturbed generator.

The original AESOPS algorithm is known to present problems of slow convergence due to its heuristic nature. These problems do not occur with the improved forms of the AESOPS algorithm [6,14,15,16,17,18] which are full Newton-Raphson methods and possess quadratic convergence in the neighborhood of the solution. The authors are not aware of any reported work on practical computation of transfer function dominant poles other than AESOPS.

The Proposed Algorithm

A very restrictive characteristic of the AESOPS algorithm is that only the rotor electromechanical eigenvalues can be computed. The electromechanical eigenvalues are dominant in the $\Delta\omega^i(s) / \Delta Pmec^i(s)$ transfer function, ω^i and $Pmec^i$ being the rotor speed and mechanical power of the i-th disturbed generator. As there are critical eigenvalues associated with other different