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Modern Tools for the Small-Signal Stability Analysis and Design of FACTS Assisted Power Systems

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Introduction(1/3)

- State-of-the art techniques for small-signal analysis and control design of FACTS assisted power systems

- Comprehensive set of time, frequency and modal domain tools derived from the same kernel: the descriptor system model of the linearized power system

- The descriptor system approach involves the mixed use of differential and algebraic equations, yielding mathematical models for dynamic systems of high complexity that retain the individual equations (and identity) of its various components.

- The matrices involved are very sparse, leading to efficient computation

Introduction(2/3)

- Existing sparse eigensolution algorithms, use single spectral transformation (such as Shift-Invert) and may allow for the computation of several eigenvalues (Simultaneous Iterations; Modified Arnoldi Methods)
- Transfer Function Zeros for SISO and MIMO systems
- Transfer Function Residues and other modal sensitivities
- Computing the Dominant Pole Spectrum of scalar transfer functions
- Modal Equivalents built from pole and residue information

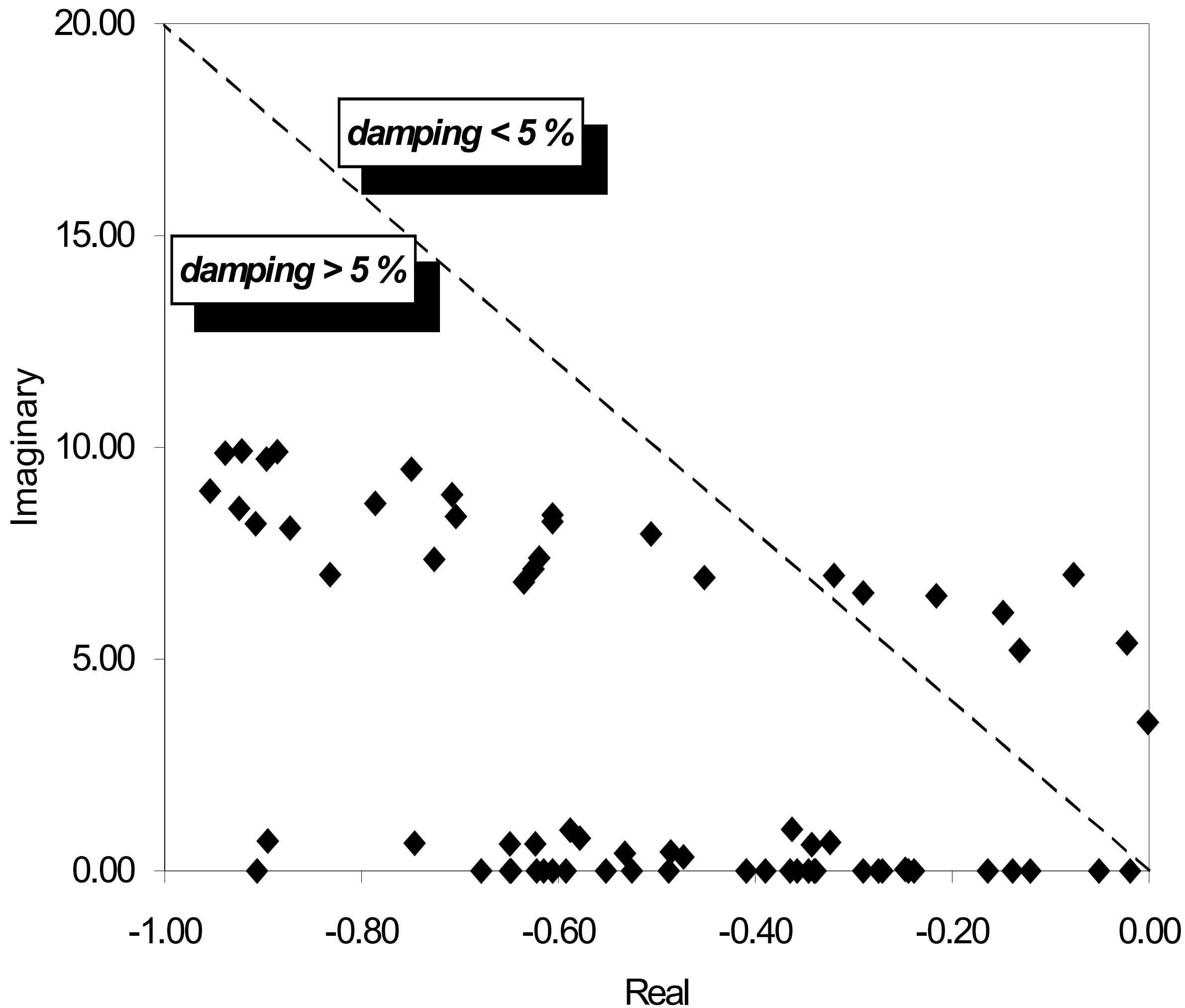
Introduction(3/3)

- The Refactored Bi-Iteration (RBI) method is a sparse eigensolution algorithm that employs multiple moving shifts and subspace bi-orthogonalizations to deal with unsymmetrical matrices
- RBI shows an unprecedented convergence rate and, despite the multiple factorizations, is highly cost-effective for eigensolutions of large power system matrices
- Same eigensolution algorithms and modal sensitivities applied to small-signal voltage stability, particularly at the point of collapse (maximum system loadability point)
- Graphical visualization of results enhances productivity

The South-Southeast Brazilian System (1986 Operations Planning Model)

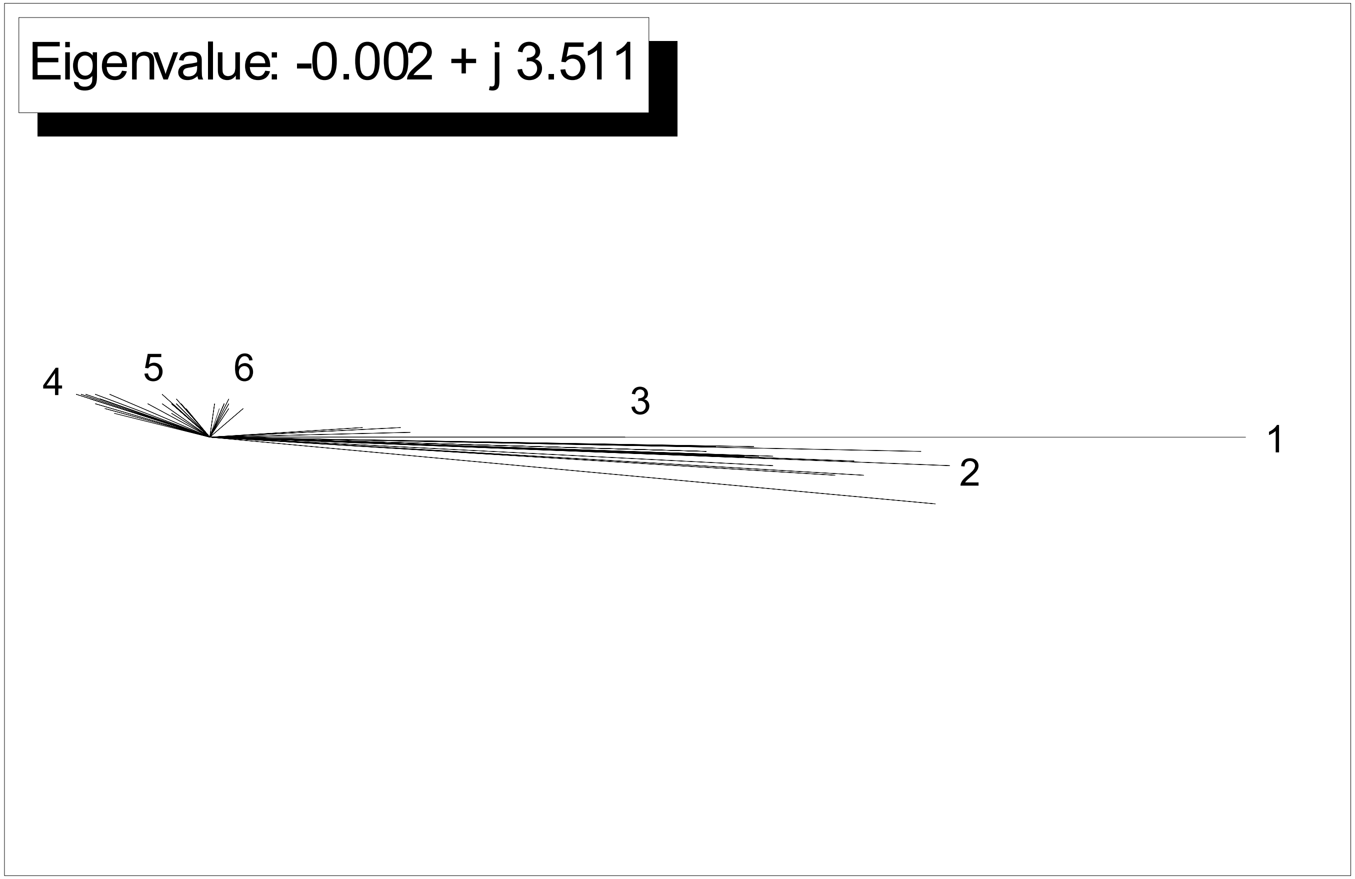
- 616-Bus, 50-Generator Model, with no PSSs
- 362 States having 8 Poorly-Damped Electromechanical Modes
- Objective I: determine the least-damped and unstable electromechanical modes
- Objective II: identify the best set of candidate lines for placing TCSCs so as to adequately damp these 8 modes
- Objective III: place the TCSCs at the various lines and adequately tune their Power Oscillation Damping (POD) controllers
- Objective IV: Check whether all modes are adequately damped

System Eigenvalues (1986 model, no PSSs)



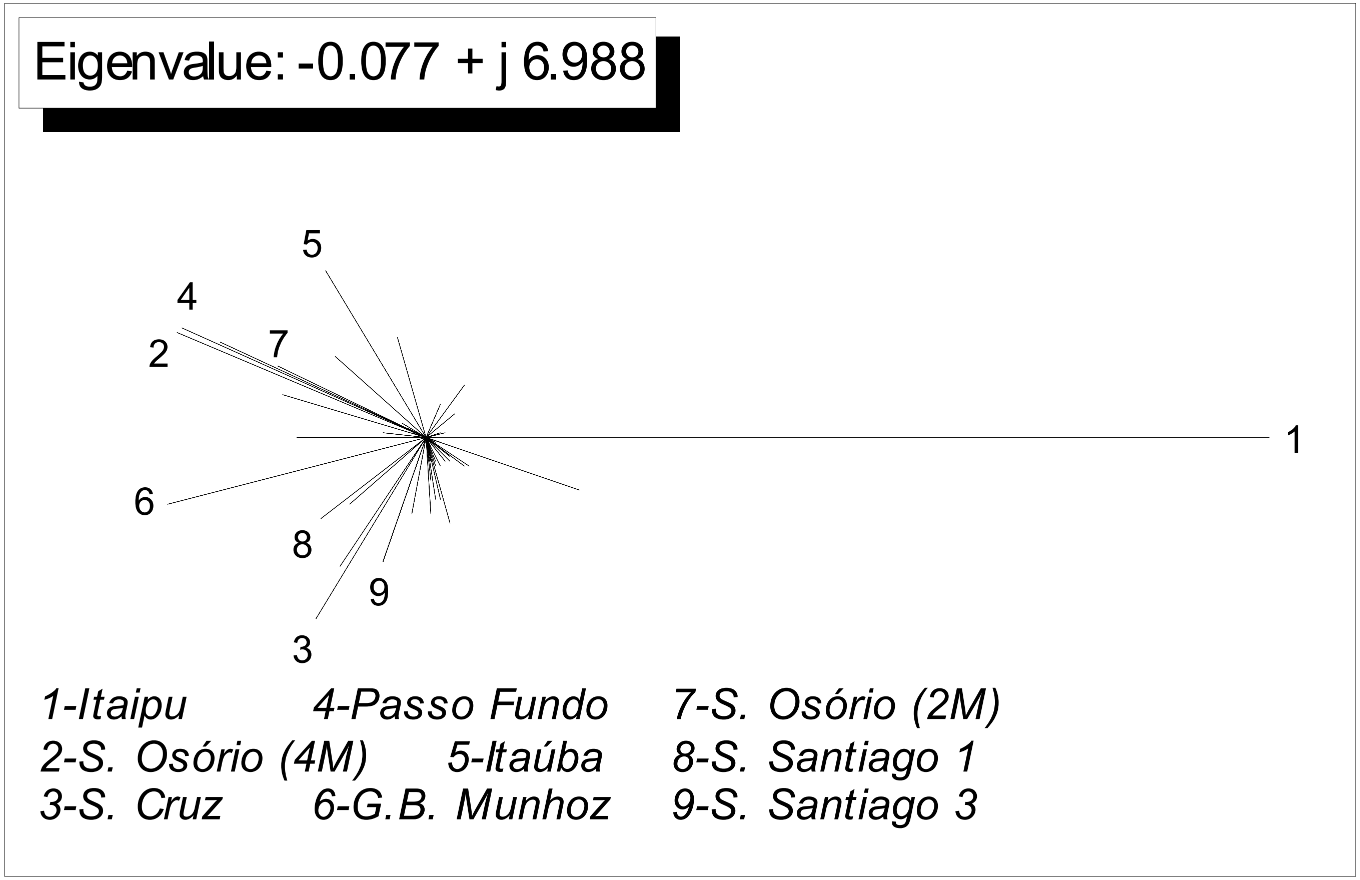
Eigenvalues for 50-generator system without PSSs or other damping controllers (362 state variables)

Mode-Shape of Major Inter-Area Mode



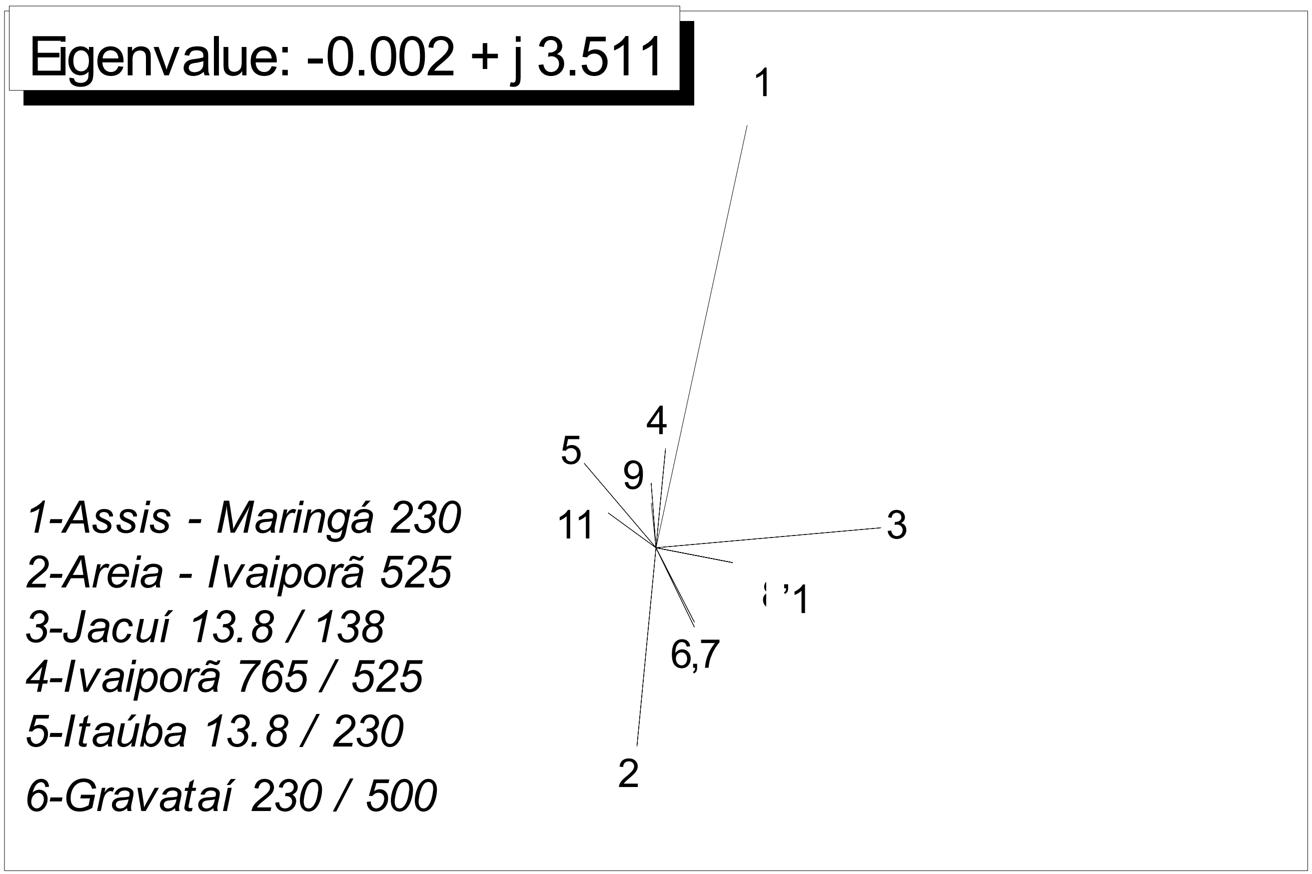
Rotor speed mode shape of the South-Southeast inter-area mode (0.56Hz)

Mode-Shape of the Itaipu Mode



Rotor speed mode shape of the Itaipu "local" mode (1.11Hz)

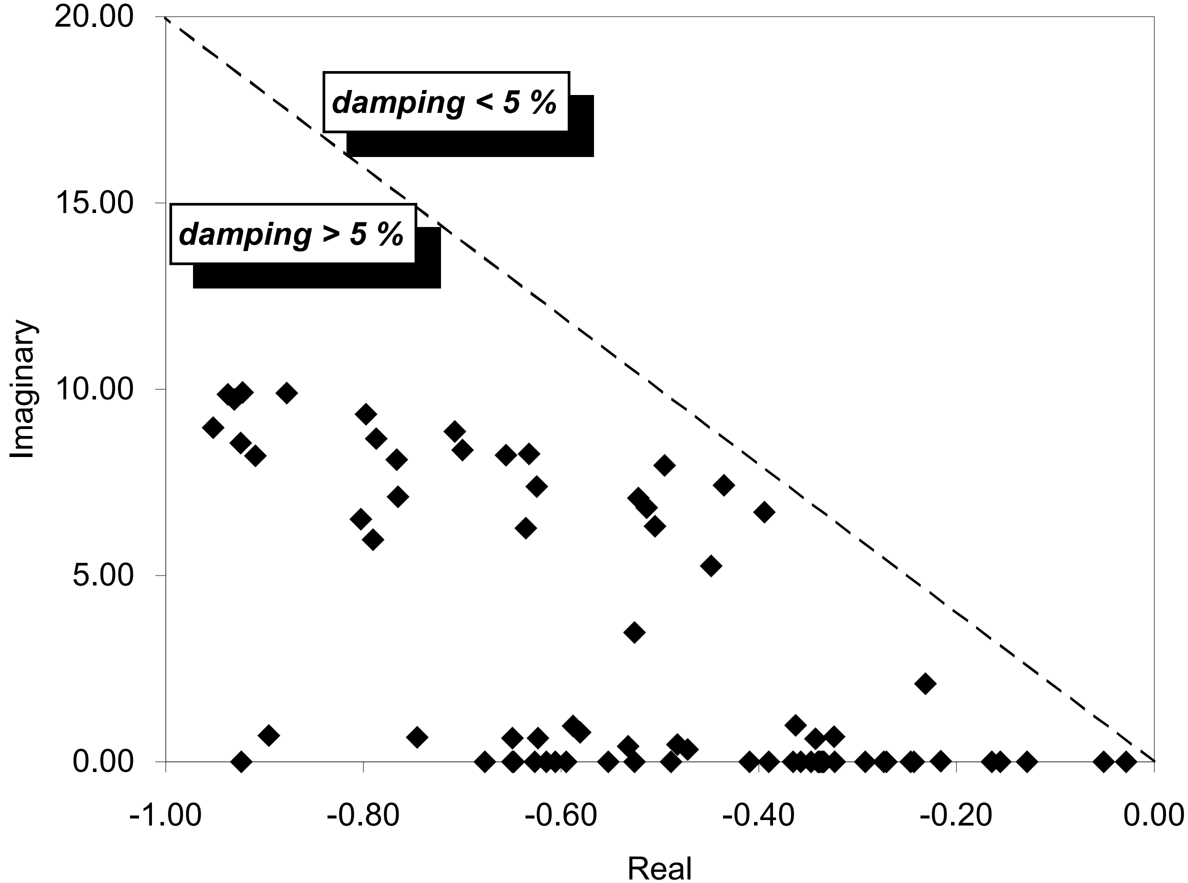
Determining Best Candidate Line for Placing a TCSC to Damp the 0.56 Hz Mode



Residues for the transfer functions

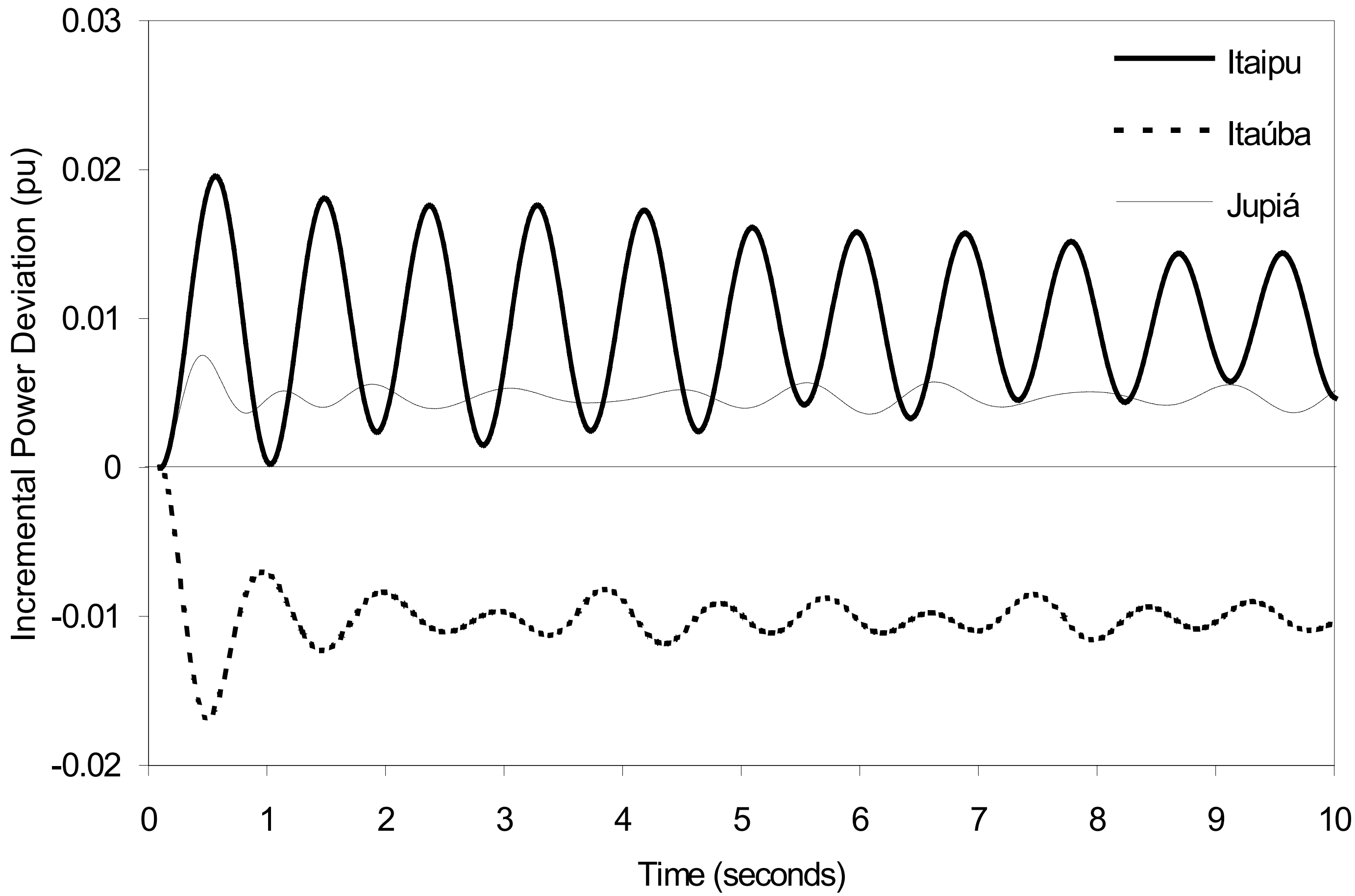
$\Delta P_{kj}(s)/\Delta B_{kj}(s)$ for $s = -0.002 \pm j3.511$

System Eigenvalues Adequately Damped through Installation of 8 TCSC Devices



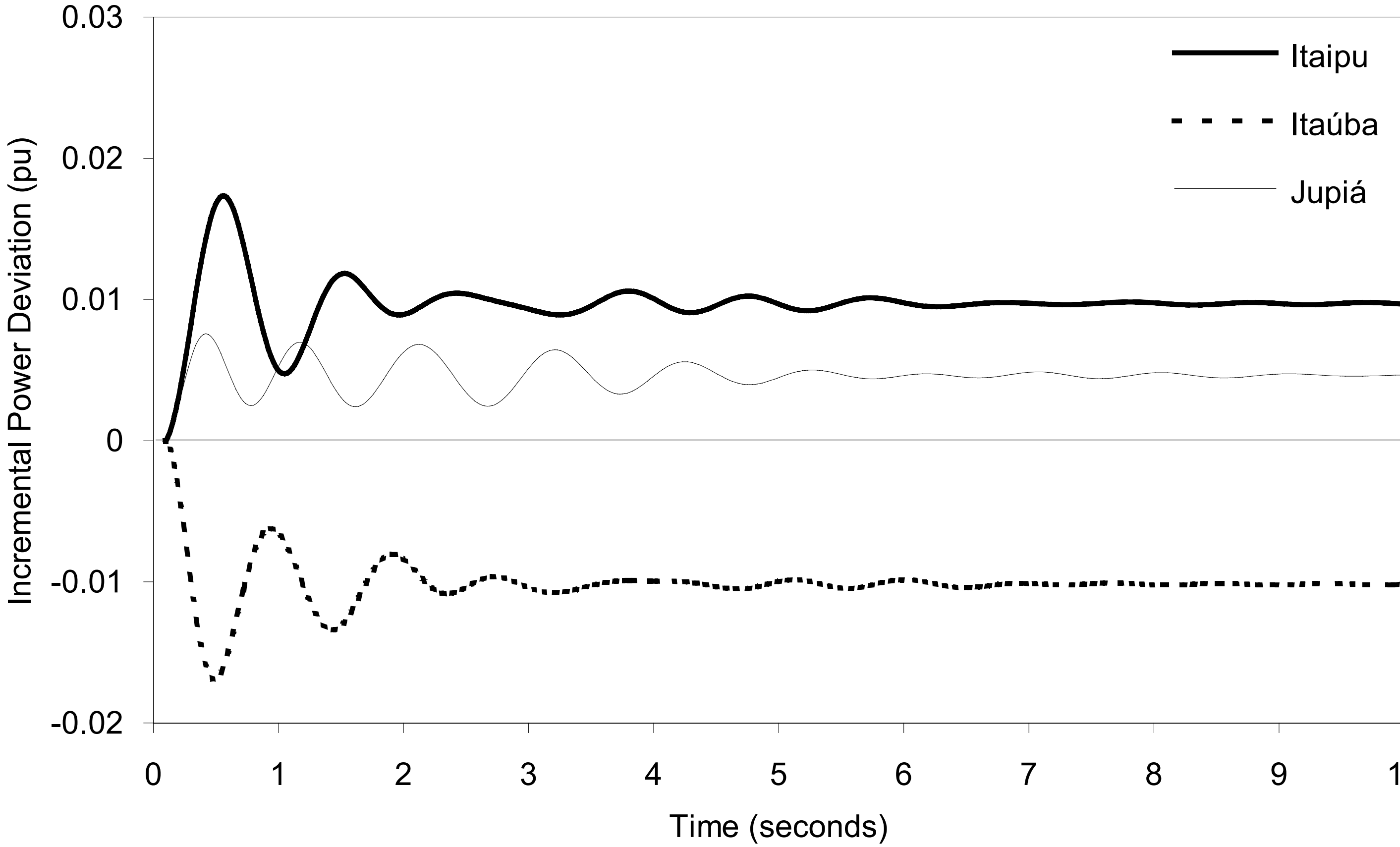
Eigenvalues for 50-generator system with eight TCSC damping devices (375 state variables)

System Undamped Oscillations (No PSSs)



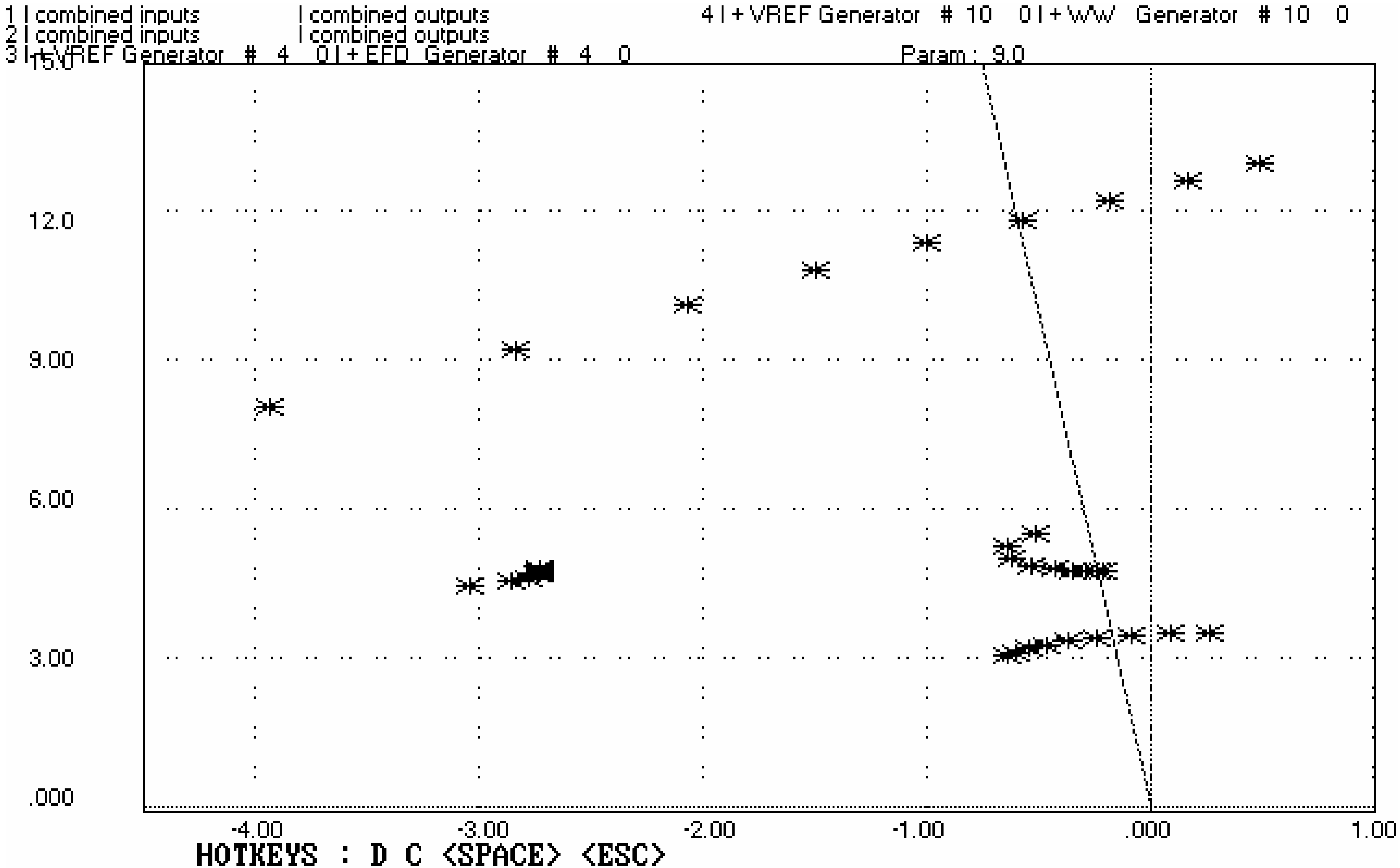
Step response for 50-generator system without damping devices (362 states)

System Damped Response (with 8 TCSCs)



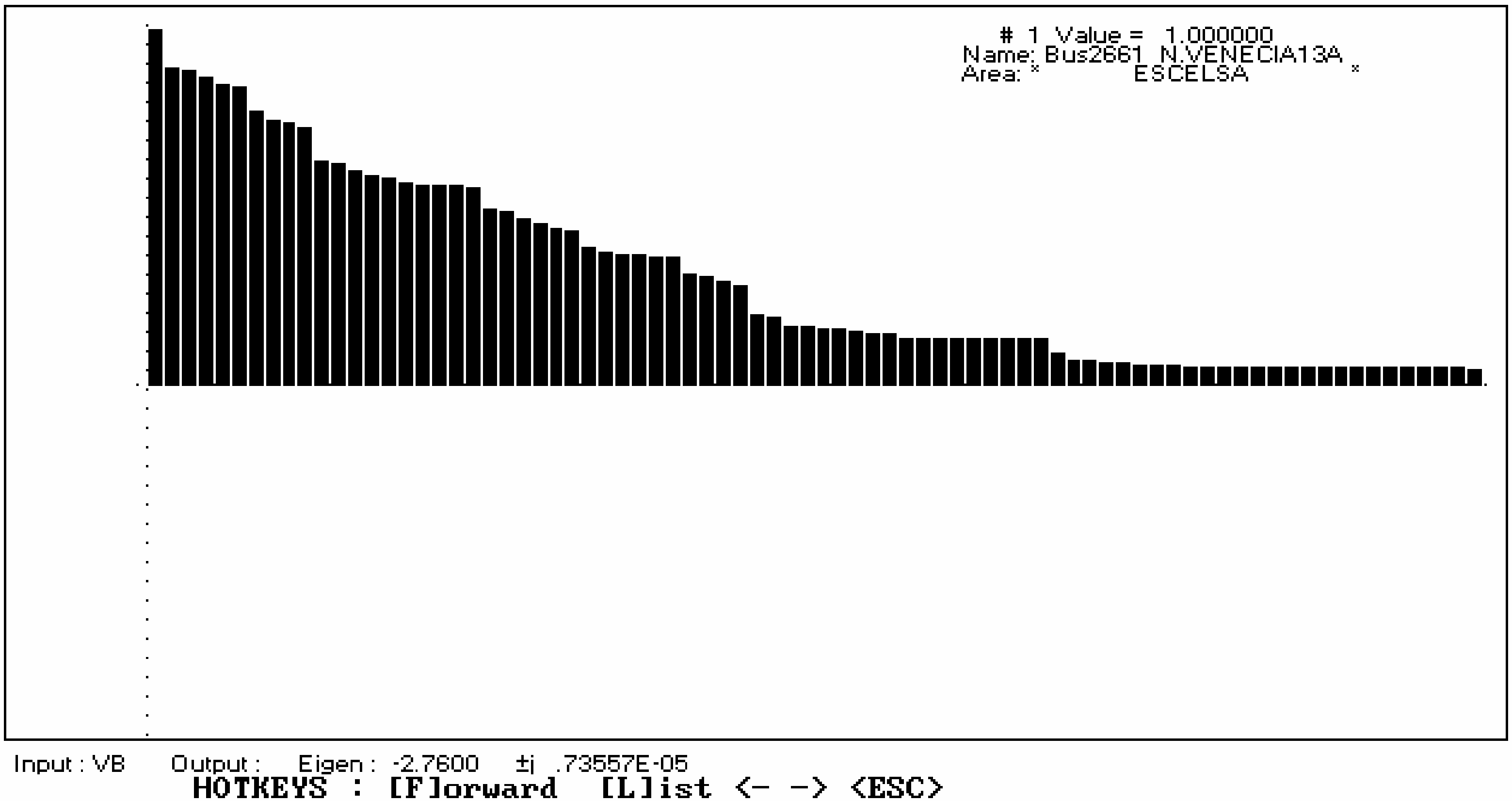
Same step disturbance applied to 50-generator system with eight TCSC damping devices (375 states)

Example of a Root-Locus Plot



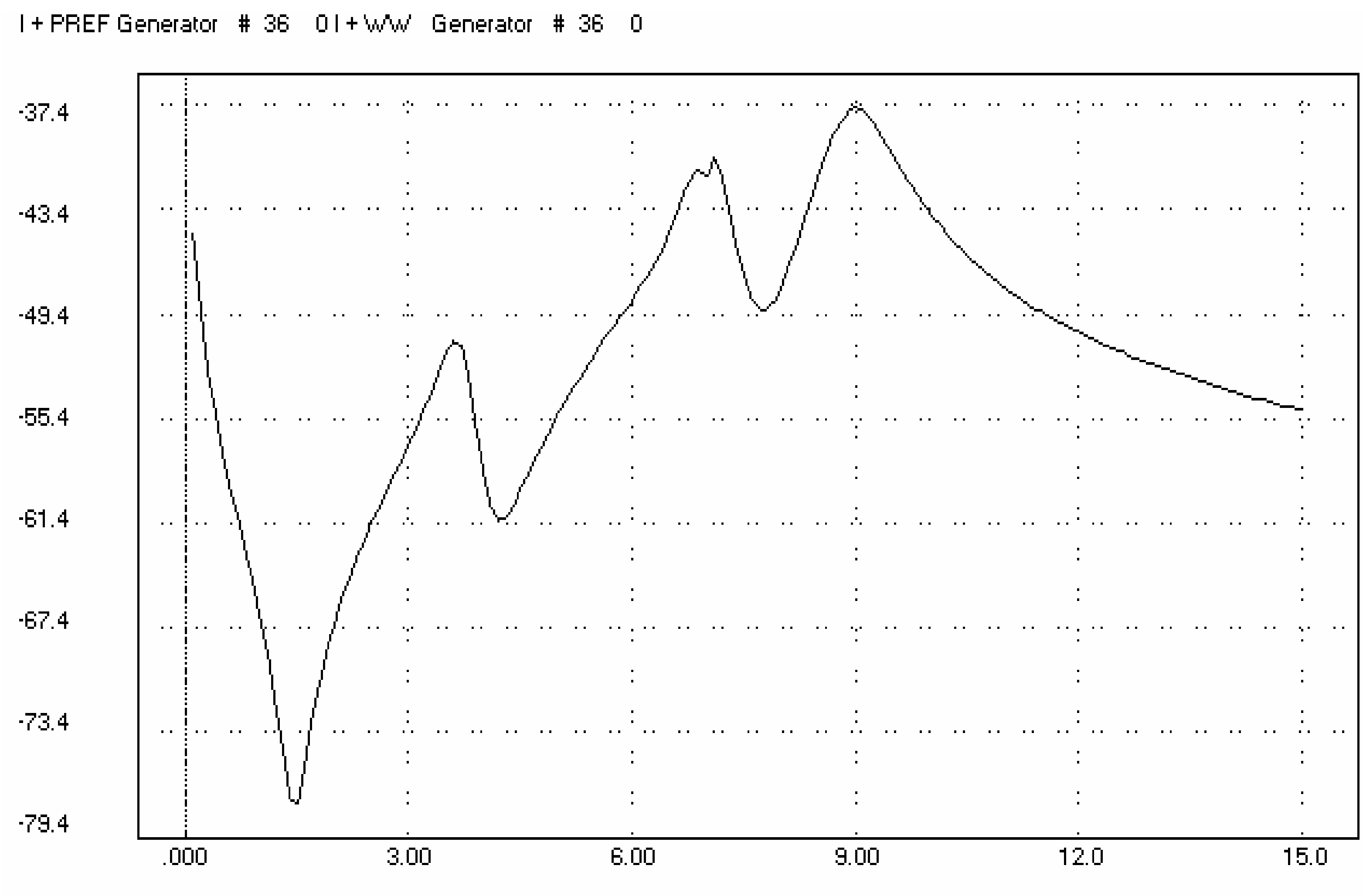
Root-locus plot for varying PSS gain of test system

Bar-Chart for Voltage Collapse Mode



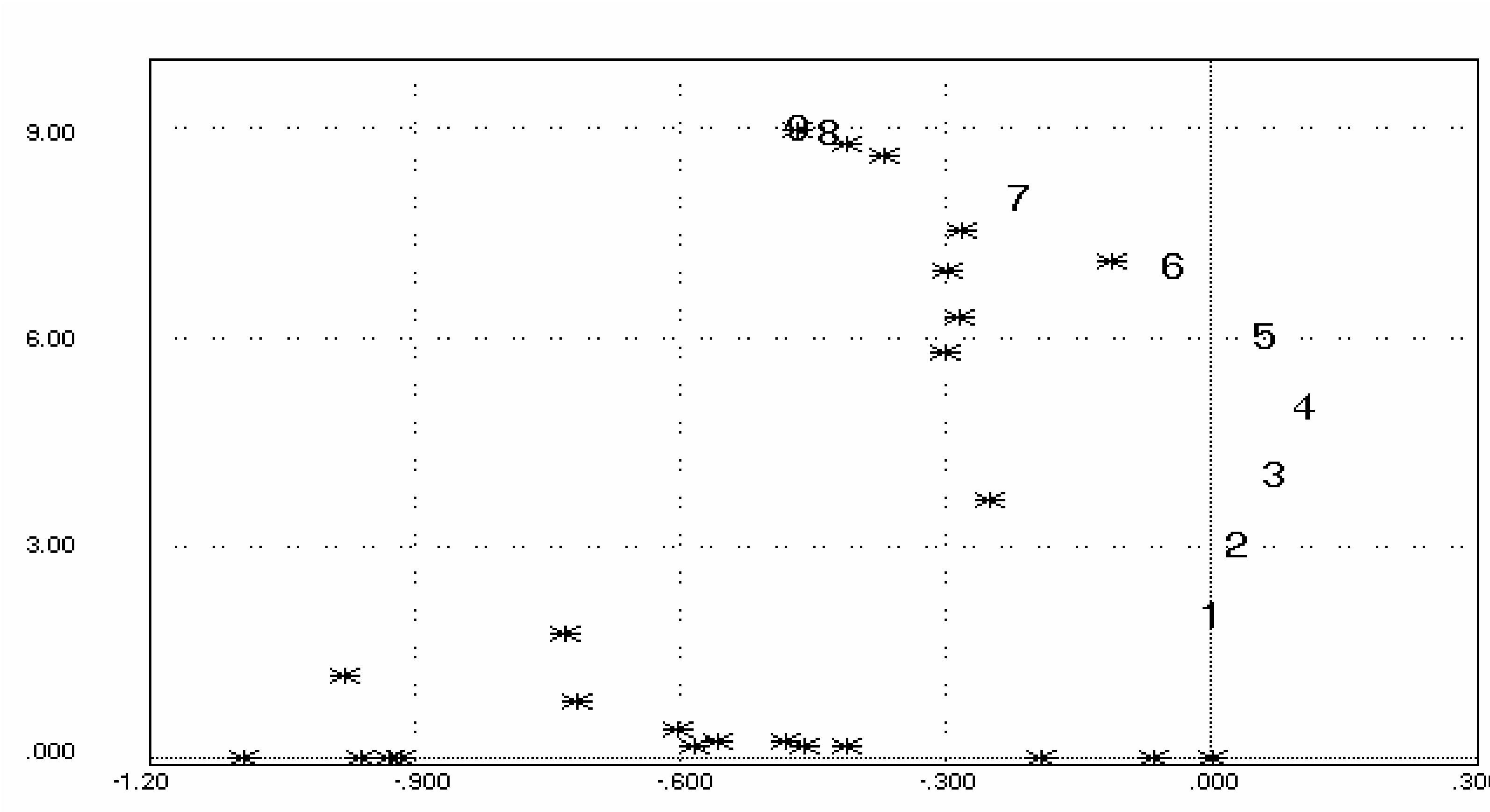
Voltage Stability Analysis of the Rio de Janeiro Area

Frequency Response Plot for N. England System



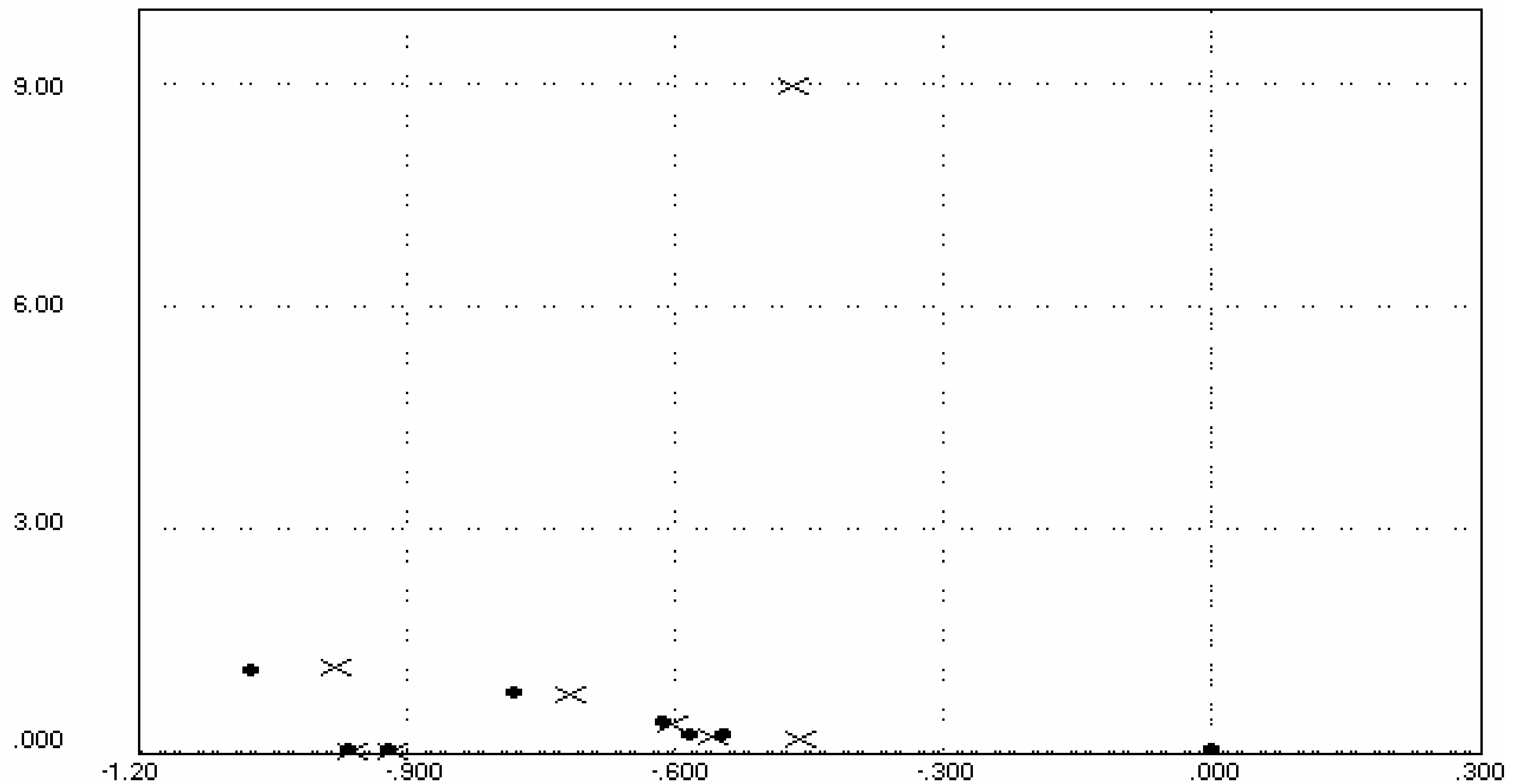
Bode Plot of $\Delta\omega^{36}(s) / \Delta P_{mec}^{36}(s)$ for the N. England System

Selective Convergence of Dom. Pole Algorithm



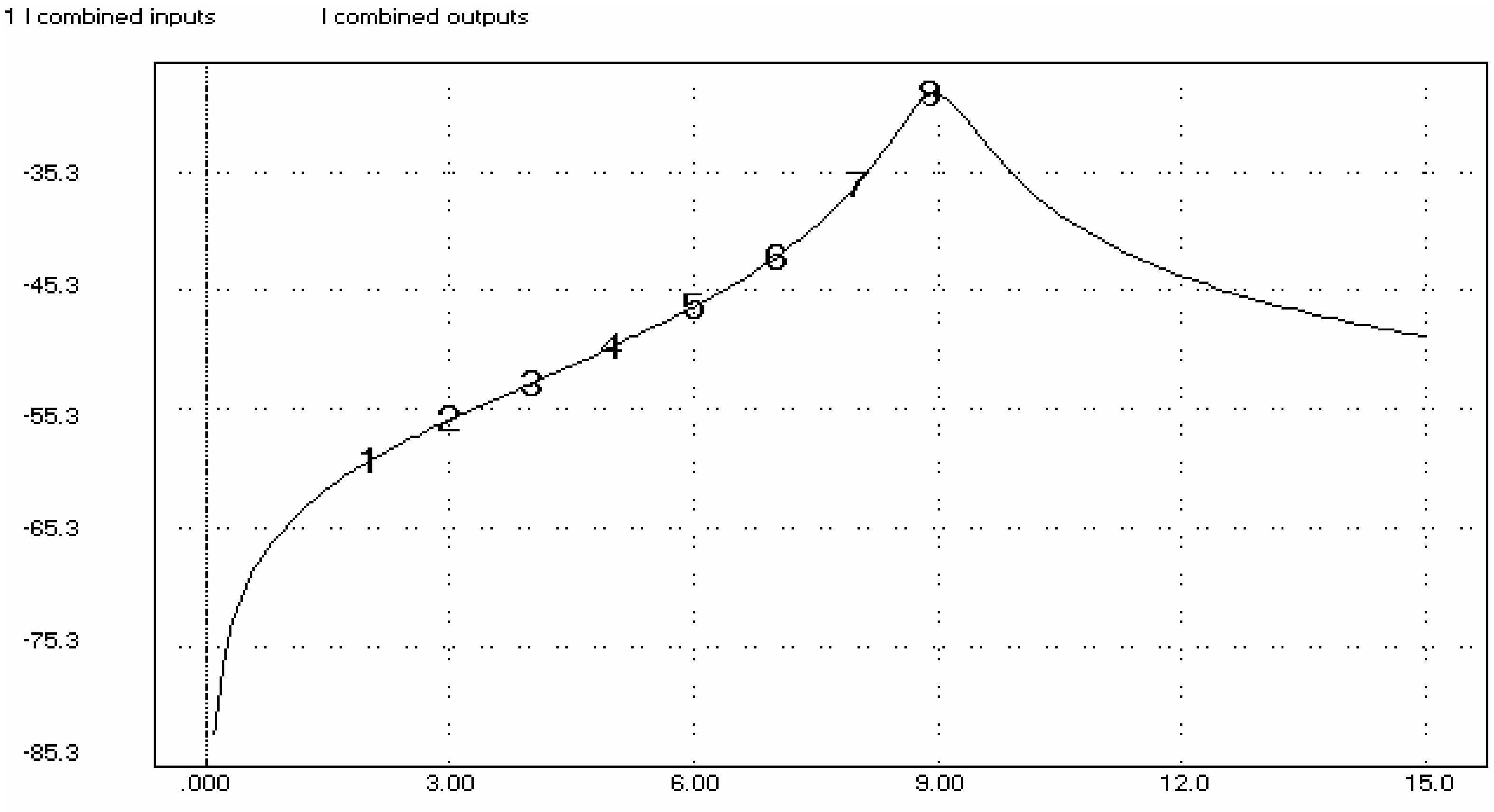
Trajectory of eigenvalue estimate with final convergence to the dominant pole of transfer function $\Delta\omega^{35\text{-}36}(s)/\Delta P_{mec}{}^{35\text{-}36}(s)$ of the New England system

Pole-Zero Spectrum Seen by Dominant Pole Algorithm (DPA)



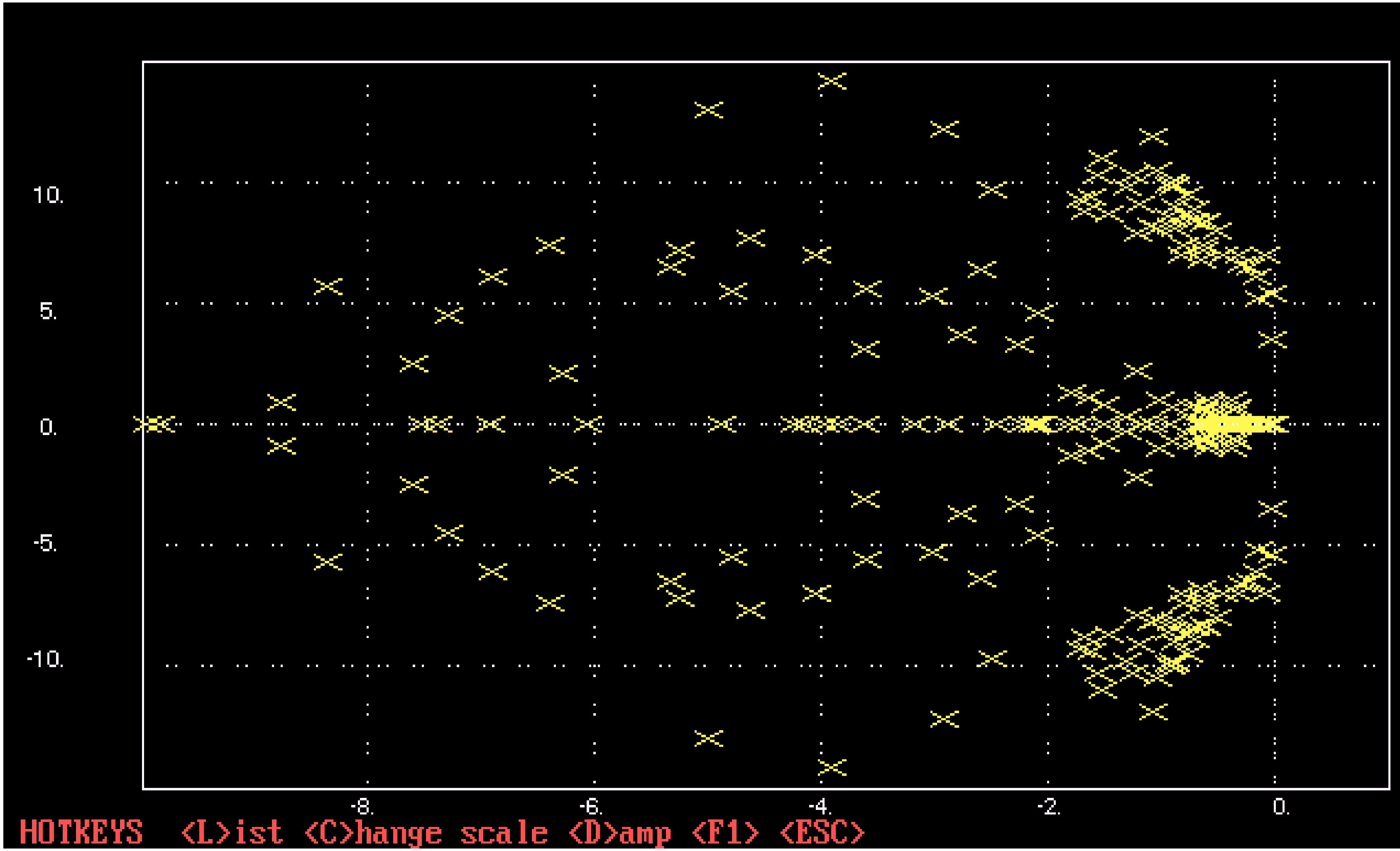
Dominant pole-zero spectrum for transfer function $\Delta\omega^{35\text{-}36}(s) \,/\, \Delta P_{mec}{}^{35\text{-}36}(s)$ of the New England system

Trajectory of Eigenvalue Estimate for DPA



Bode magnitude plot for transfer function $\Delta\omega^{35\text{-}36}(s)/\Delta P_{mec}{}^{35\text{-}36}(s)$ of the New England test system

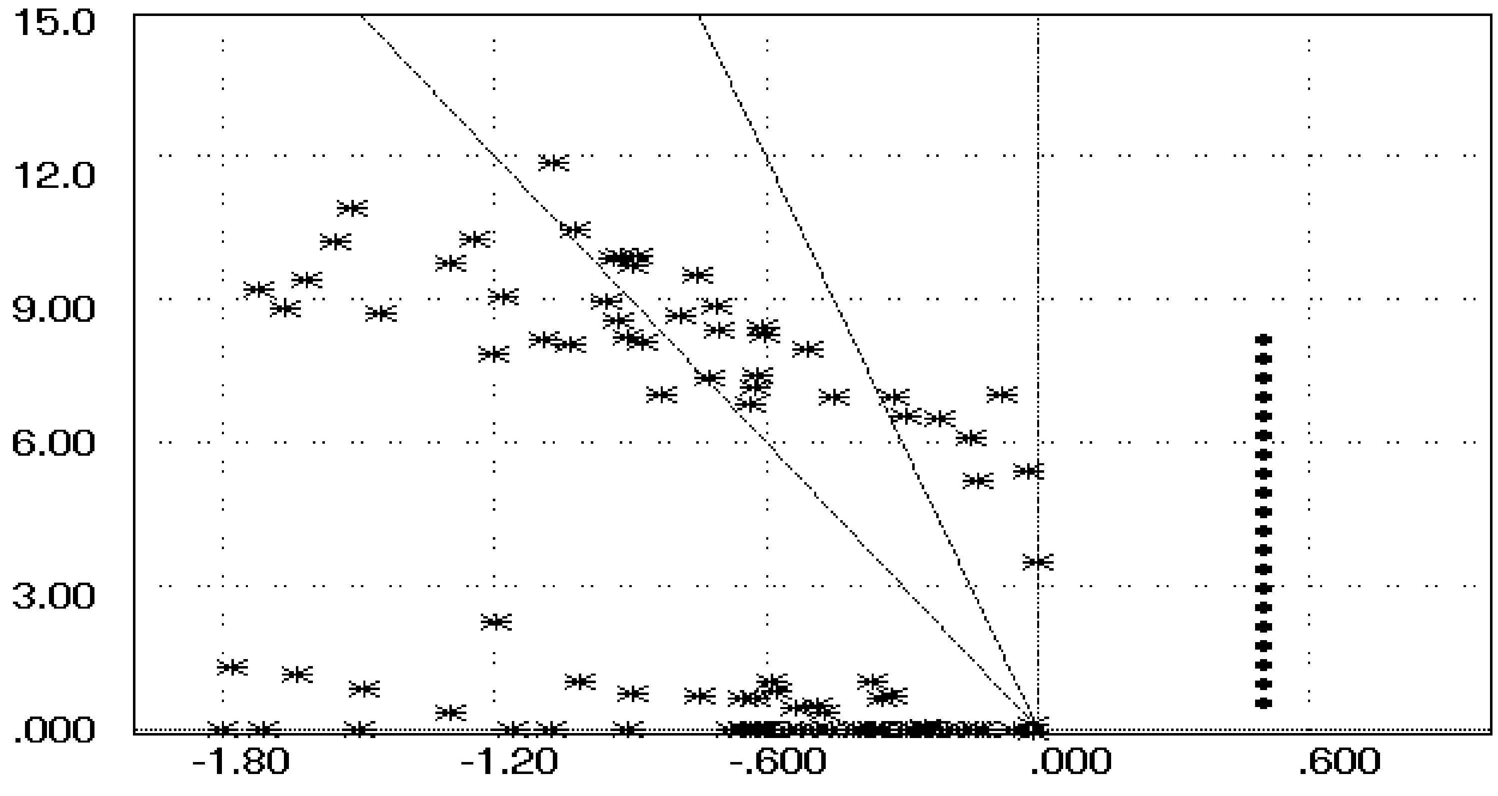
System Eigenvalues (1986 model, no PSSs)



Eigenvalue spectrum for system without PSSs or other damping controllers (362 state variables)

RBI Results for the 362-State Matrix

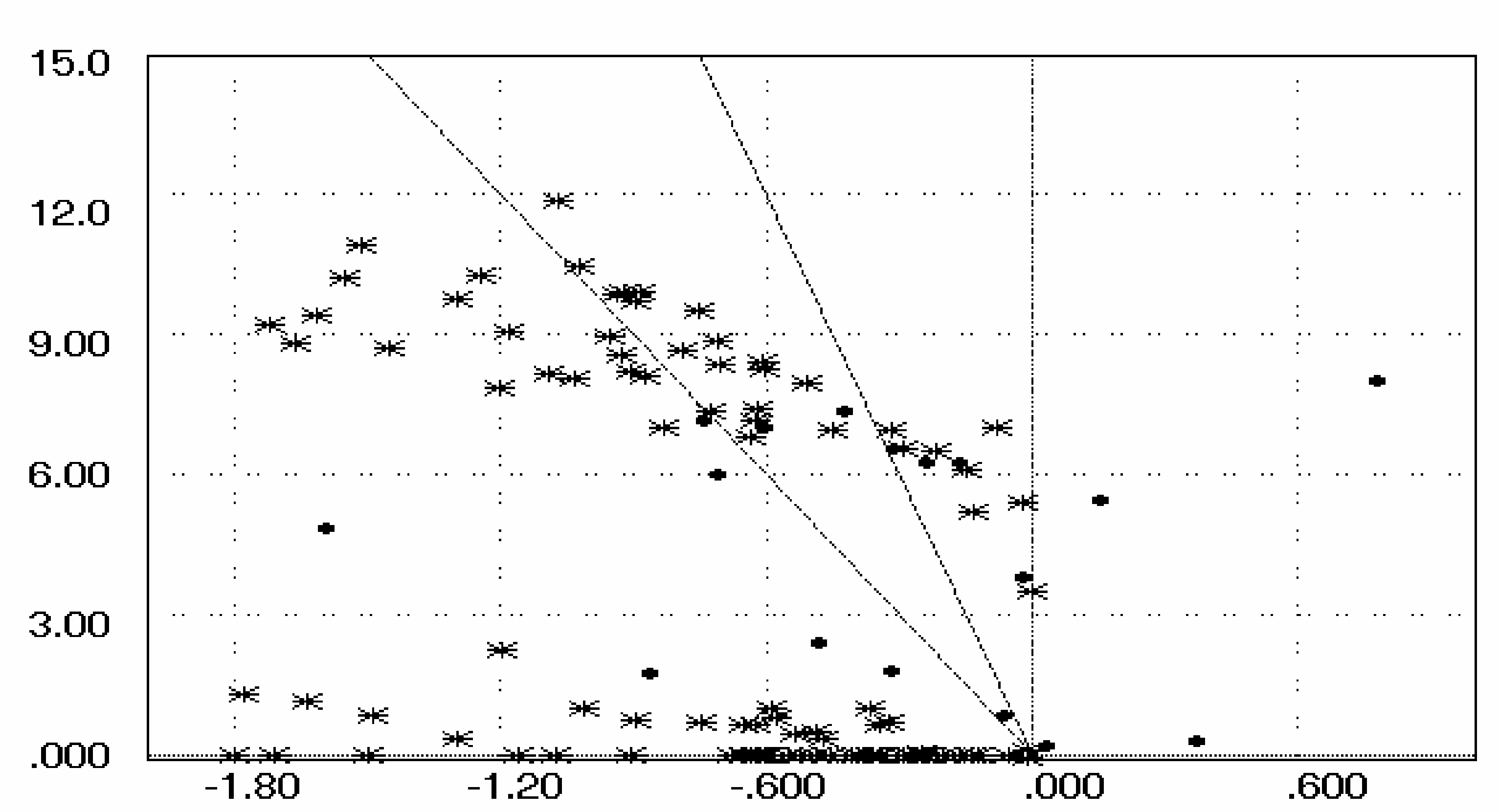
Convergence Demo 1/5



•Full system eigenvalues shown by asterisks
•Initial shifts (20) shown as black circles

RBI Results for the 362-State Matrix

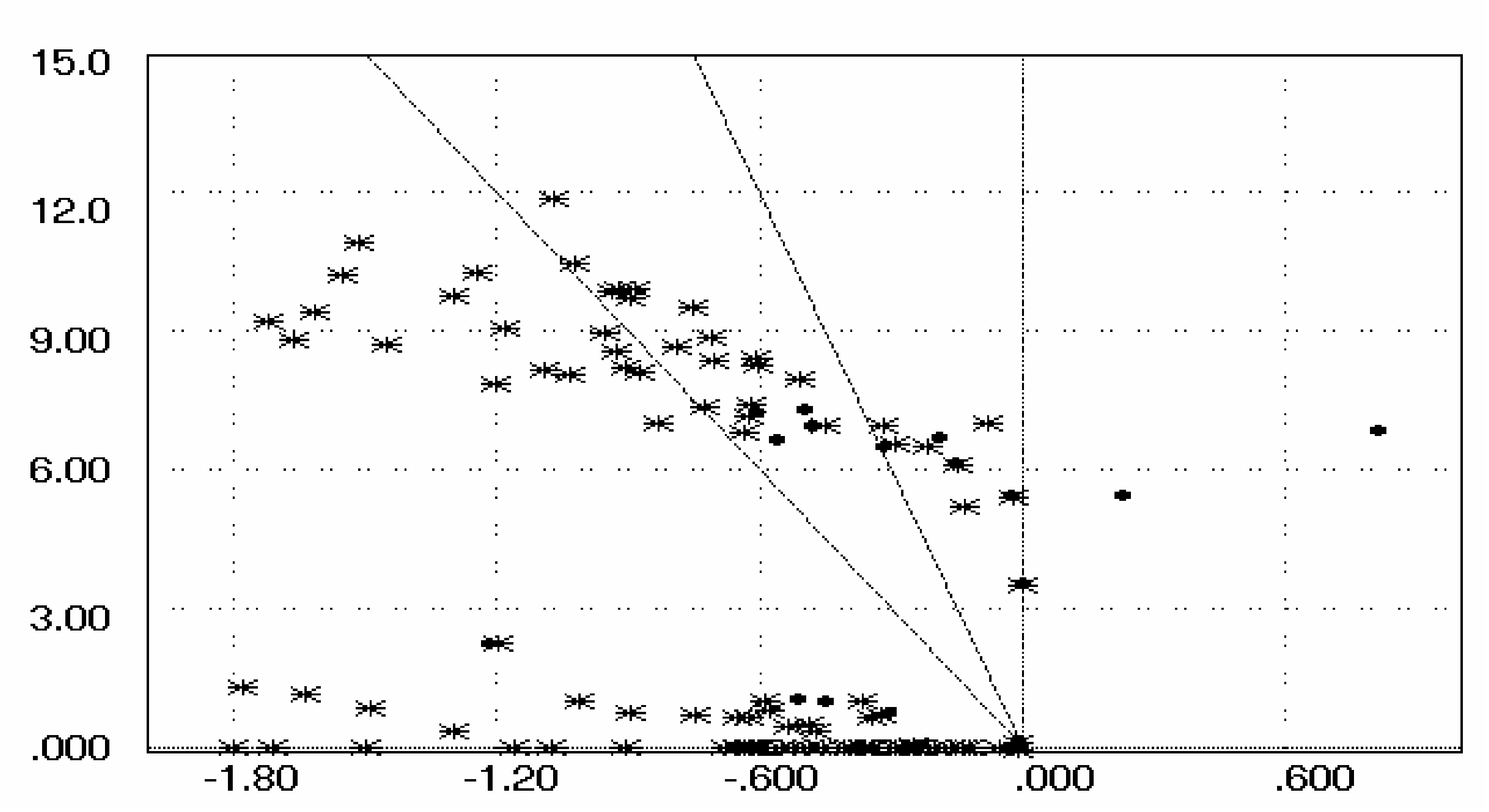
Convergence Demo 2/5



•Full system eigenvalues shown by asterisks
•Moving shifts after first iteration shown by black circles

RBI Results for the 362-State Matrix

Convergence Demo 3/5

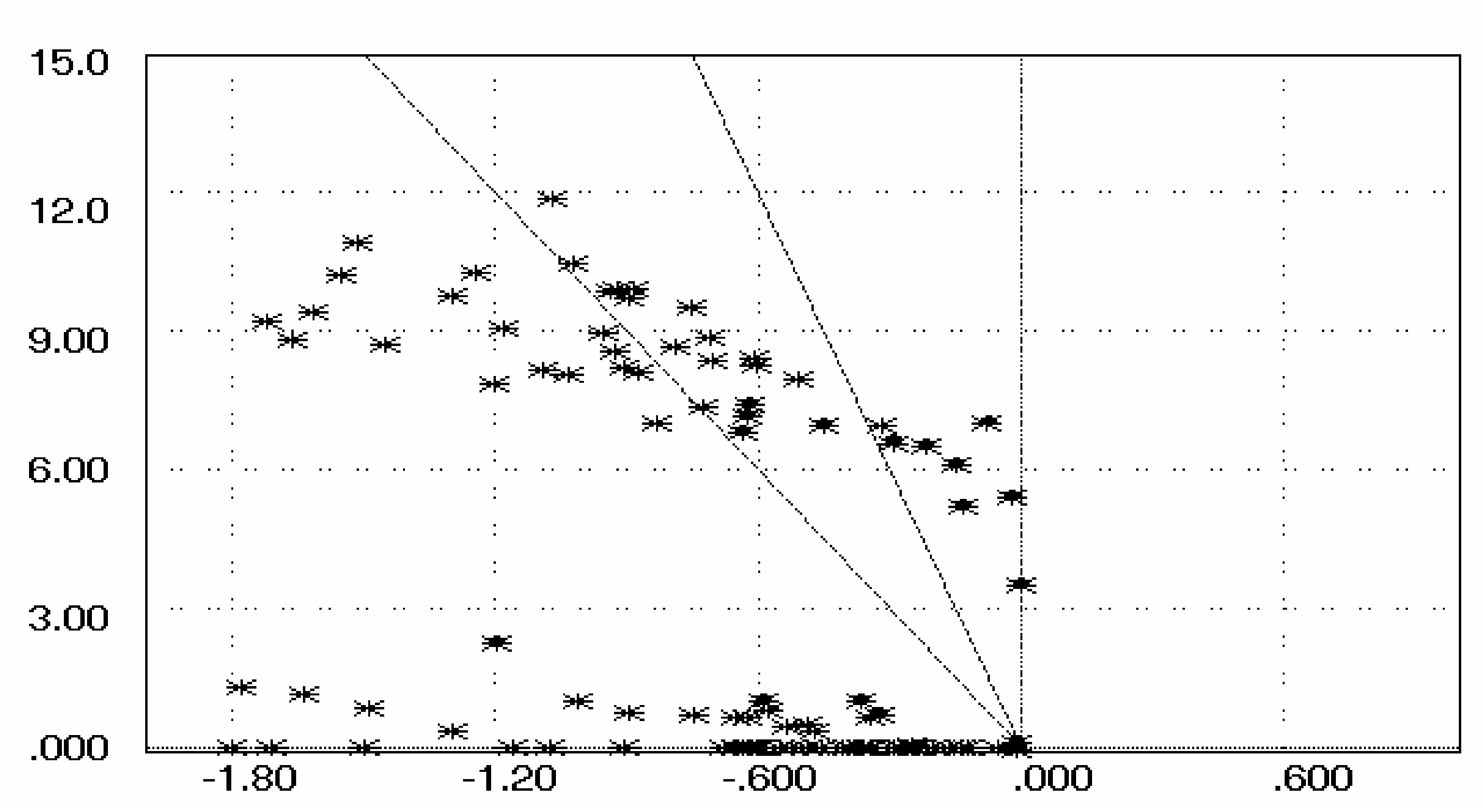


•Full system eigenvalues shown by asterisks

•Moving shifts after second iteration shown by black circles

RBI Results for the 362-State Matrix

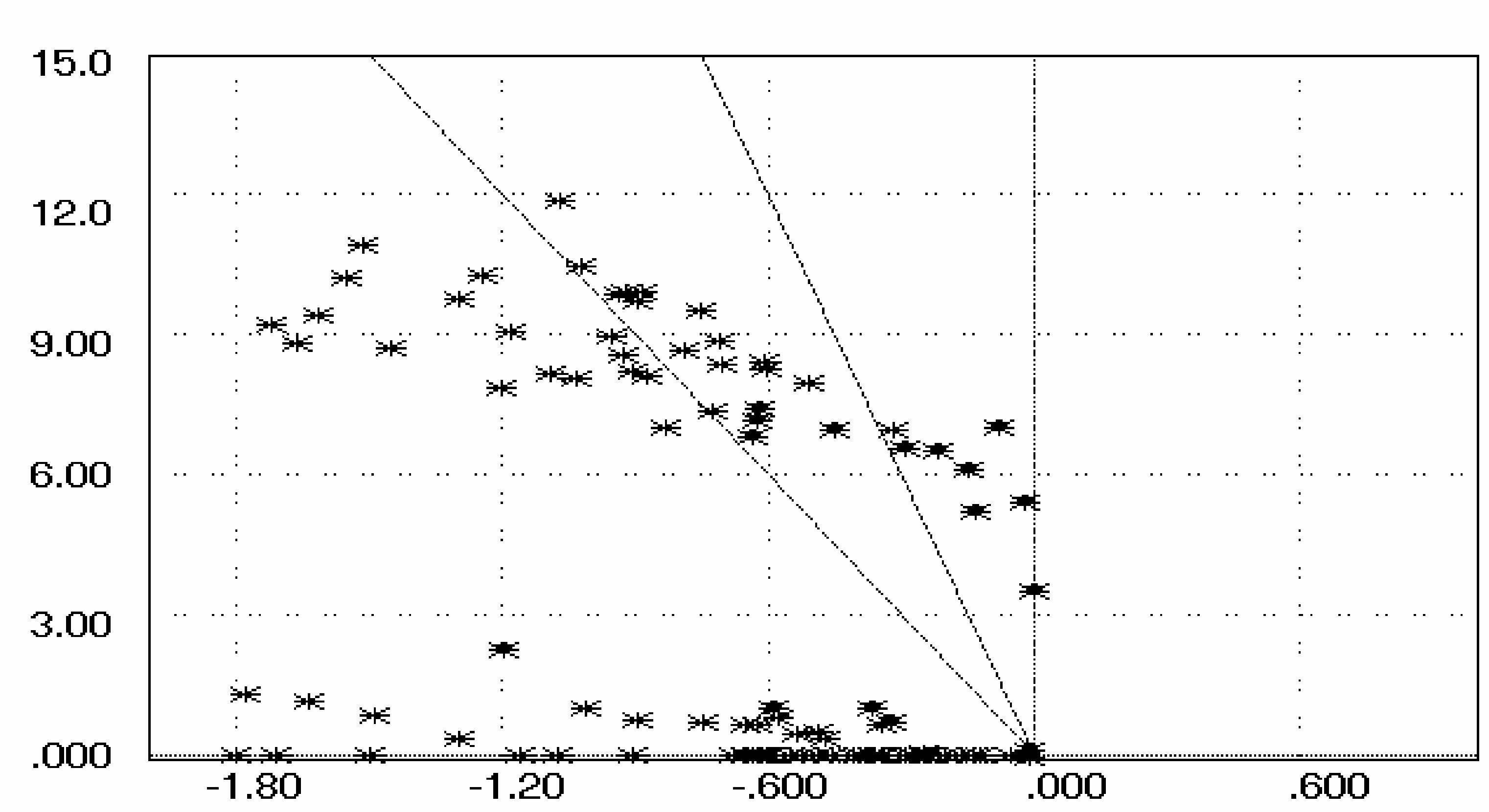
Convergence Demo 4/5



- Full system eigenvalues shown by asterisks
- Moving shifts after third iteration shown by black circles

RBI Results for the 362-State Matrix

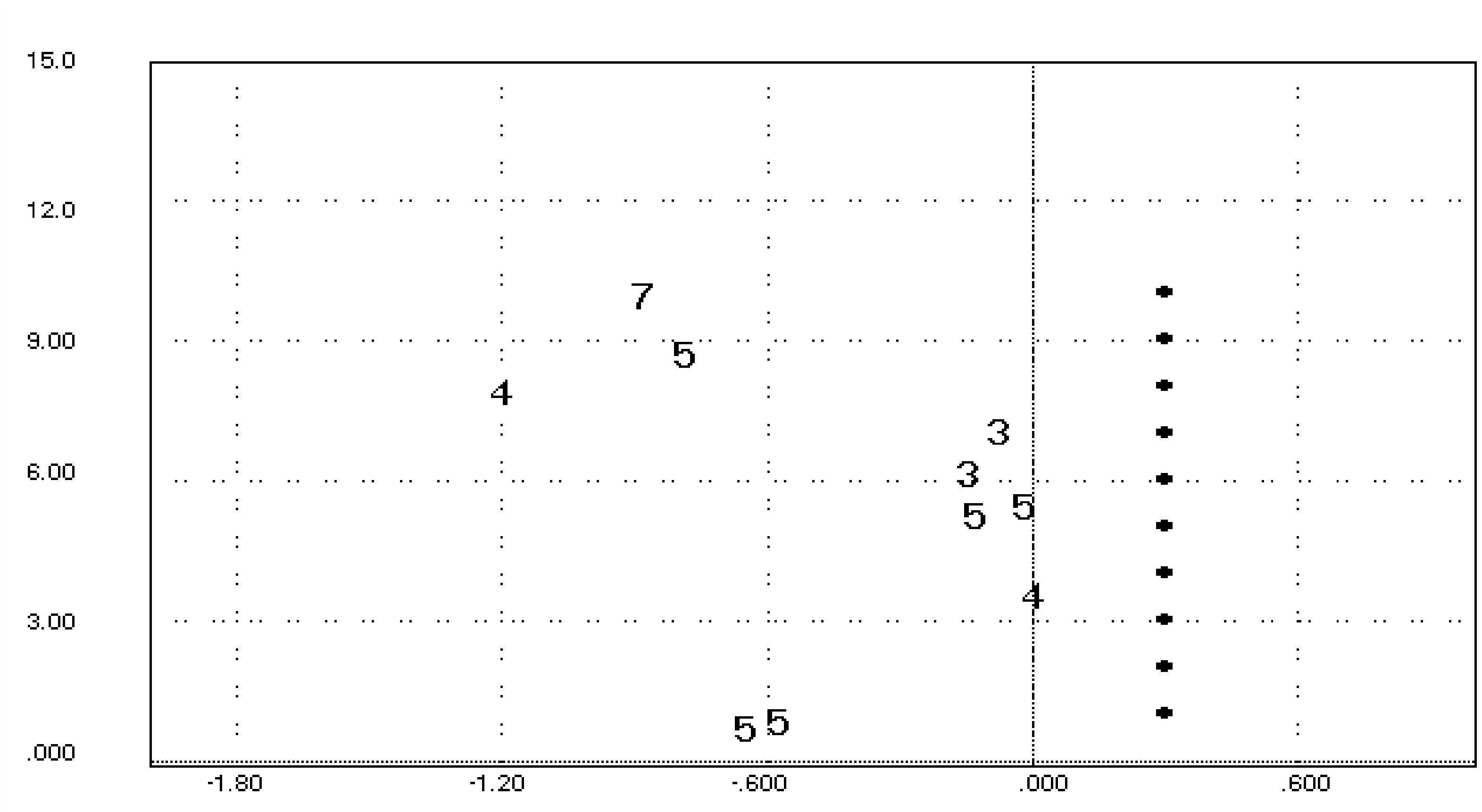
Convergence Demo 5/5



•Full system eigenvalues shown by asterisks

•Moving shifts after fourth iteration shown by black circles

Fast Convergence of RBI Algorithm for the 50-generator System Matrix (362 states)



The numerals indicate the iterations needed for accurate convergence of the RBI Algorithm (10 initial shifts)

Conclusions

- Ample set of powerful tools and algorithms for small-signal stability analysis and coordinated controller design. They are an effective complement to non-linear simulations.

- RBI shows an unprecedented convergence rate and, despite the multiple factorizations, is highly cost-effective for eigensolutions of large power system matrices

- Graphical visualization of results enhances the productivity of engineering studies and may be helpful in the development of sophisticated eigensolution algorithms

- The Dominant Pole Algorithm (DPA) is very effective for selective eigenanalysis, produces root-locus plots and modal equivalents for large scale transfer functions