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Oscillations Damping Analysis and Control Studies of the Future Interconnection Between the North-Northeast and South-Southeast Systems

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Procedures for Stabilization of Electromechanical Oscillations in Interconnected Power Systems

- Application of Damping Controllers
  - Problem Identification
  - Siting
  - Input Signal Selection and Filtering
  - Closed Loop Control Design
  - Performance Evaluation
  - Adverse Side Effects

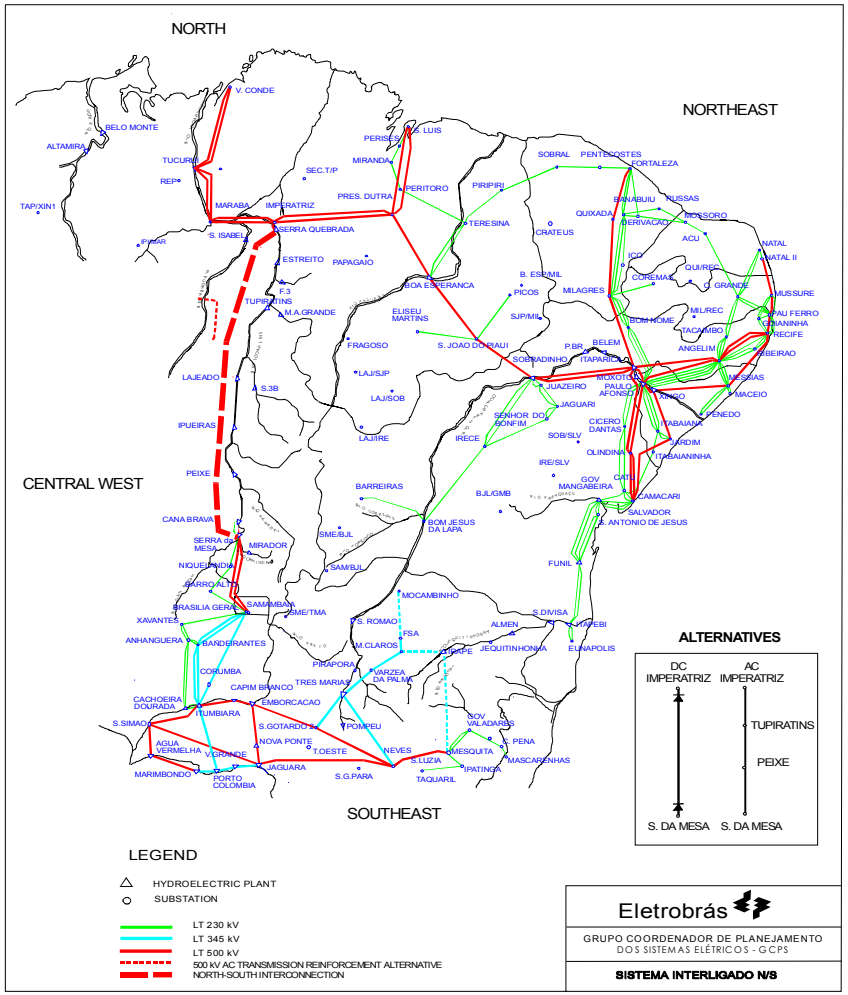
Software PacDyn
Small Signal Stability Analysis and Control

- 8 Generator Models (Salient and Round Rotors, with saturation)
- Excitation Control Systems (any kind)
- Stabilizing Signals (any kind)
- Governors (any kind)
- 2 Induction Motor Models
- HVDC Links and HVDC/CCC Schemes
- FACTS Devices
  - Static Var Compensators
  - Thyristor Controlled Series Compensators
  - STATCOM
- User Defined Controllers (UDC)
- Dynamic Loads

Software PacDyn
Small Signal Stability Analysis and Control

- Eigenvalue Computation Algorithms
  - Full eigensolution (QR and QZ)
  - Partial eigensolution (Simult. Iteration; Dominant Pole Alg.)
- Transfer Function Zeros
- Modal Sensitivities
  - Transfer Function Residues
  - Controlability Factors
  - Observability Factors (Mode Shapes)
  - Participation Factors
- Frequency and Linear Time Response Plots
- Coordinated Controller Design

Geographic Map of the Proposed North-South Interconnection

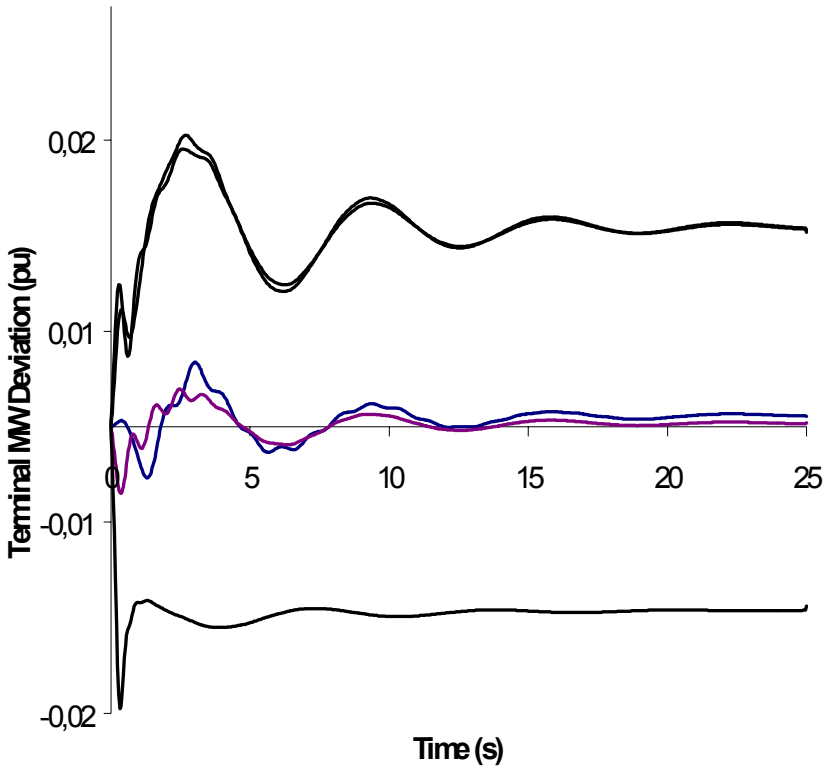


Courtesy of Eletrobrás/GTOT

Small-Signal Time Responses of Major System Generators

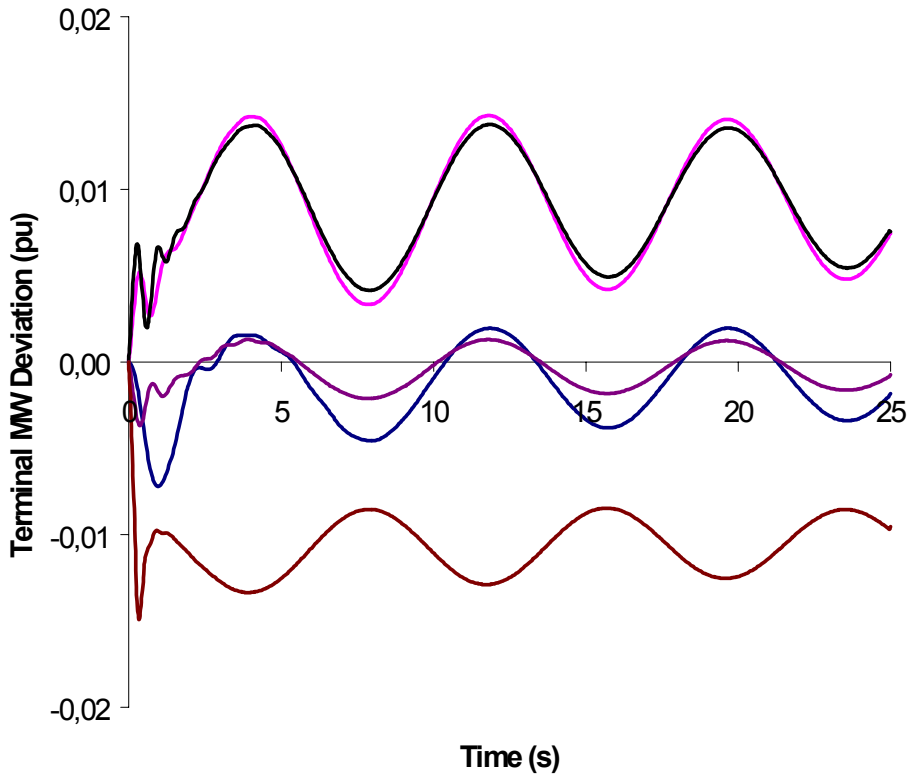
South Exporting 1,000 MW to North

$\lambda = -0.172 + j0.98$

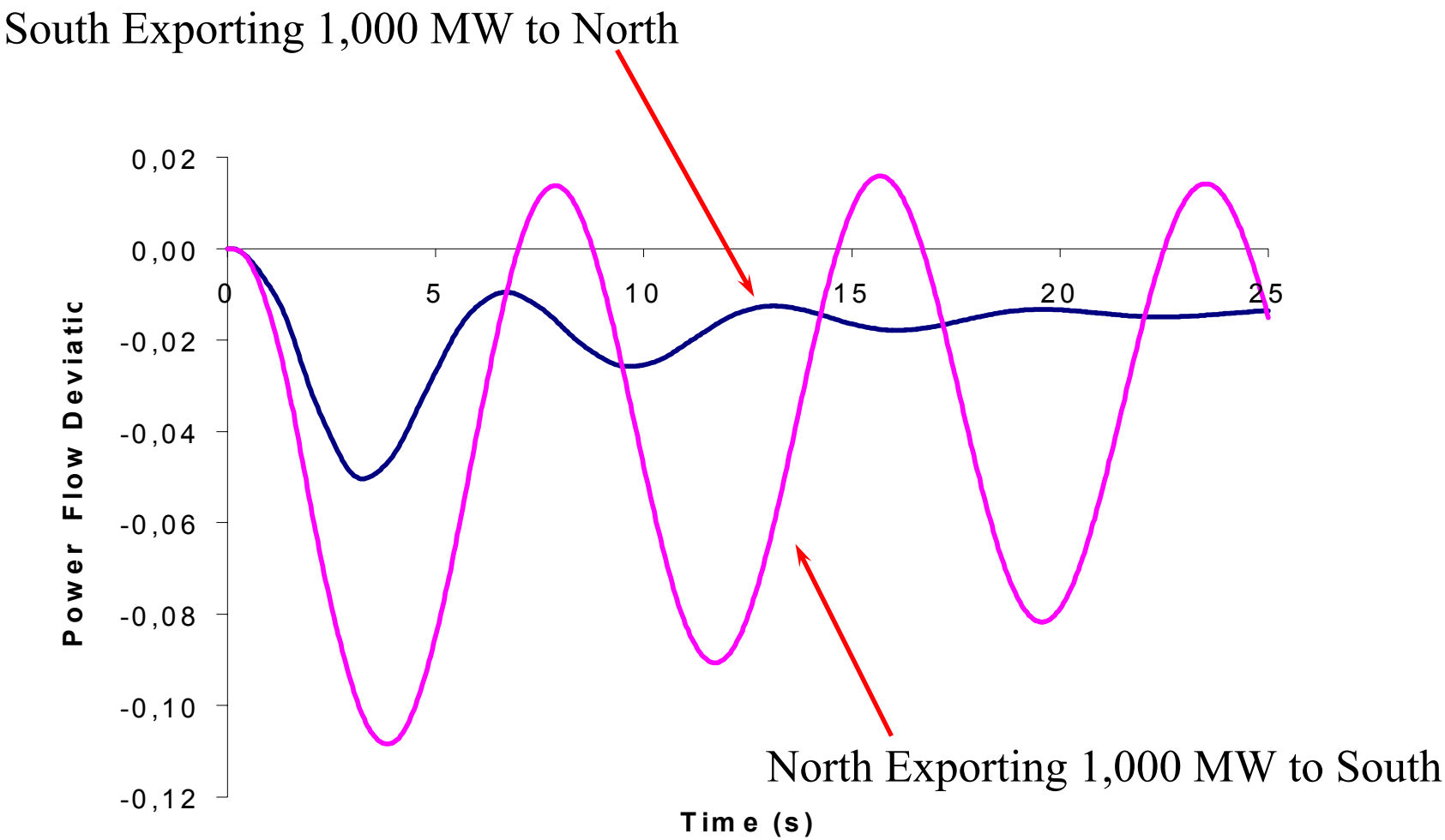


North Exporting 1,000 MW to South

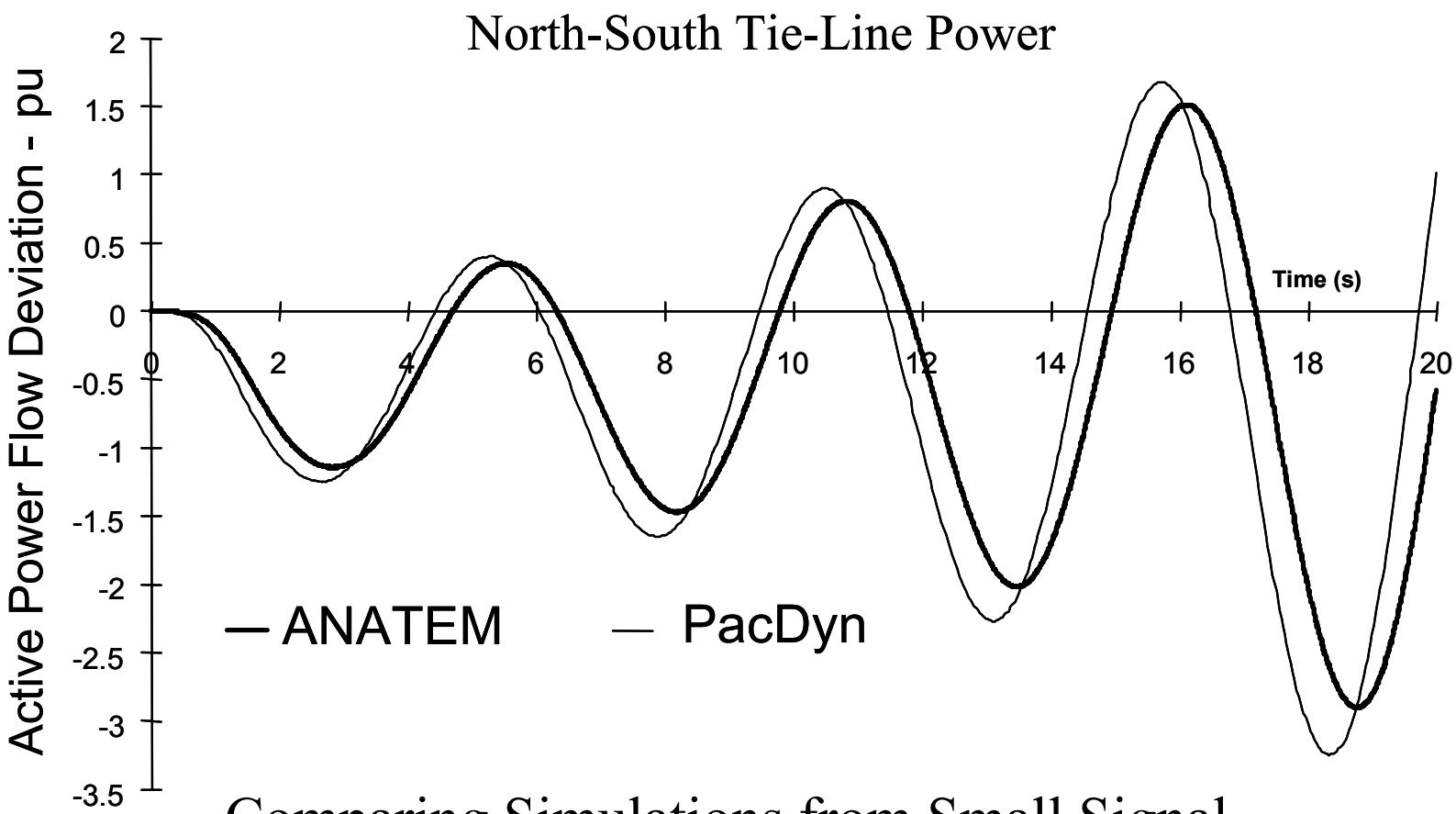
$\lambda = -0.011 + j\ 0.802$



Small-Signal Power Oscillations in the North-South Intertie



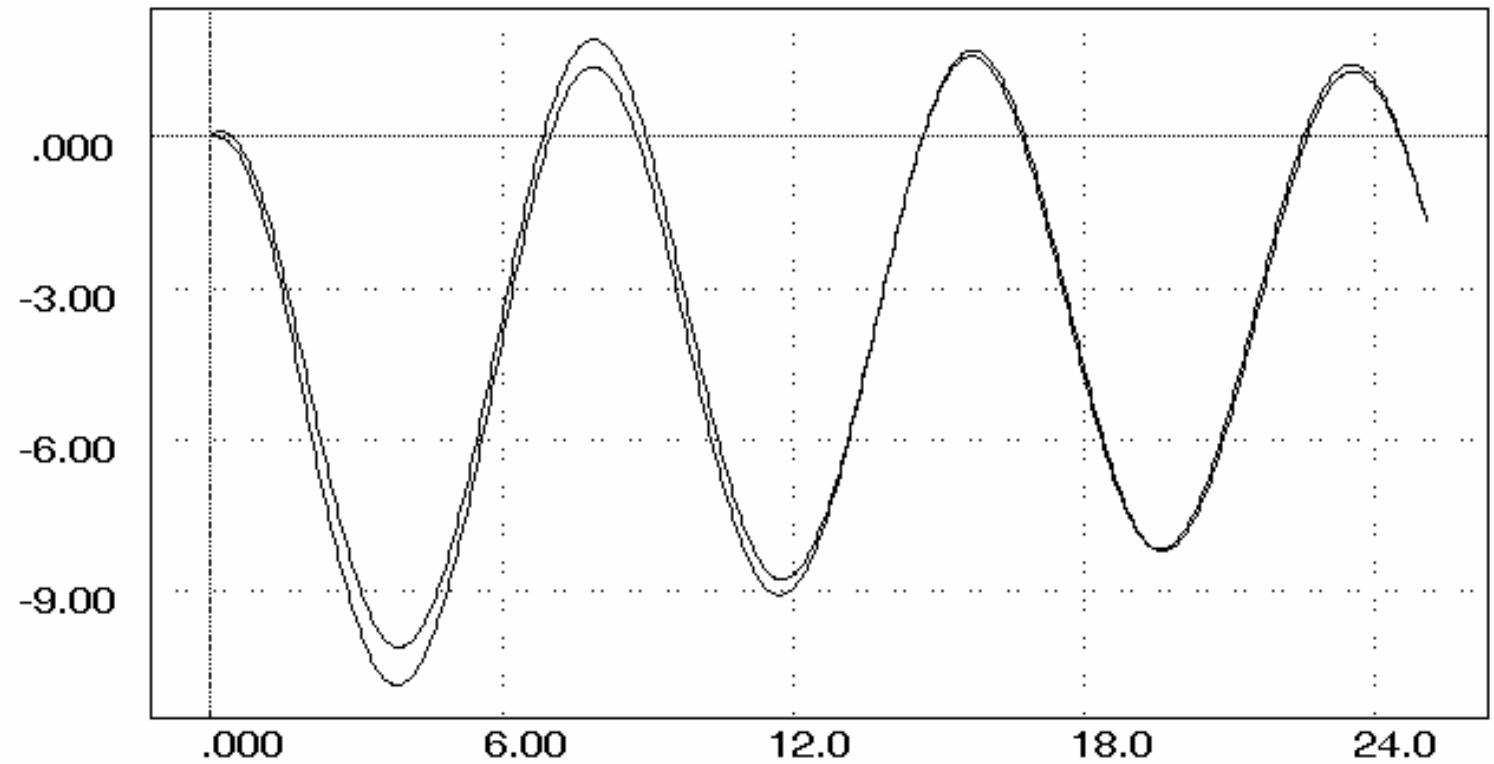
Brazilian North-South Interconnection



Comparing Simulations from Small Signal Stability and Transient Stability Programs

Brazilian North-South Interconnection

Active power flow in the North-South tie-line



Comparing step responses from the full-order linear model and a 4^{th} order modal equivalent

Brazilian North-South Interconnection

Step response equation and constants for the 4th order modal equivalent

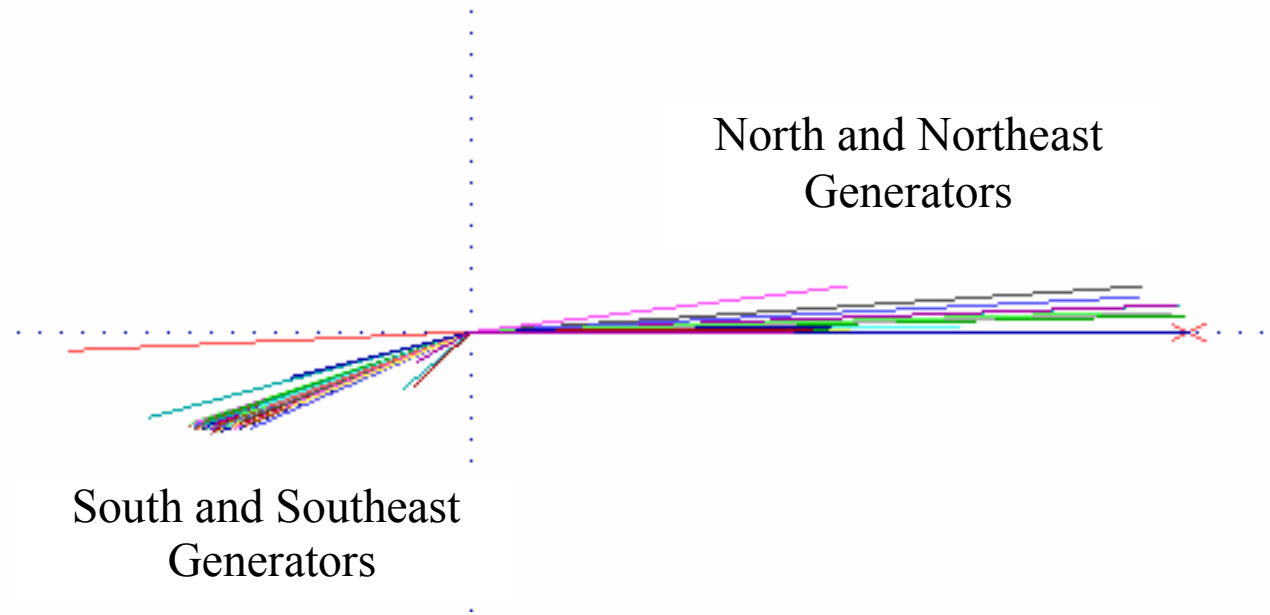
$$y(t) \cong \sum_{i=1}^{4} \frac{R_i}{\lambda_i}(e^{\lambda_i \cdot t} - 1)$$

$$\lambda_{12} = -0.011 \pm j0.802 \qquad R_{12} = -0.006 \pm j0.251$$

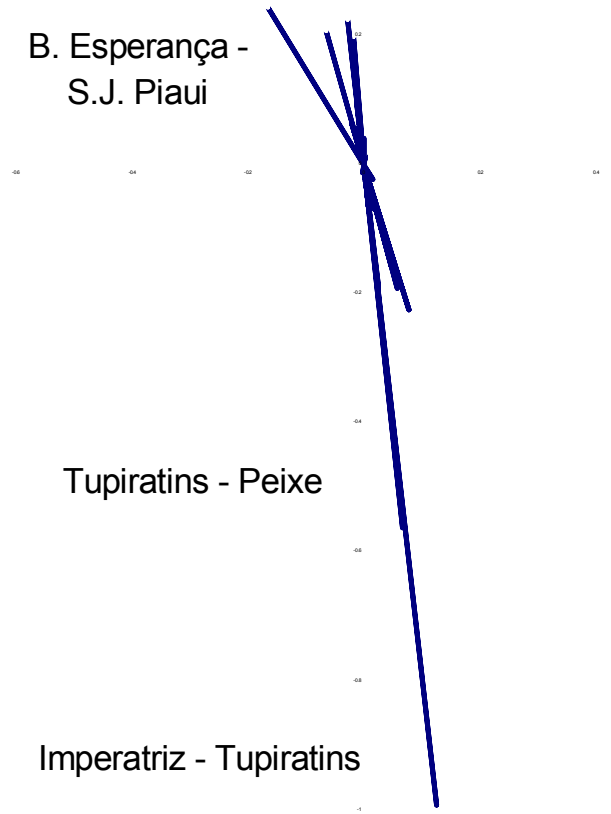
$$\lambda_{34} = -0.275 \pm j0.0044 \qquad R_{34} = -0.039 \pm j0.007$$

Rotor Speed Mode Shape for North-South Mode

$$(\lambda_{12} = -0.011 \pm j0.802)$$

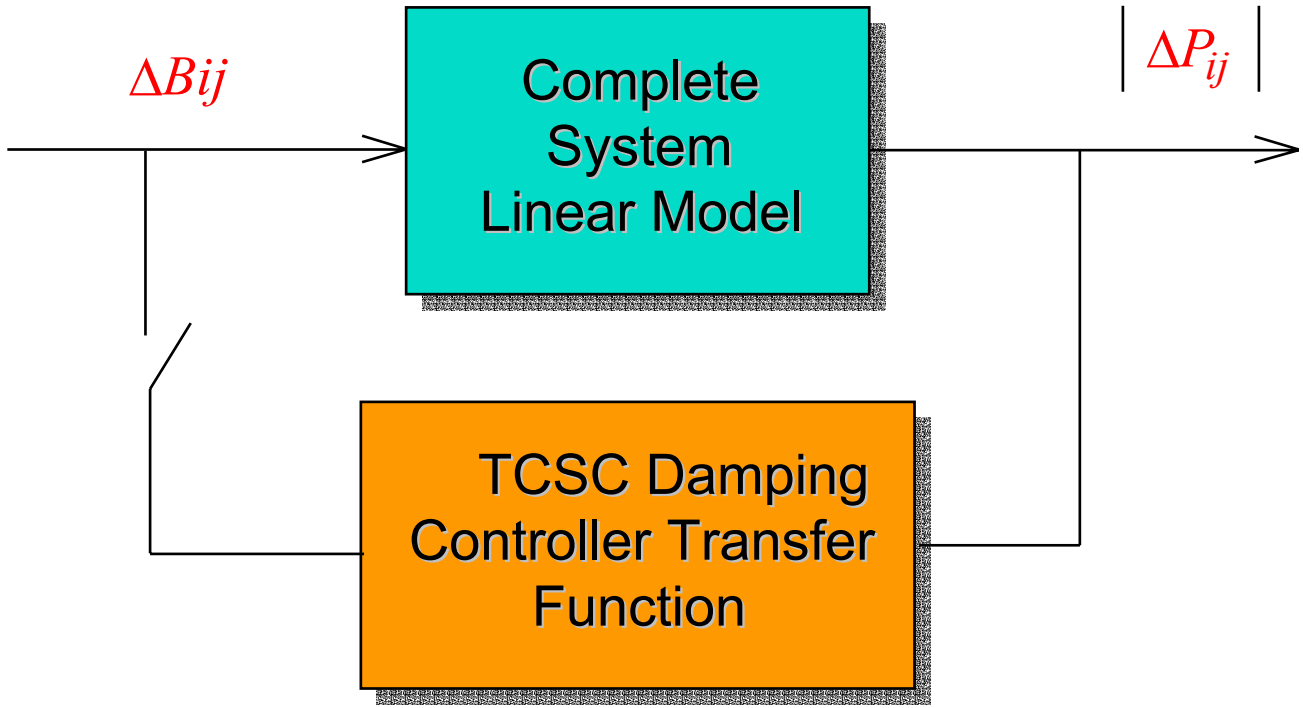


Phasor Diagram Representation of Transfer Function Residues (P_{ij}^{k}/B_{ij}^{k}, $k = 1,nl$)



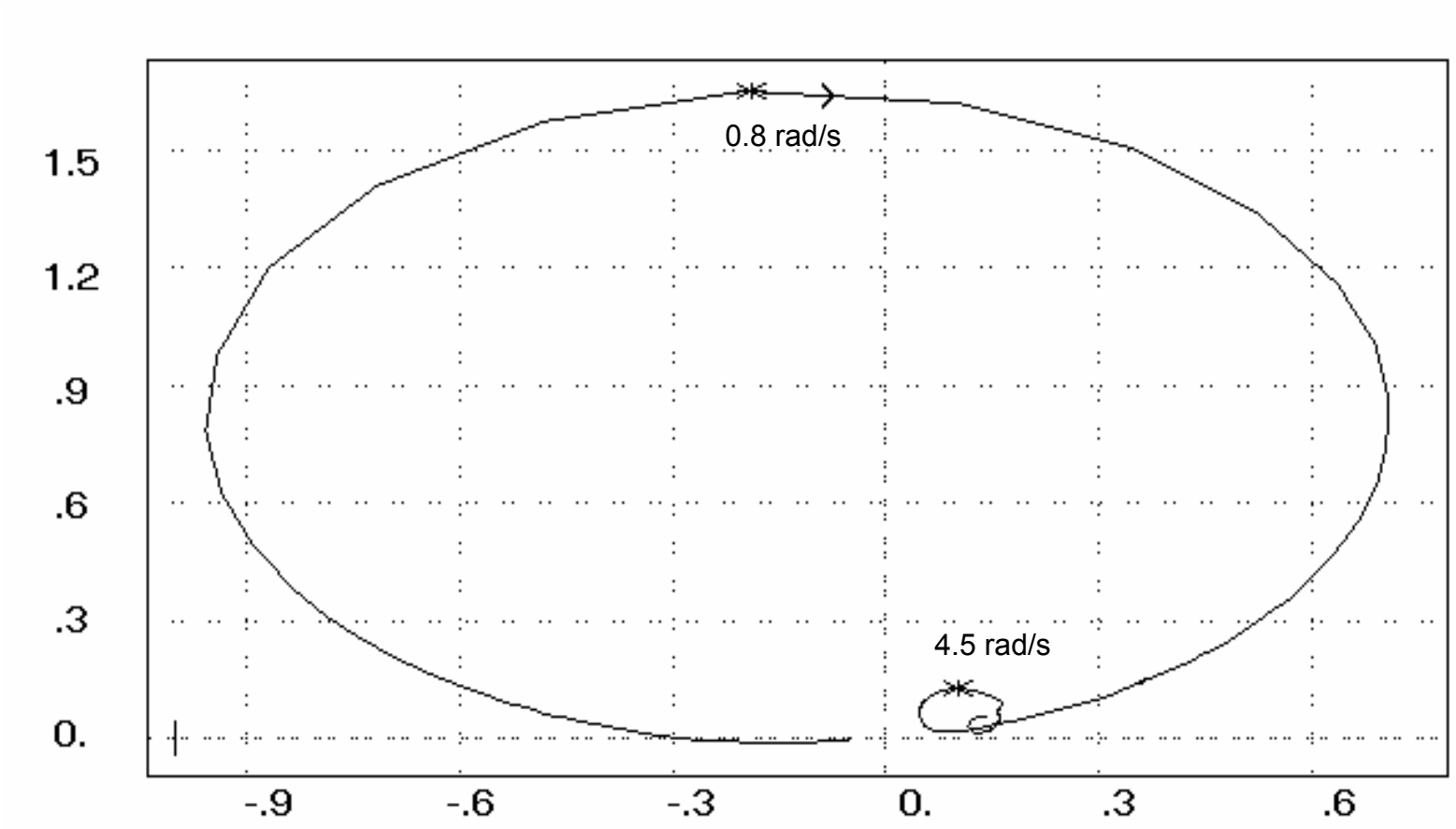
Determining the Most Effective System Branches for Installing TCSCs with PODs for Damping the N-S mode

Single TCSC with POD Controller



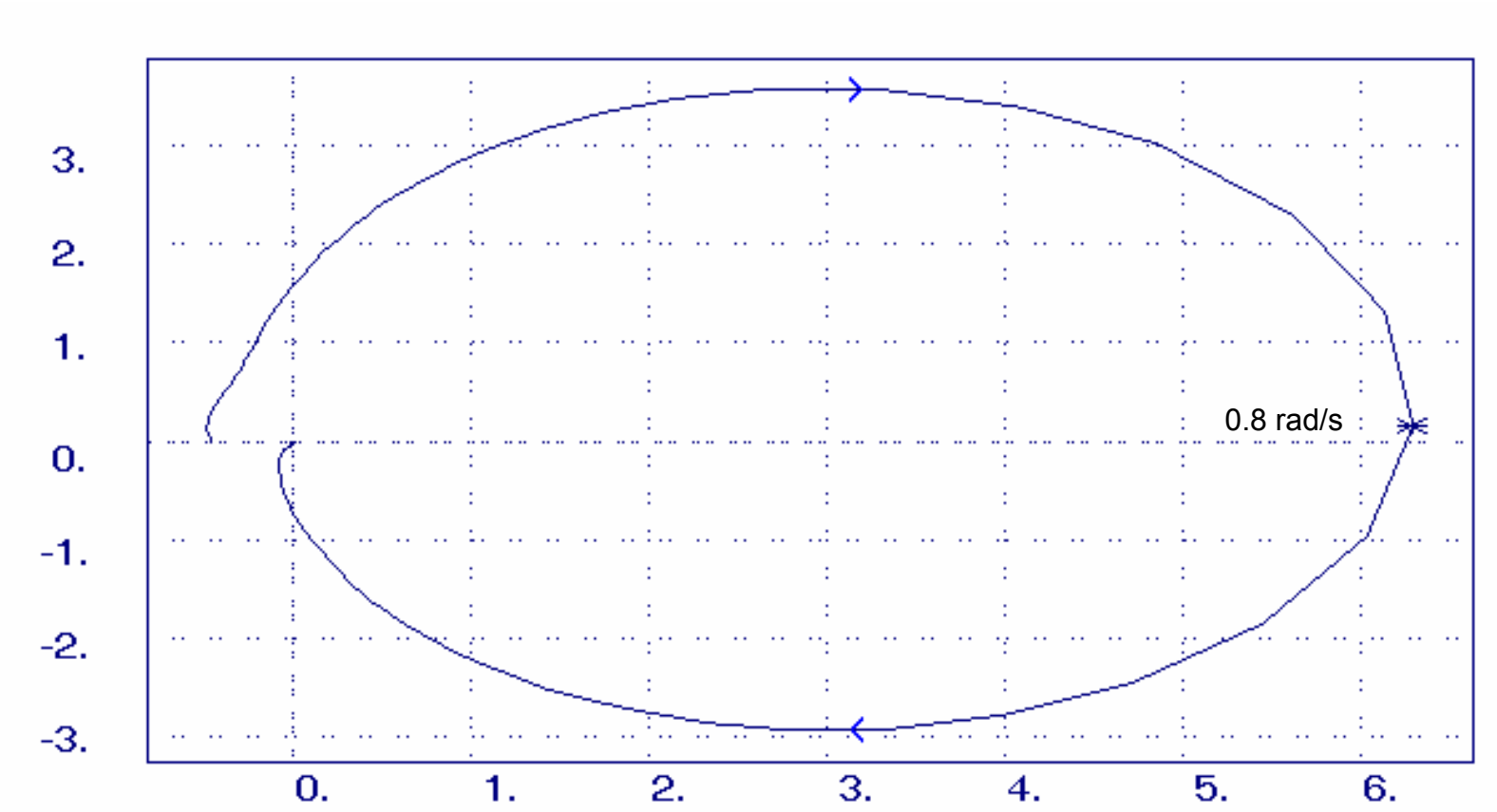
Frequency Response of $\Delta|Pij|(s) / \Delta Bij(s)$

North Exporting 1,000 MW to South

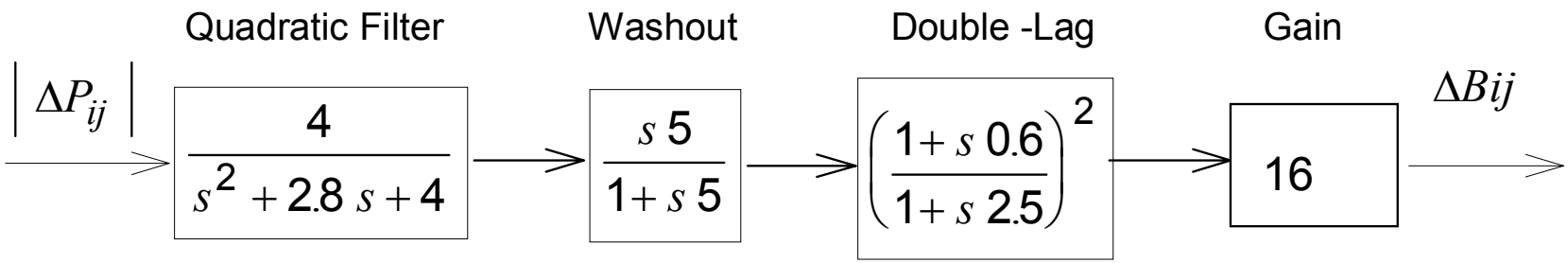


Frequency Response of Δ|*Pij*|*(s)* / Δ*Bij(s)* . *TCSC(s)*

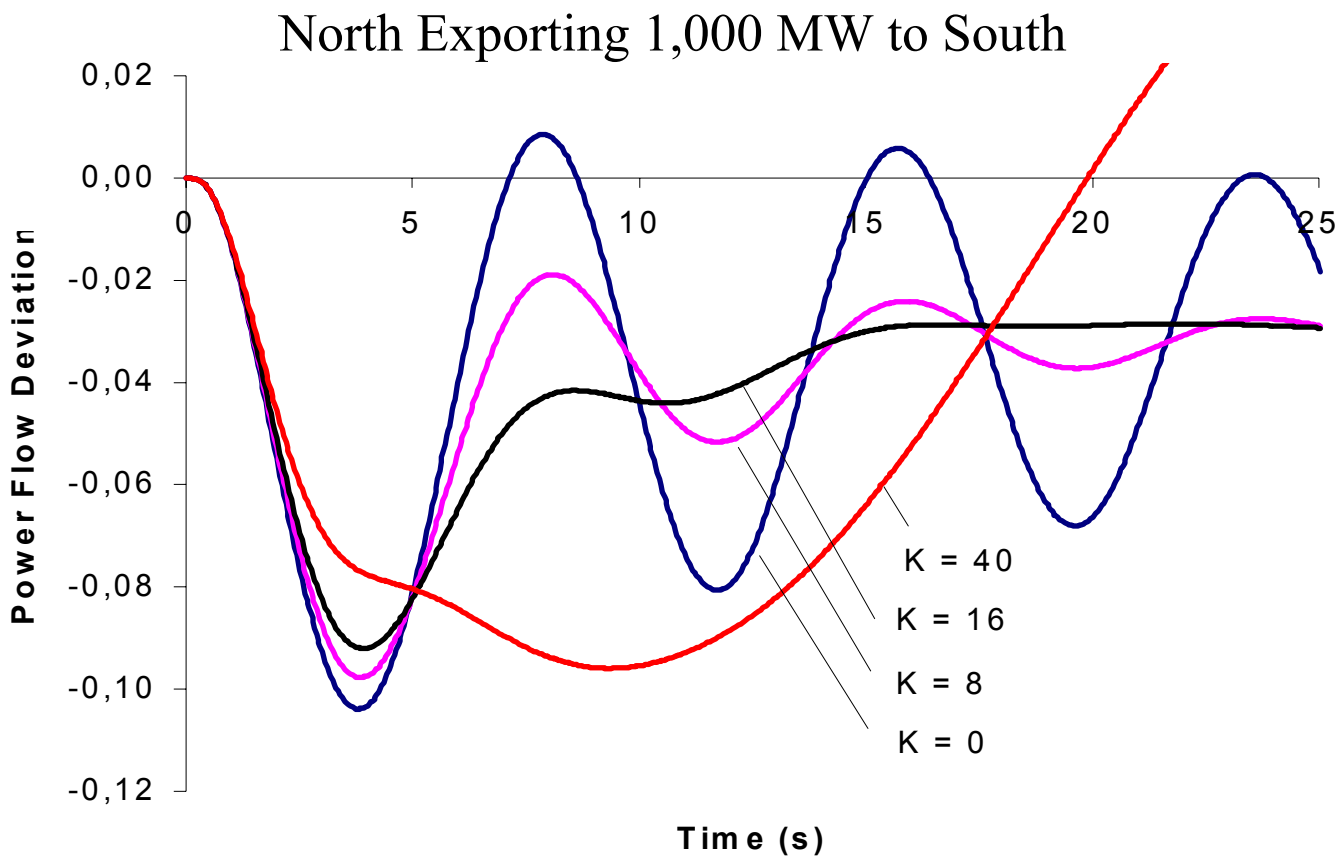
North Exporting 1,000 MW to South



Block Diagram for POD Controller of Single TCSC

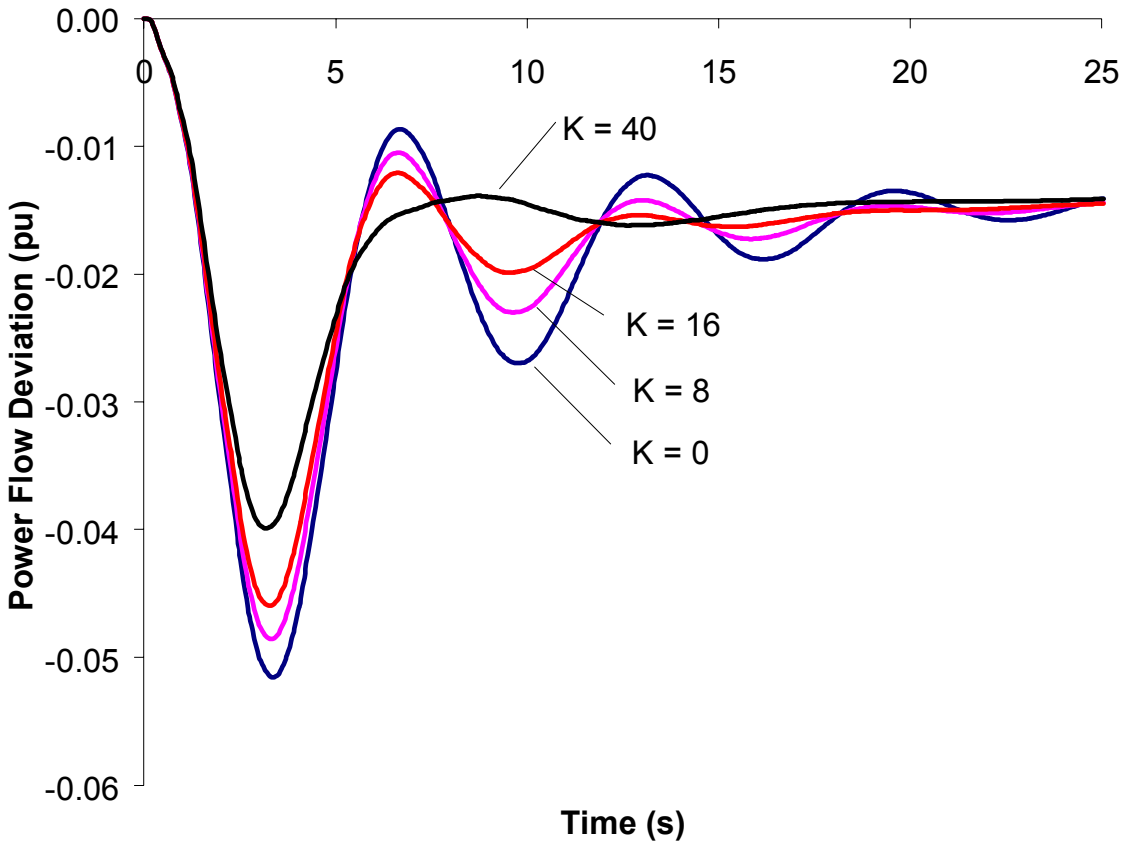


Linear Time Response of Tie-Line MW Flow as a Function of the TCSC POD Controller Gain



Linear Time Response of Tie-Line MW Flow as a Function of the TCSC POD Controller Gain

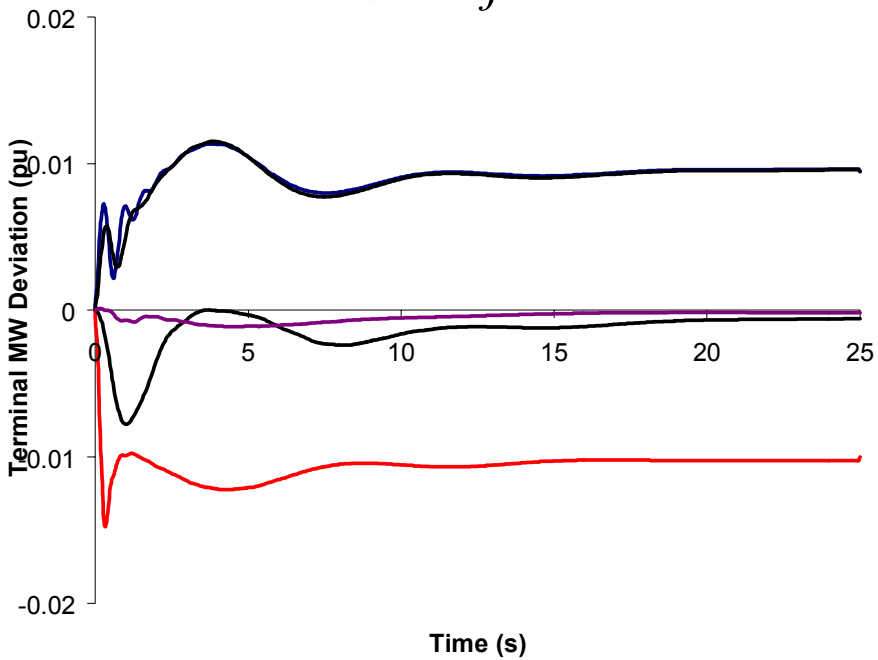
South Exporting 1,000 MW to North



Linear Time Responses of Major System Generators in the Presence of a Single TCSC with POD Controller

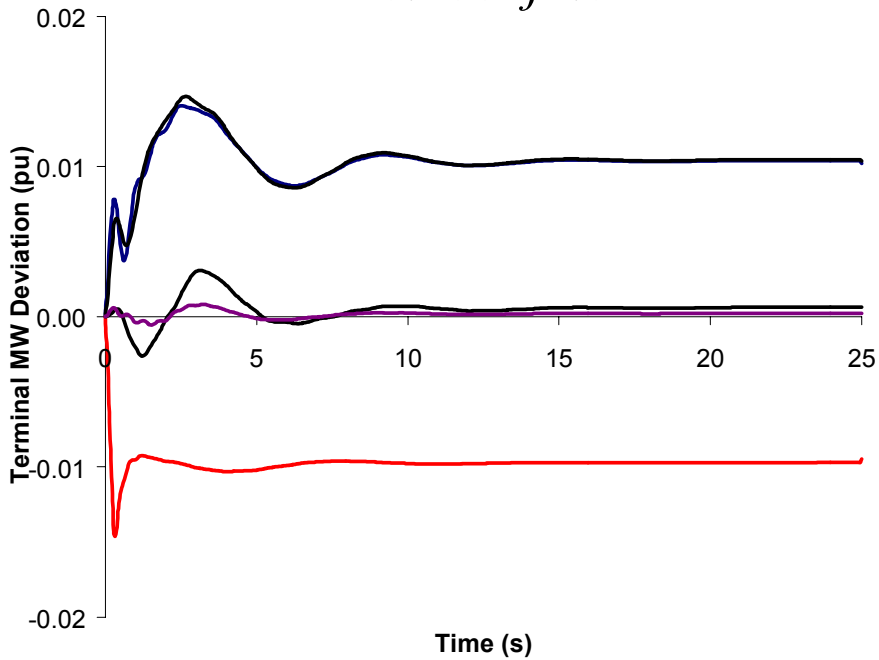
North Exporting 1,000 MW to South

$\lambda = -0.251 + j0.823$

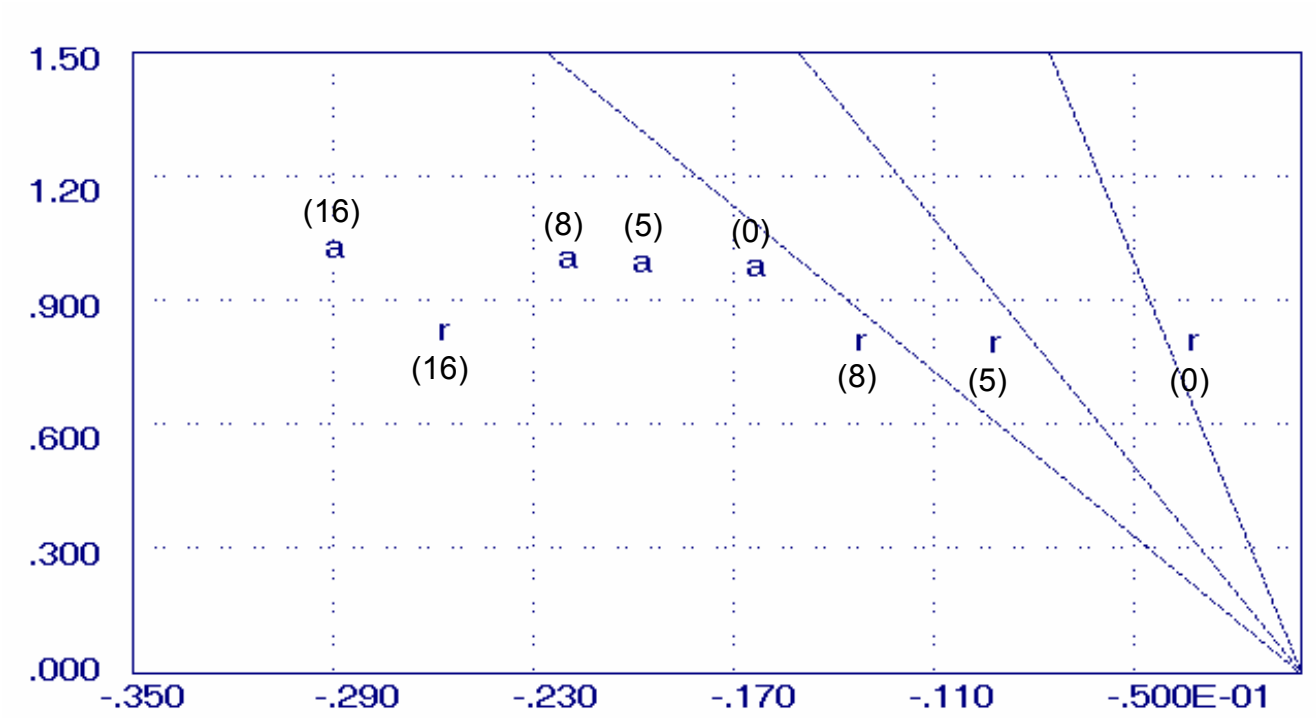


South Exporting 1,000 MW to North

$\lambda = -0.286 + j1.022$

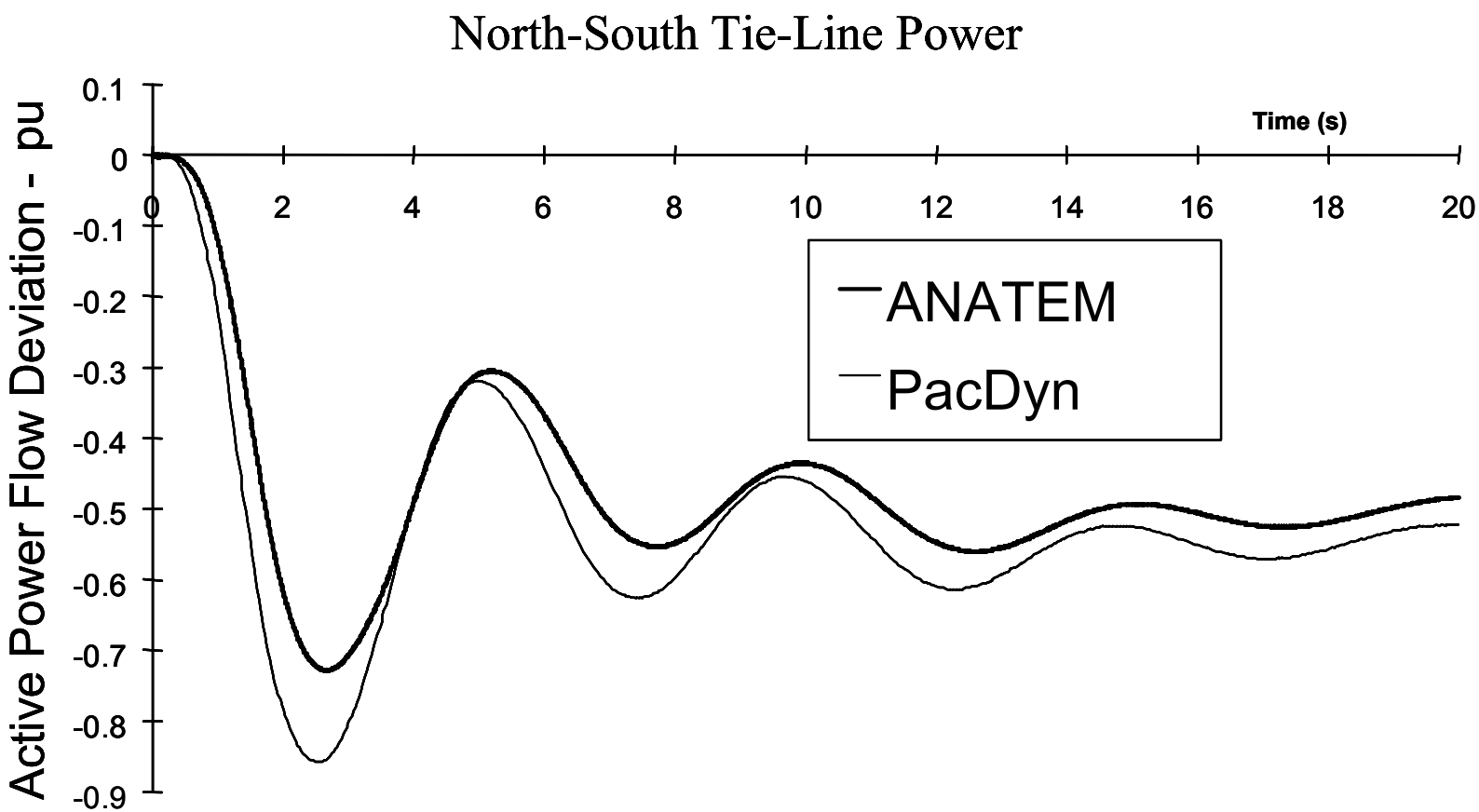


Inter-Area Eigenvalue Locus as a Function of the Gain of a Single TCSC POD Controller



Notation: Symbol ‘a’ relates to South to North, 1,000 MW Flow
Symbol ‘r’ relates to North to South, 1,000 MW Flow

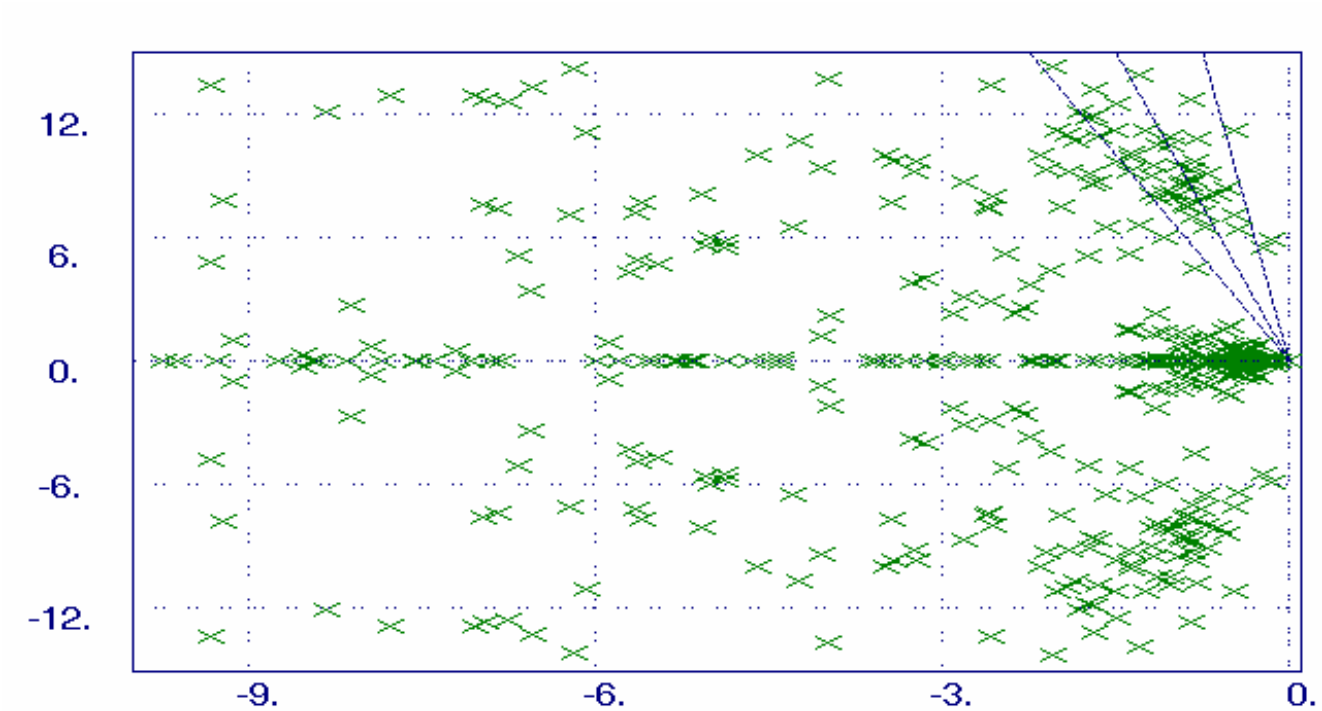
Brazilian North-South Interconnection



Comparing Simulations from Small Signal Stability and Transient Stability Programs

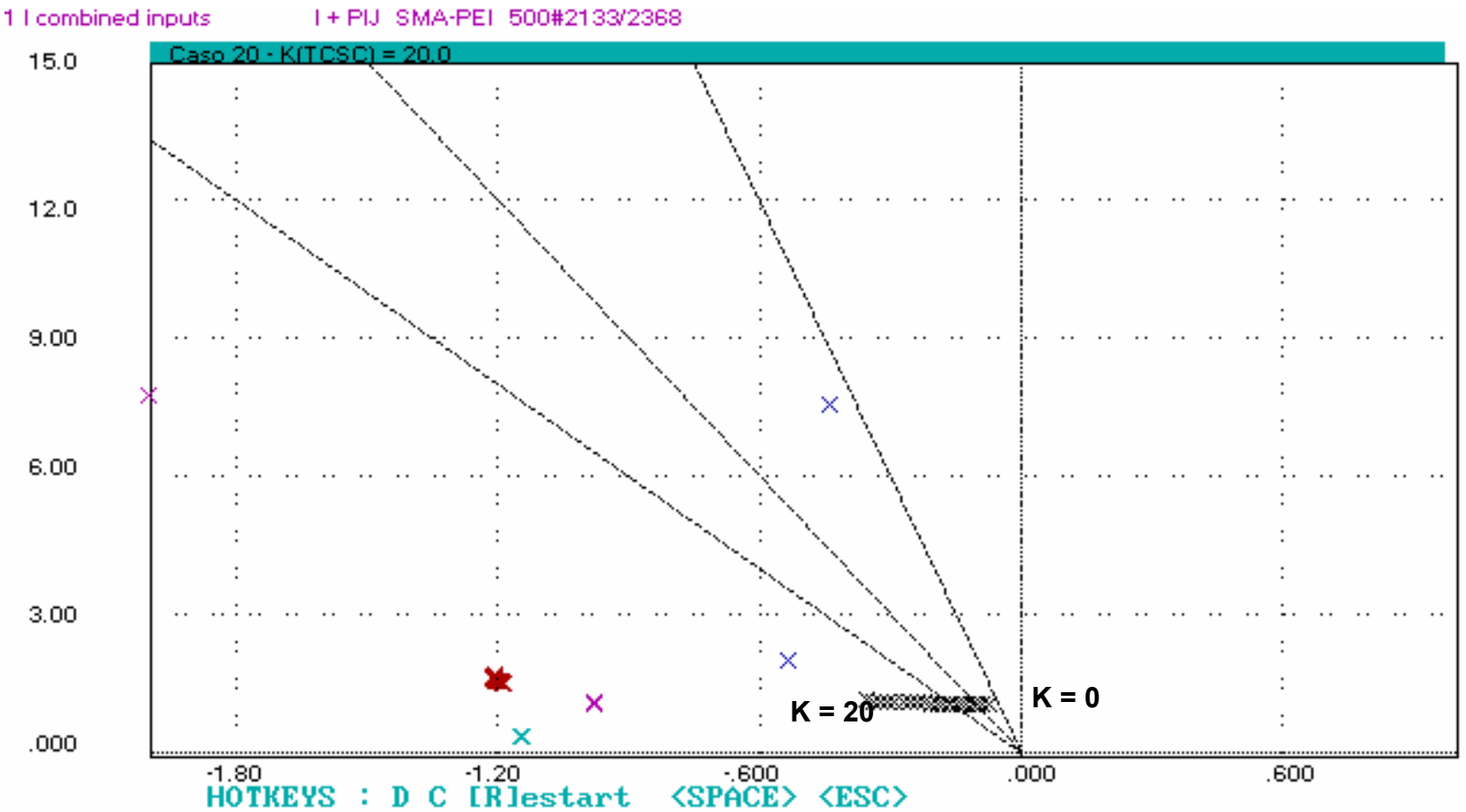
Eigenvalue Spectrum of the 50,000 MW, Brazilian North-South Interconnection (with just one TCSC POD Controller)

North Exporting 1,000 to South

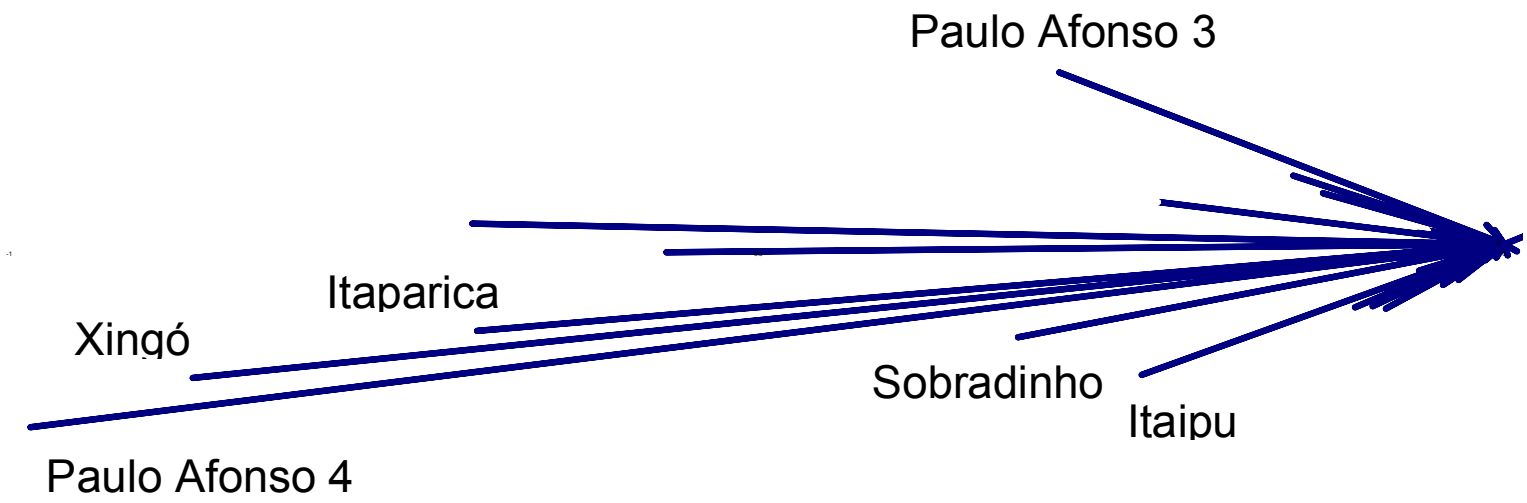


Root-Loci Varying the TCSC POD Controller Gain

North Exporting 1,000 MW to South



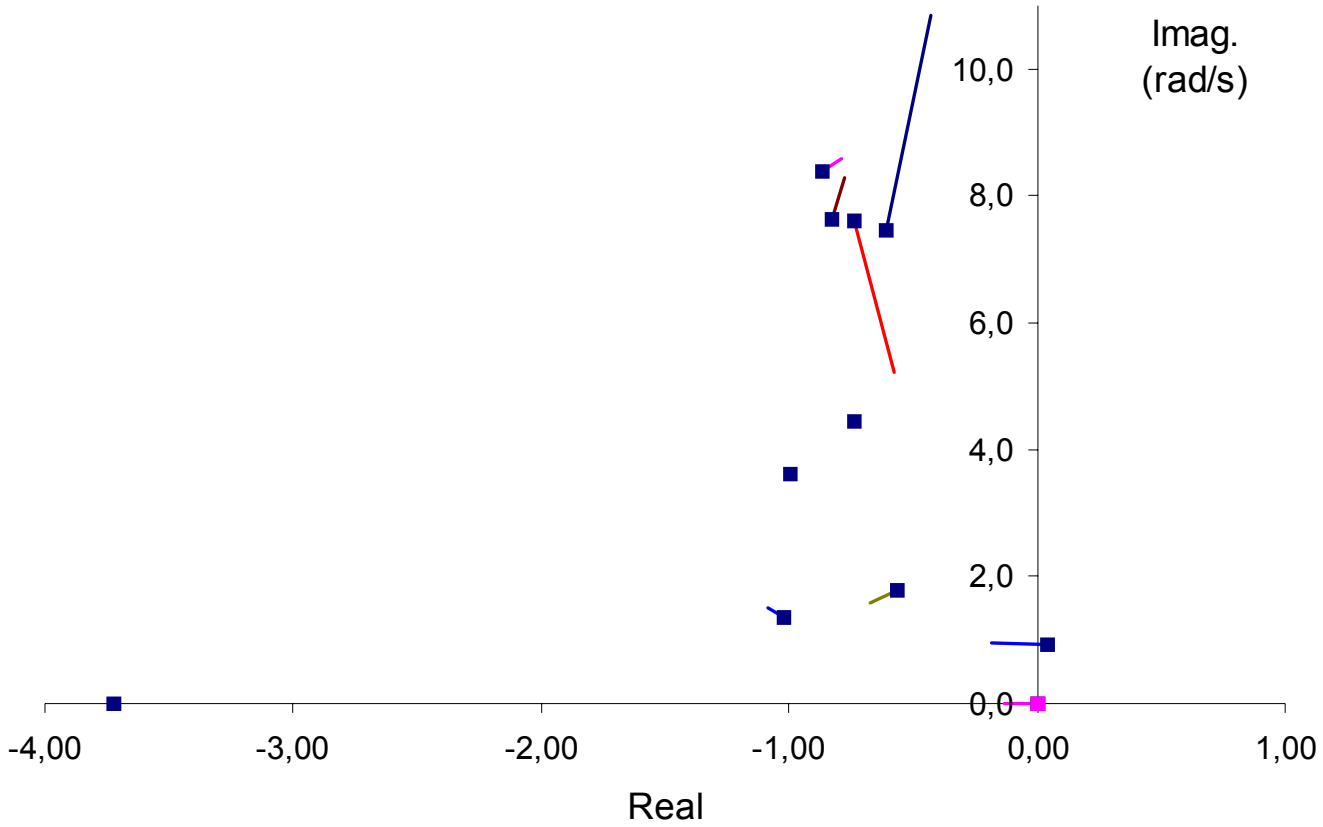
Phasor Diagram Representation of Transfer Function Residues (ω^i/V_{ref}^i, $i = 1, ng$)



Determining the Most Effective Generators for Installing Enhanced Stabilizers

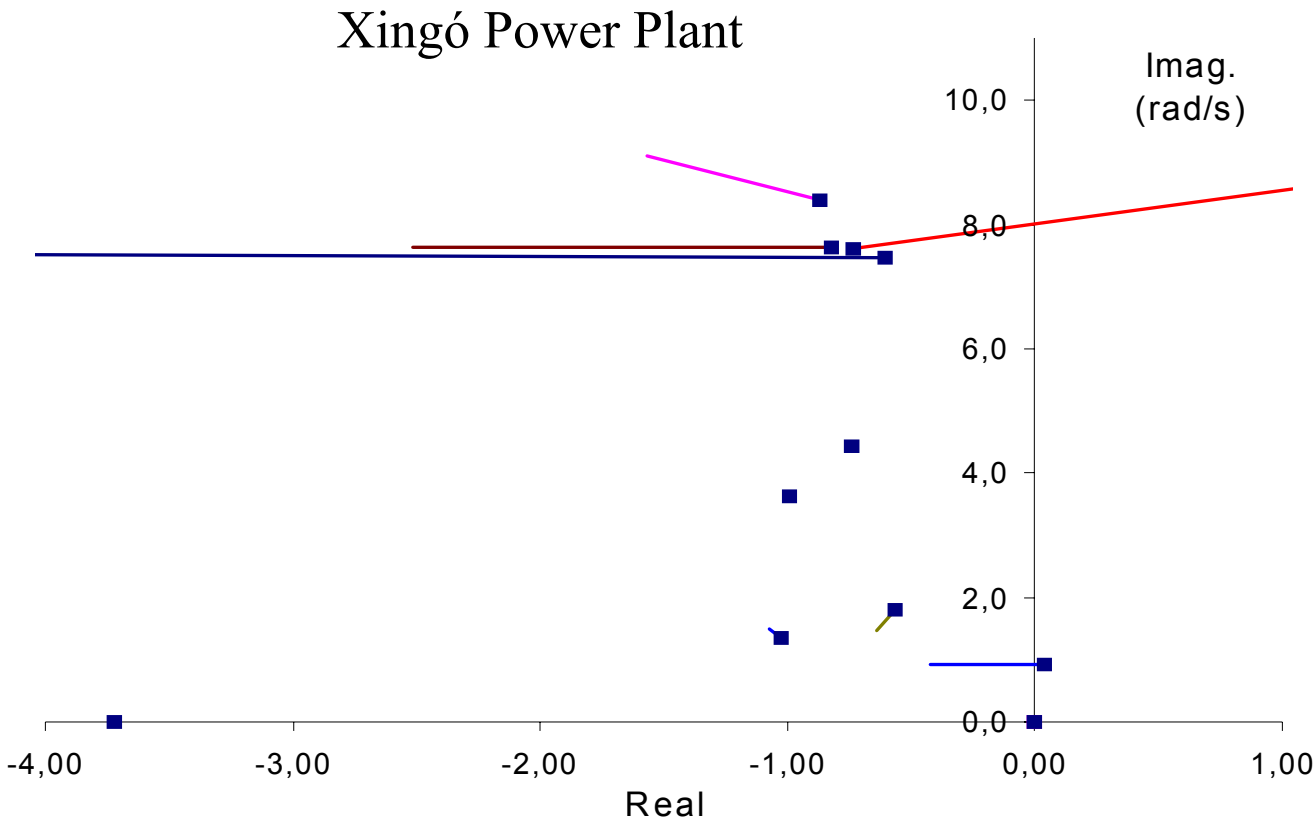
Dominant Pole Spectrum for $\Delta\omega(s) / \Delta V_{ref}(s)$

Xingó Power Plant



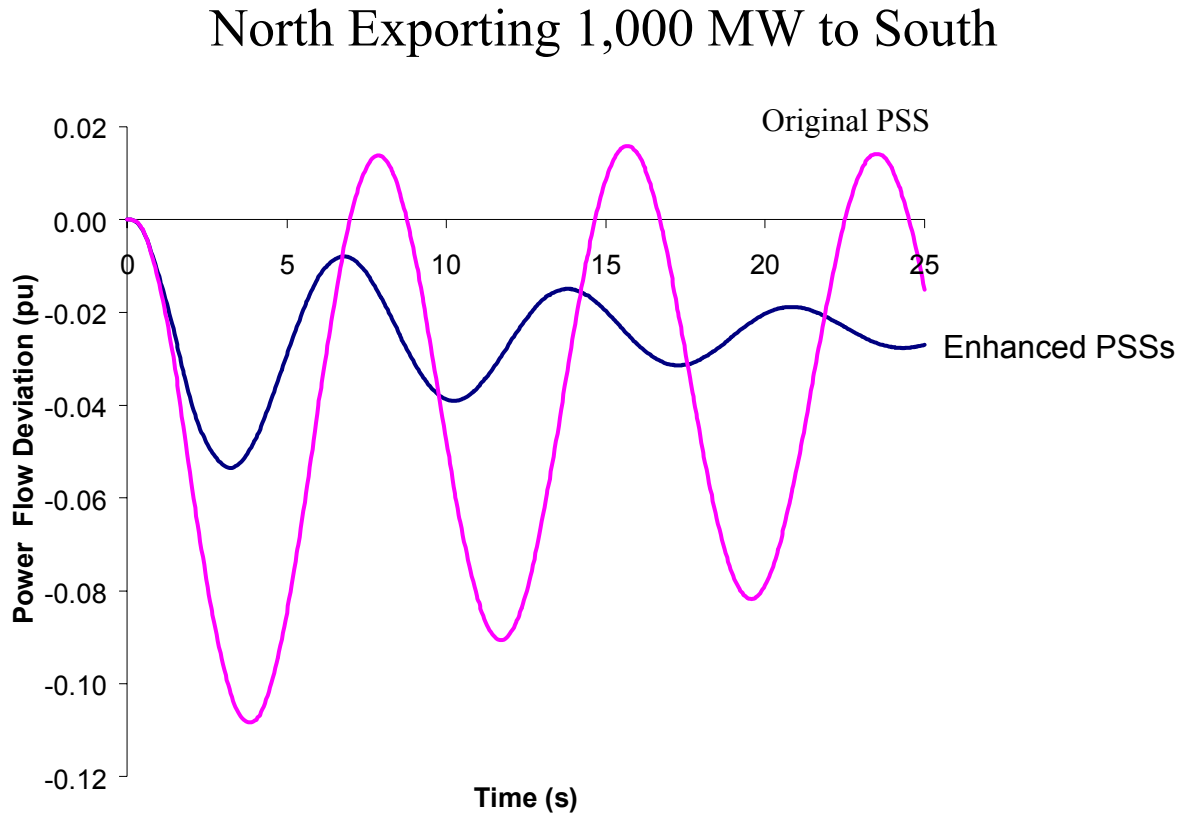
Pole Residues are also depicted

Initial Displacements of Dominant Poles Due to Incremental Gain Stabilizer



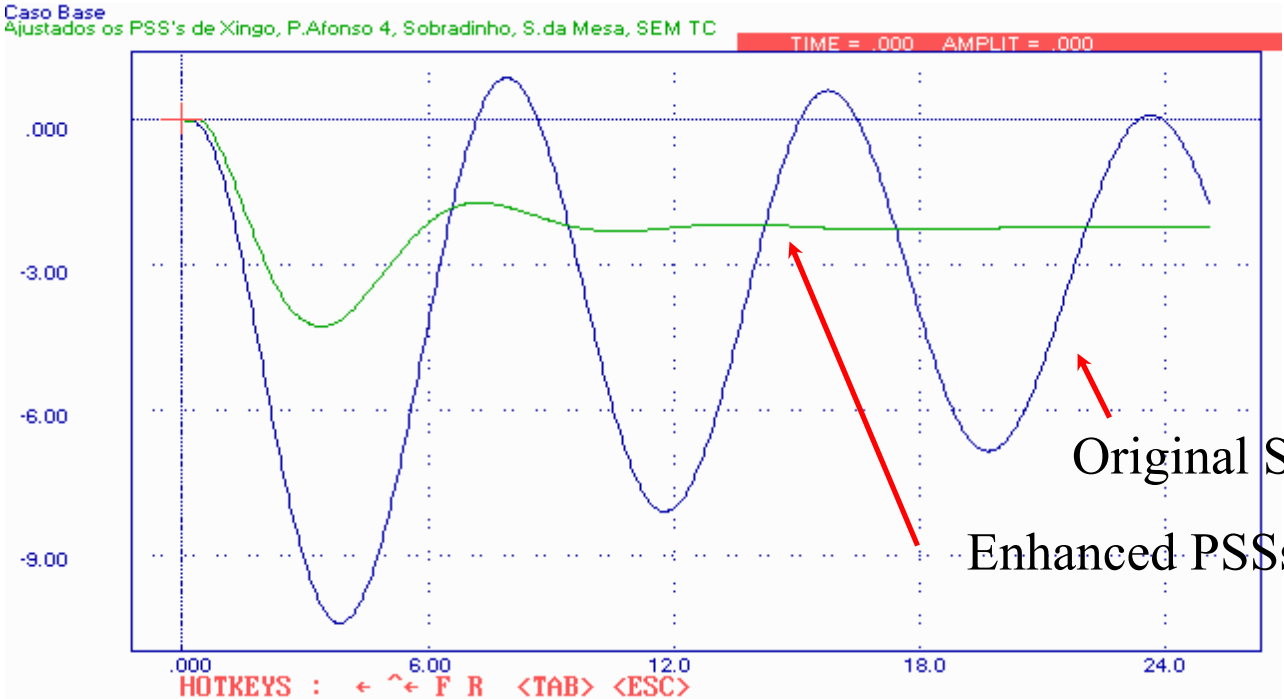
$$PSS(s) = \varepsilon \left(\frac{3s}{1+3s} \right) \left(\frac{1+0.4s}{1+0.04s} \right)^2 \left(\frac{1+0.27s}{1+2.7s} \right)$$

Tie-Line Small-Signal Power Oscillations for Original and Enhanced PSSs in Xingó and P. Afonso IV



Small-Signal Power Oscillations at North-South Intertie

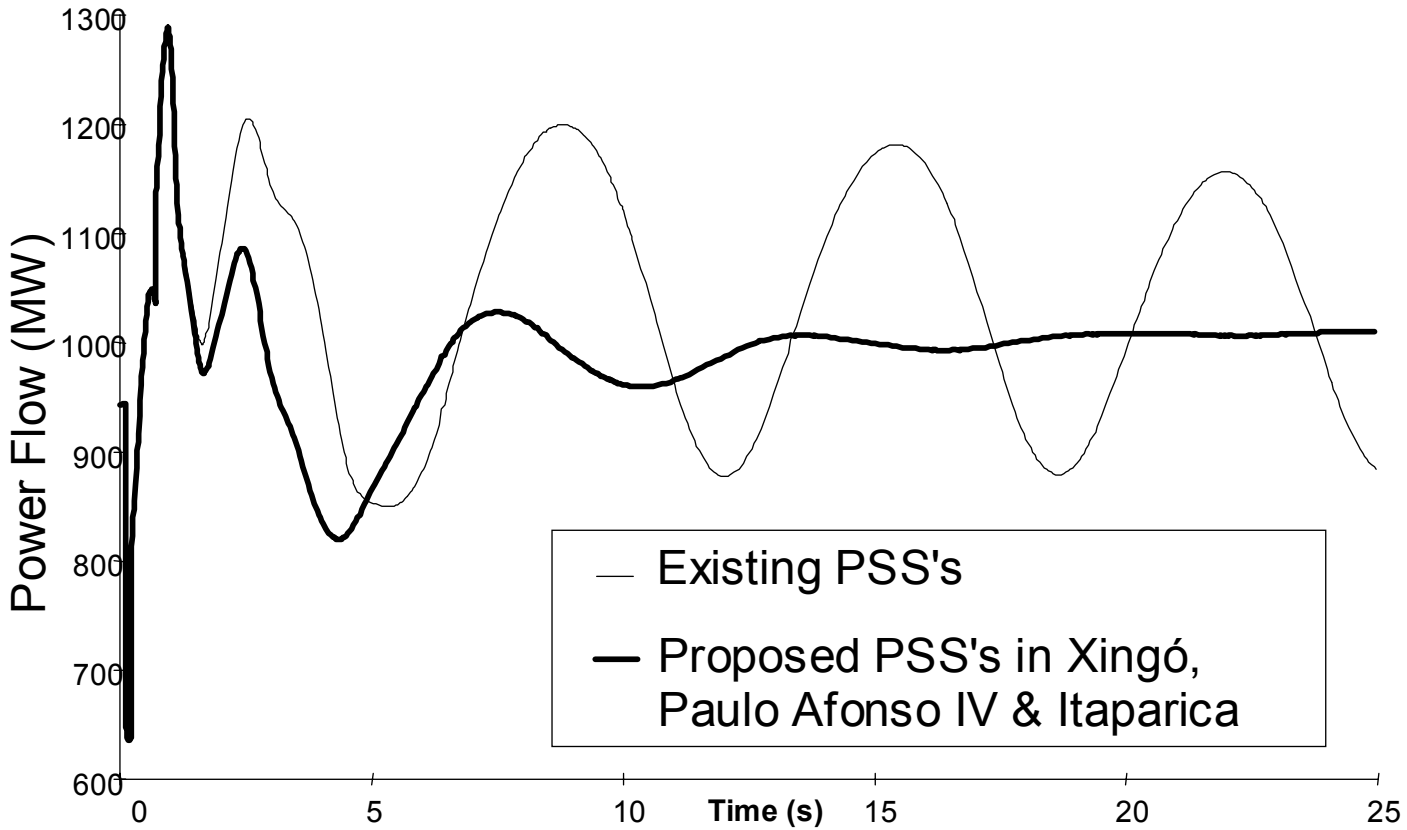
North Exporting 1,000 MW to South



Enhanced PSSs in Xingó, P. Afonso IV, Itaparica and Sobradinho

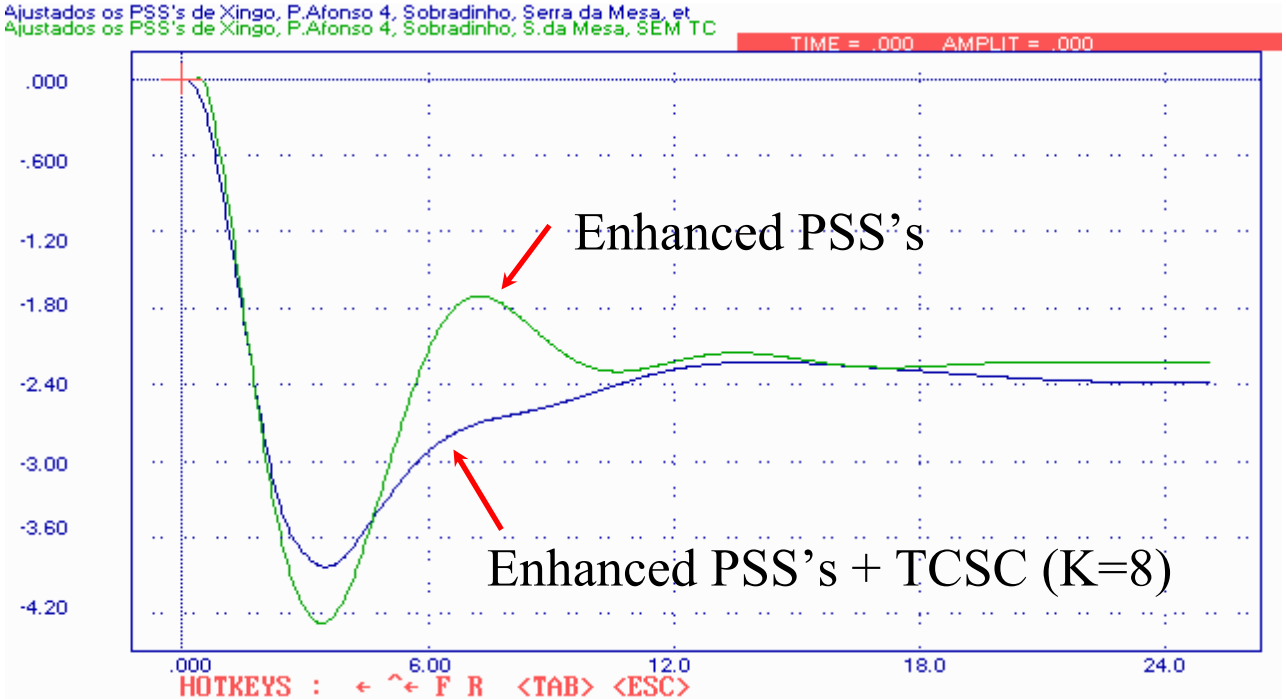
Brazilian North-South Interconnection

Transient Stability Simulation of a Fault with Line Clearance and Subsequent Reclosure



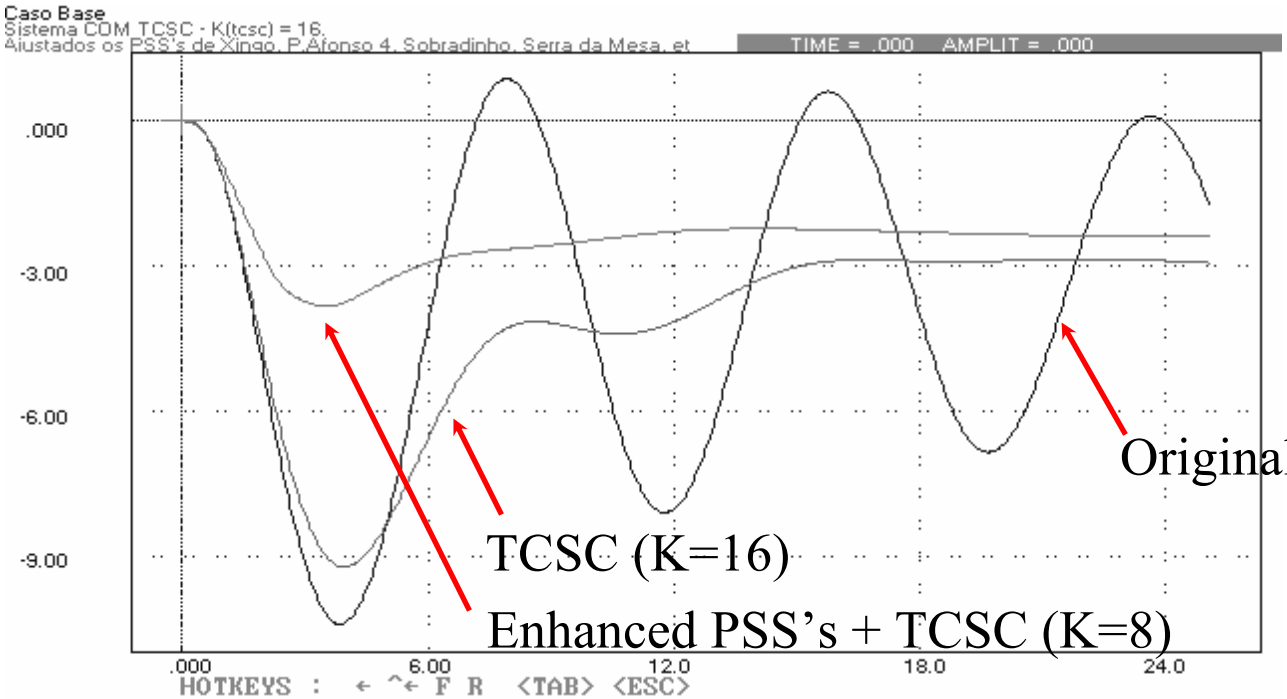
Small-Signal Power Oscillations at North-South Intertie

North Exporting 1,000 MW to South



Small-Signal Power Oscillations at North-South Intertie

North Exporting 1,000 MW to South



Conclusions

- Power Oscillation Damping (POD) controller on a TCSC located along the North-South Inter-Tie was shown to effectively damp the Brazilian 0.17 Hz North-South mode
- Enhanced PSSs in four Northeastern power plants can also effectively damp this oscillation
- Small signal analysis software is very effective for coordinated stabilizer design
- Good graphics and program interactivity makes the engineer's task much easier in complex engineering studies
- Step responses of linearized system model, as demonstrated in this paper, when used for preliminary comparison of alternative damping solutions, may speed-up oscillation damping control studies (50 times faster than transient stability solutions)