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The Dominant Pole Spectrum Eigensolver DPSE

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Introduction(1/3)

- Recent developments and increased use of modal analysis in studies of electrical, mechanical and civil engineering as well as in many other fields

- Good opportunities for use of modal equivalents in power system dynamics and control, harmonic analysis and real-time simulations of electromagnetic transients.

Introduction (2/3)
Transfer Function Pole Dominance

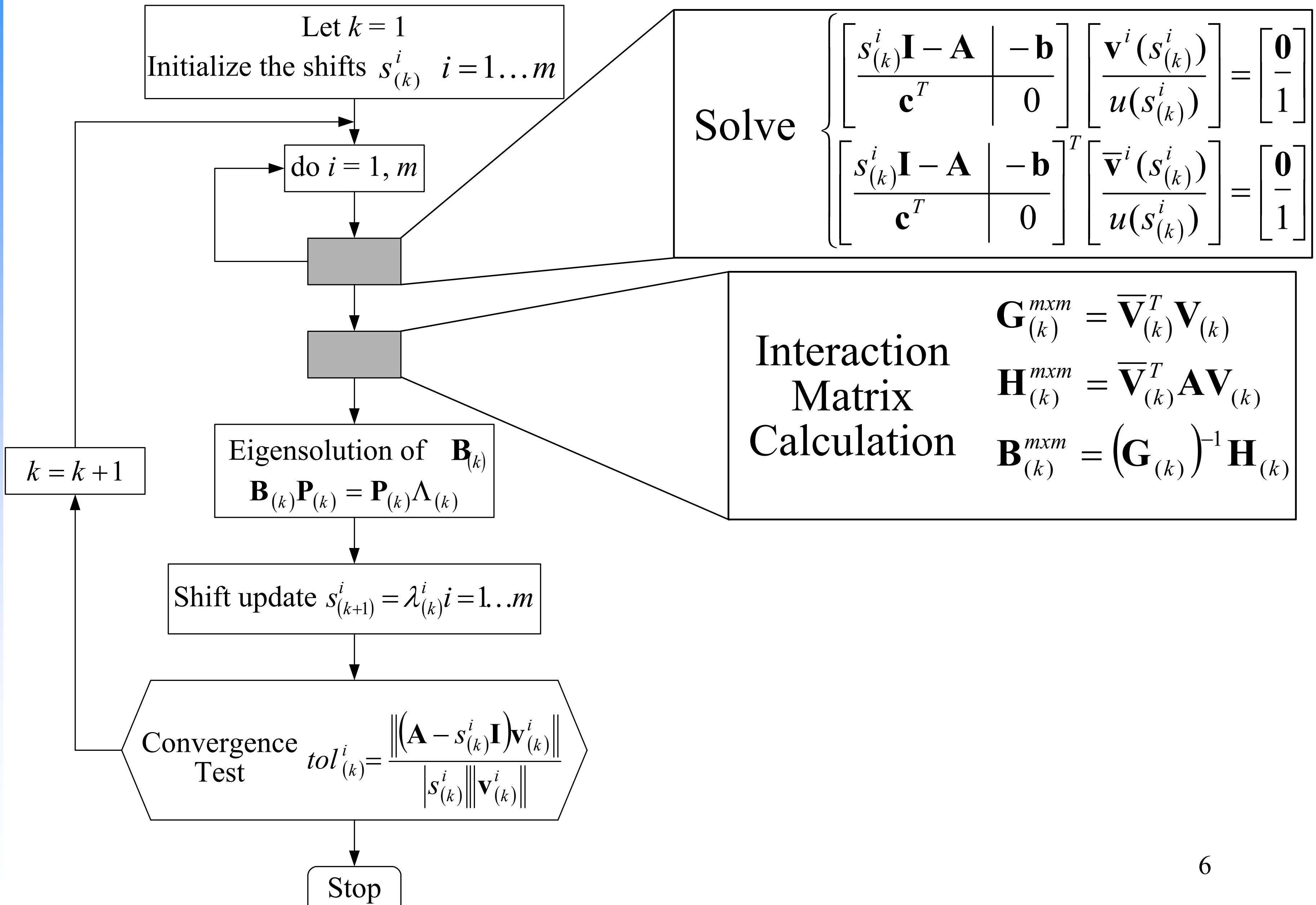
- Concept little exploited in Numerical Linear Algebra
- Power system applications: AESOPS algorithm [Byerly, 1978; Kundur, 1990] and Selective Modal Analysis [Pagola, 1988]
- Need for numerical efficiency, robustness and more general eigensolution selectivity in power system small signal stability analysis and decentralized control design
- Simple and efficient implementation of Newton- Raphson algorithm applied to specified transfer functions: The Dominant Pole Algorithm (DPA) [Martins et alli, 1996]
- DPA is a one-at-a-time eigensolution method

Introduction (3/3)

- The Dominant Pole Spectrum Eigensolver (DPSE) is a generalization of the DPA, that simultaneously solves for several dominant poles of a given scalar transfer function $F(s)$

- DPSE solves several DPA processes in a parallel manner, immediately followed by a reorthogonalization process at every iteration, so that repeated solutions are avoided.

The DPSE Algorithm



Basic Concepts leading to Modal Equivalents of Scalar *F*(*s*)

Partial Fraction Expansion

$$F(s) = \sum_{i=1}^{n} \frac{R_i}{s - \lambda_i}$$

Step Input

$$y(s) = F(s) \cdot \frac{1}{s} \approx \sum_{i=1}^{p} \frac{R_i}{s - \lambda_i} \cdot \frac{1}{s}$$

Inverse Laplace Transform

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

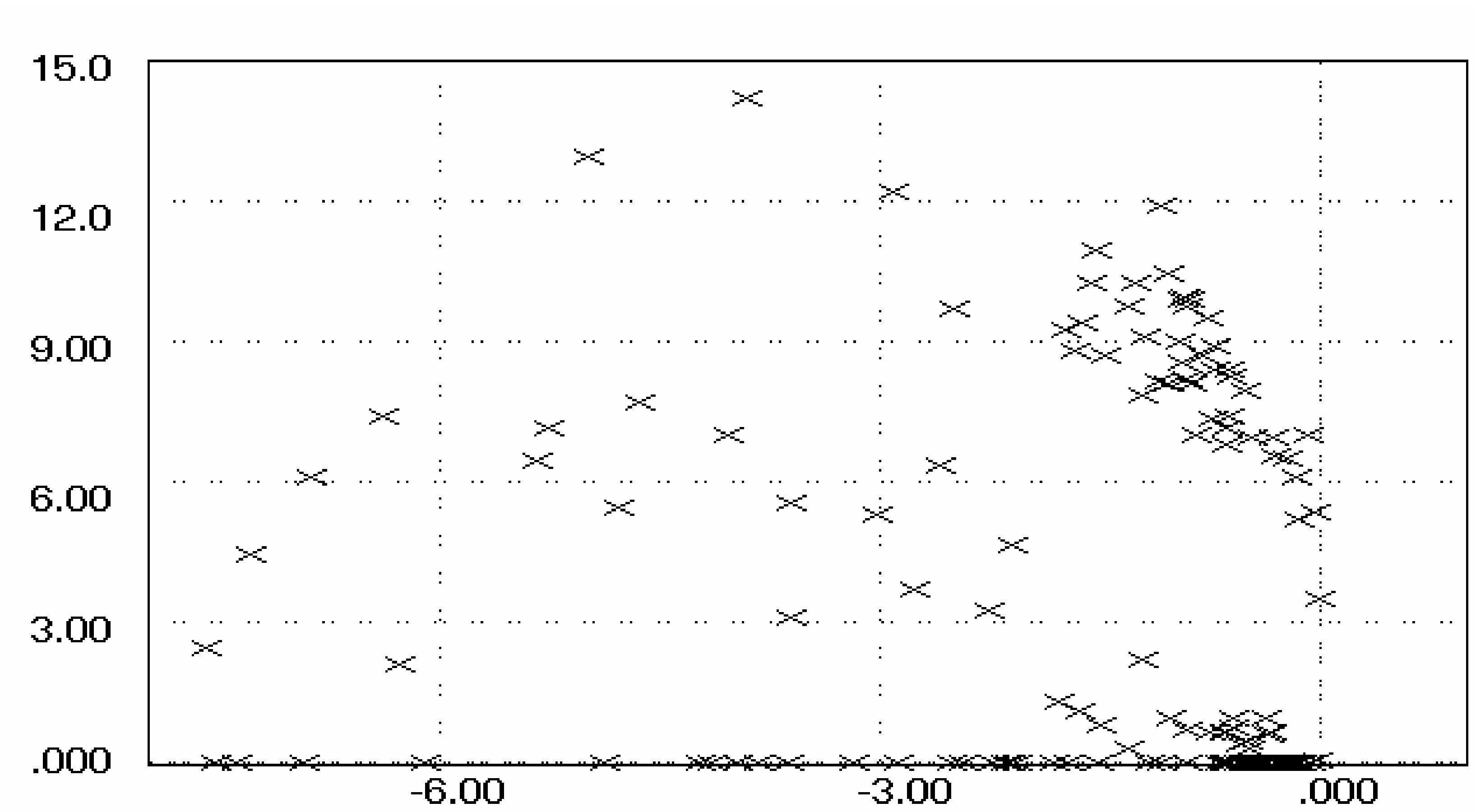
DPSE Results on the South-Southeast Brazilian System (1986 Operations Planning Model)

- 616-Bus, 50-Generator Model, with no PSSs
- 362 State Variables
- 8 Poorly-Damped Electromechanical Modes
- Transfer Functions Considered

$$F_1(s) = \Delta V_t^{Itaipu}(s) \big/ \Delta V_{ref}^{Itaipu}(s)$$

$$F_2(s) = P_t^{GPR}(s) \Big/ \left(\Delta P_{mec}^{Itaipu}(s) - \Delta P_{mec}^{Jacui}(s) + \Delta P_{mec}^{Itauba}(s) \right)$$

DPSE Results

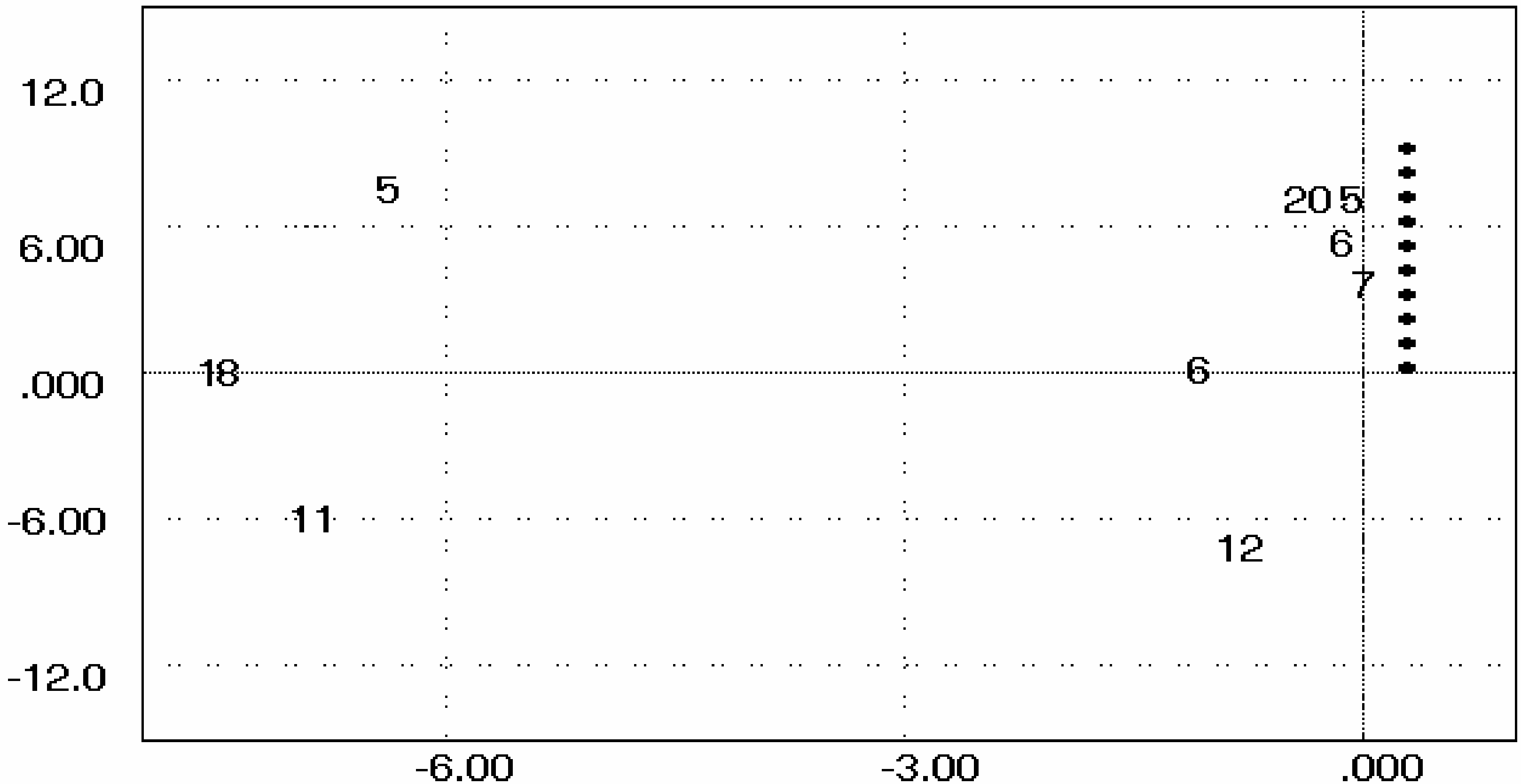


Eigenvalue Spectrum of 50-Generator System

Units: *x*-axis in seconds^{-1}; *y*-axis in radians/s

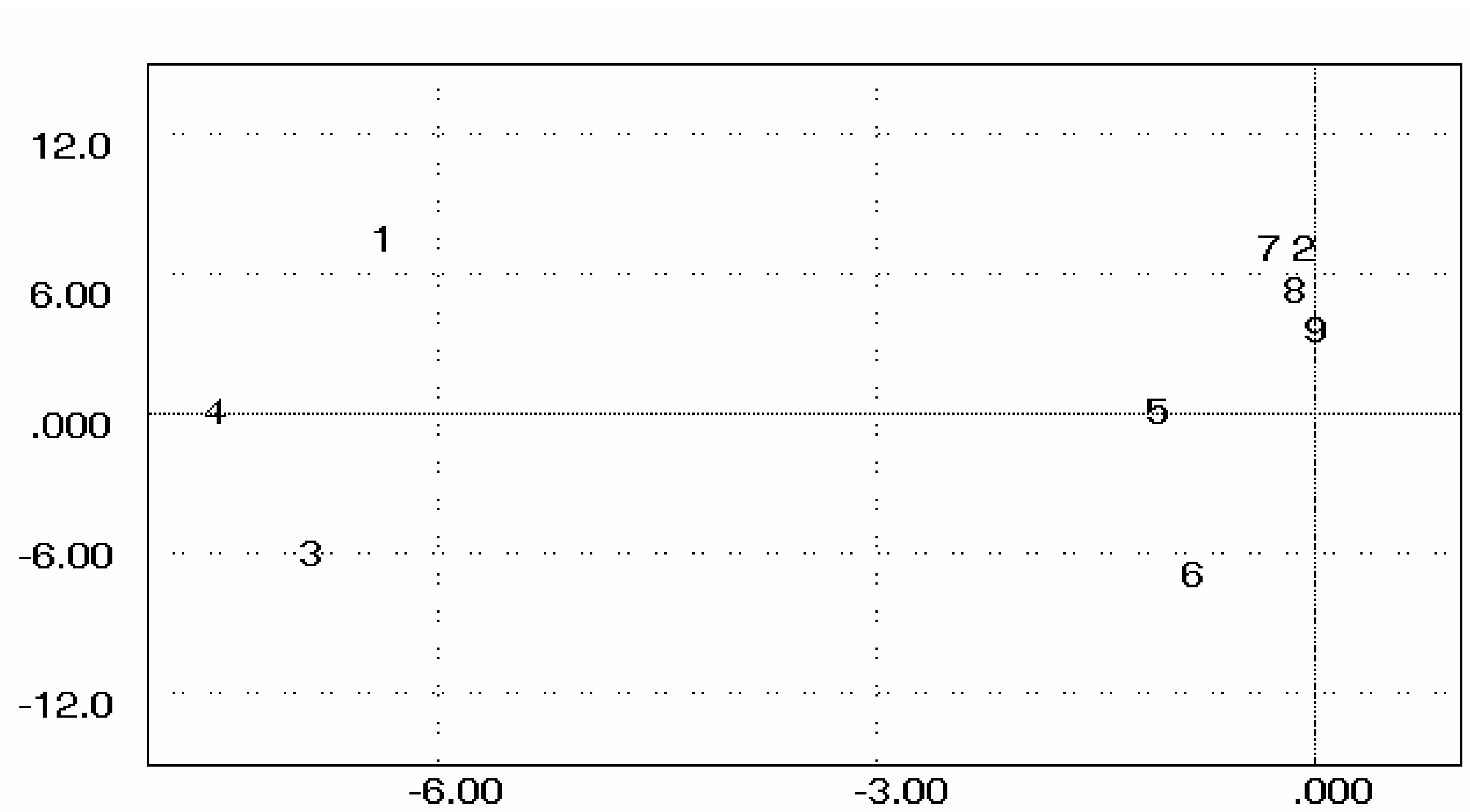
DPSE Results for $F_1(s)$

The 10 Initial Eigenvalue Estimates are Shown as Black Dots in the Right Half Plane



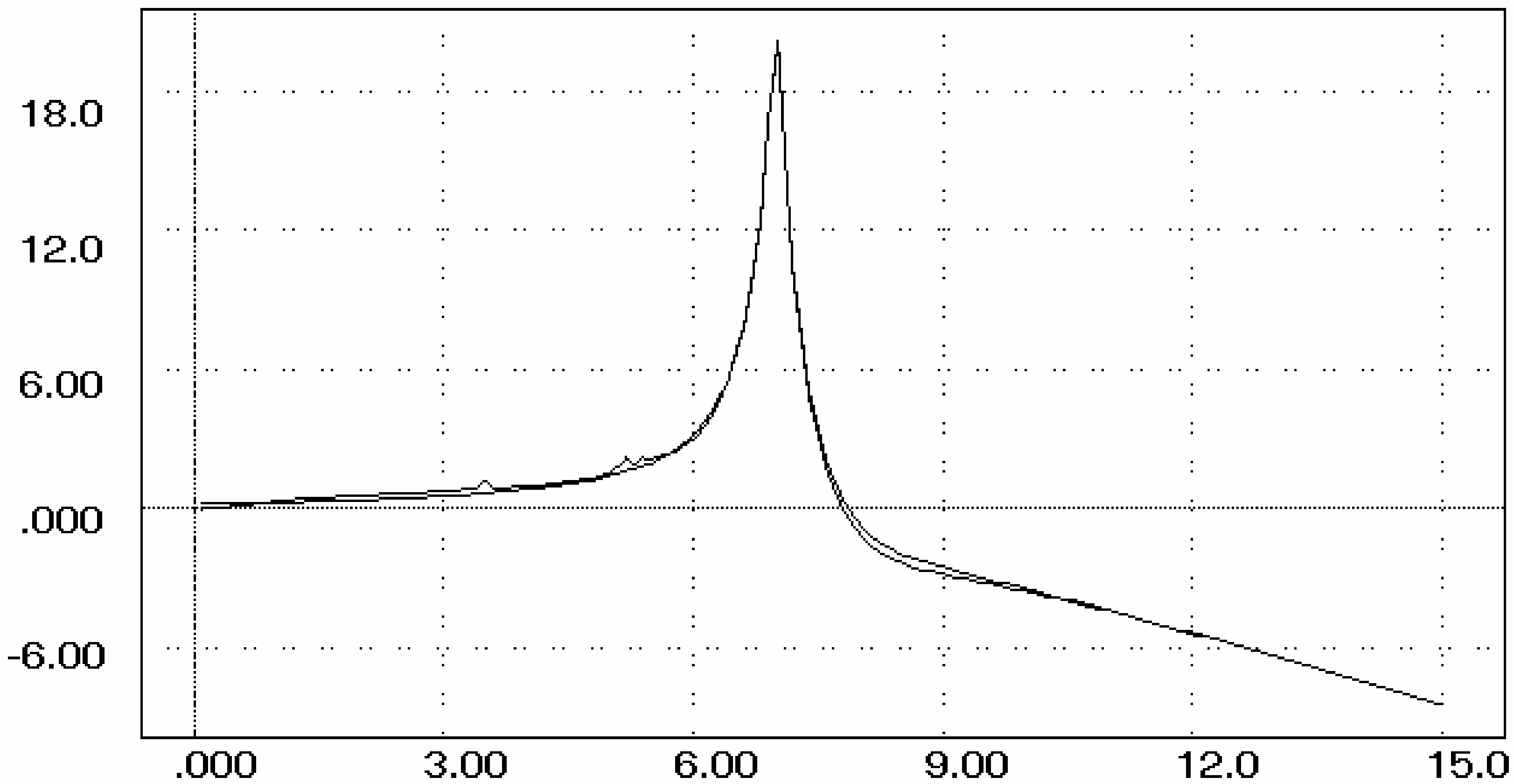
Loci of Dominant Poles in $F_1(s)$ with Information on the Number of Iterations Required for Accurate Convergence of Each Pole

DPSE Results for $F_1(s)$



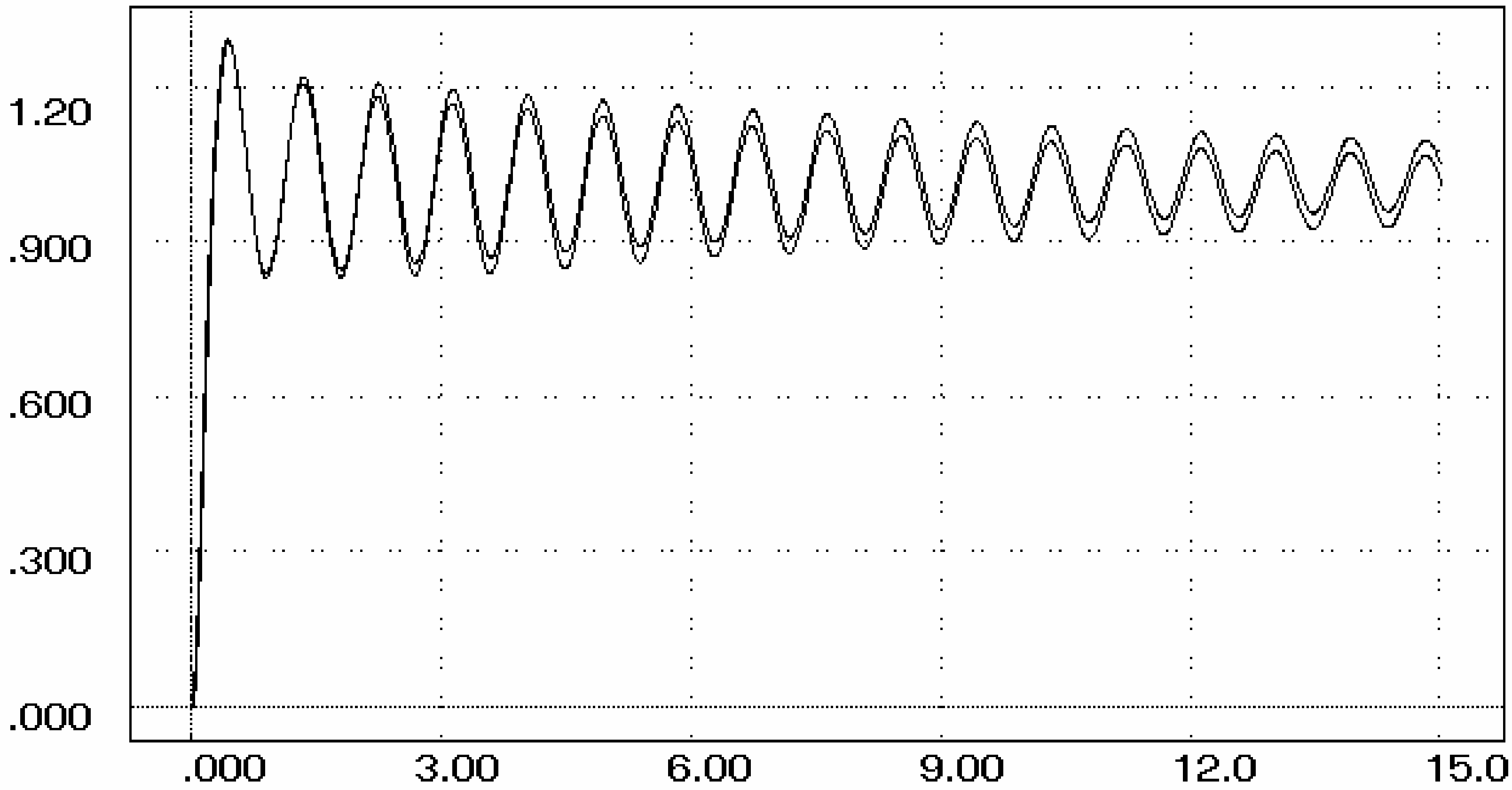
Loci of Dominant Poles in $F_1(s)$ with Information on Ranking Order According to Residue Magnitude

DPSE Results: Modal Equivalent for $F_1(s)$



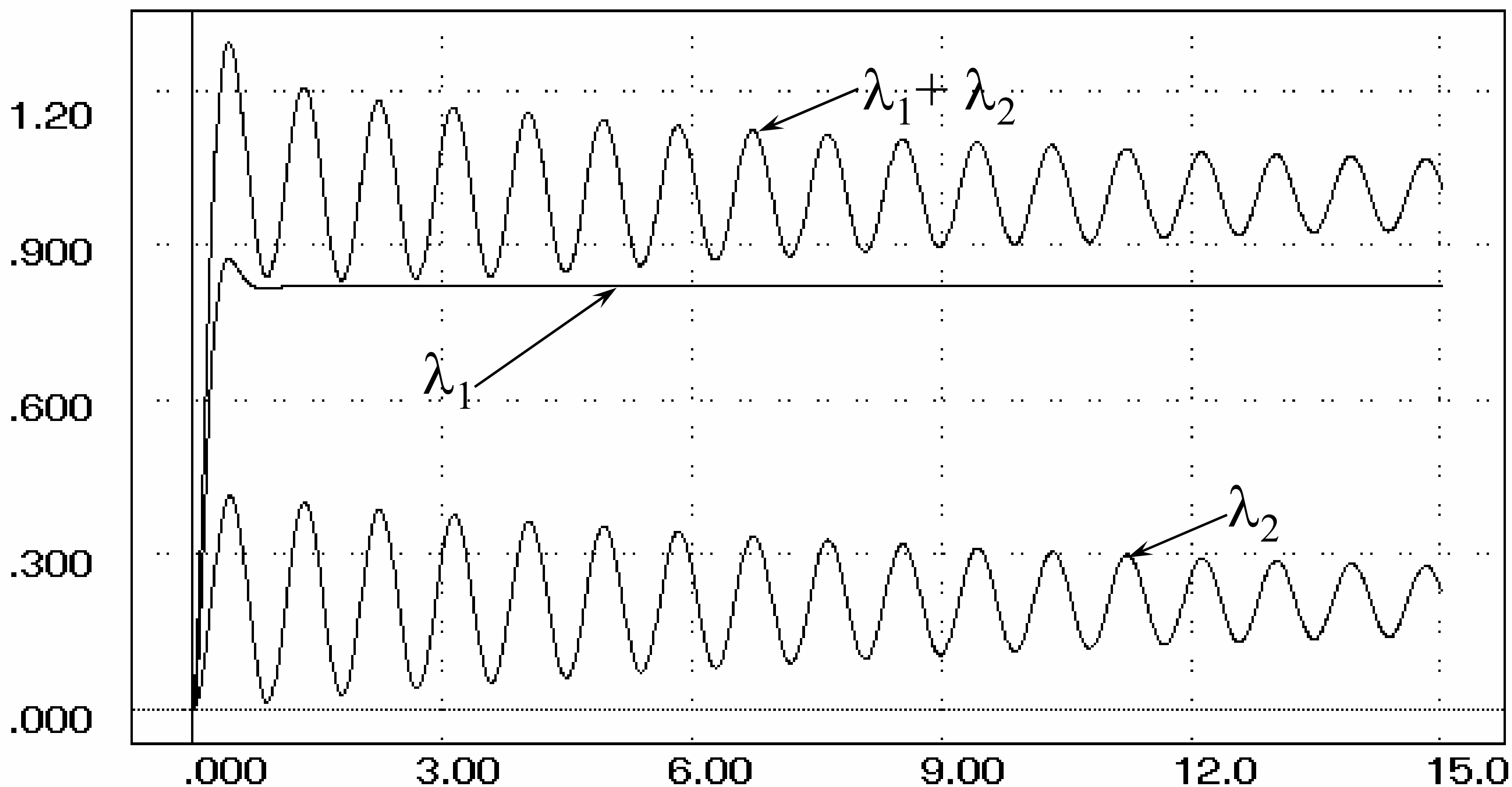
Bode Plot for both $F_1(s)$ and its 4[th] - order Modal Equivalent
Units: x-axis in radians/second; y-axis in decibels

DPSE Results: Modal Equivalent for $F_1(s)$



Step Response for both $F_1(s)$ and its 4th - order Modal Equivalent
Units: x-axis in seconds; y-axis in per-unit

DPSE Results: Modal Equivalent for $F_1(s)$



Contributions of the Two Most Dominant Modes to the Step Response of $F_1(s)$

DPSE Results: Modal Equivalent for $F_1(s)$

$$y(t) \cong \frac{R_1}{\lambda_1}(e^{\lambda_1 \cdot t} - 1) + \frac{R_1^*}{\lambda_1^*}(e^{\lambda_1^* \cdot t} - 1) +$$

$$+ \frac{R_2}{\lambda_2}(e^{\lambda_2 \cdot t} - 1) + \frac{R_2^*}{\lambda_2^*}(e^{\lambda_2^* \cdot t} - 1)$$

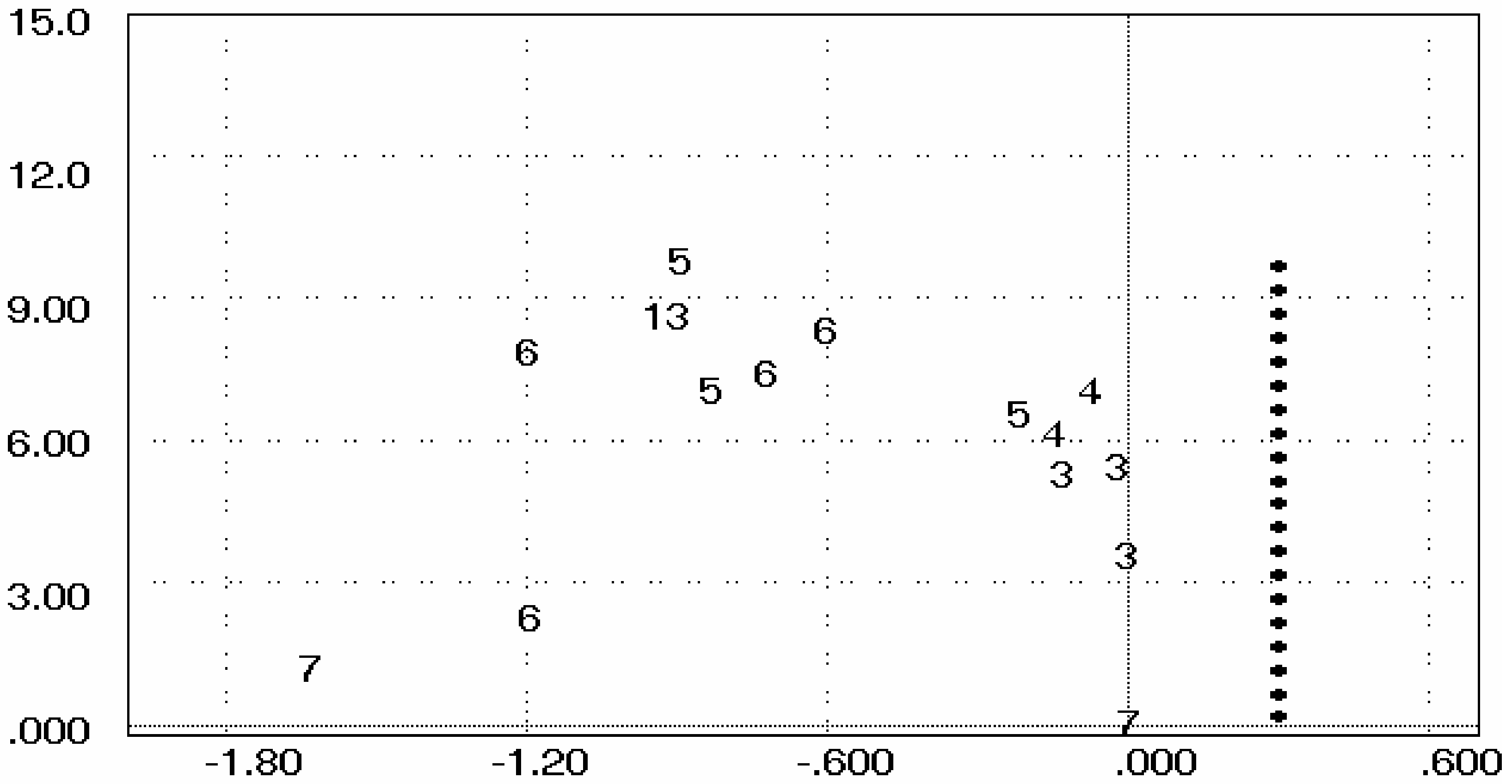
where the upperscript '*' denotes complex-conjugate, and:

$$\lambda_1 = -6.3886 + j7.3829 \qquad \lambda_2 = -.7672 + j6.9884$$

$$R_1 = -.2681 - j5.5145 \qquad R_2 = +.0181 - j.7350$$

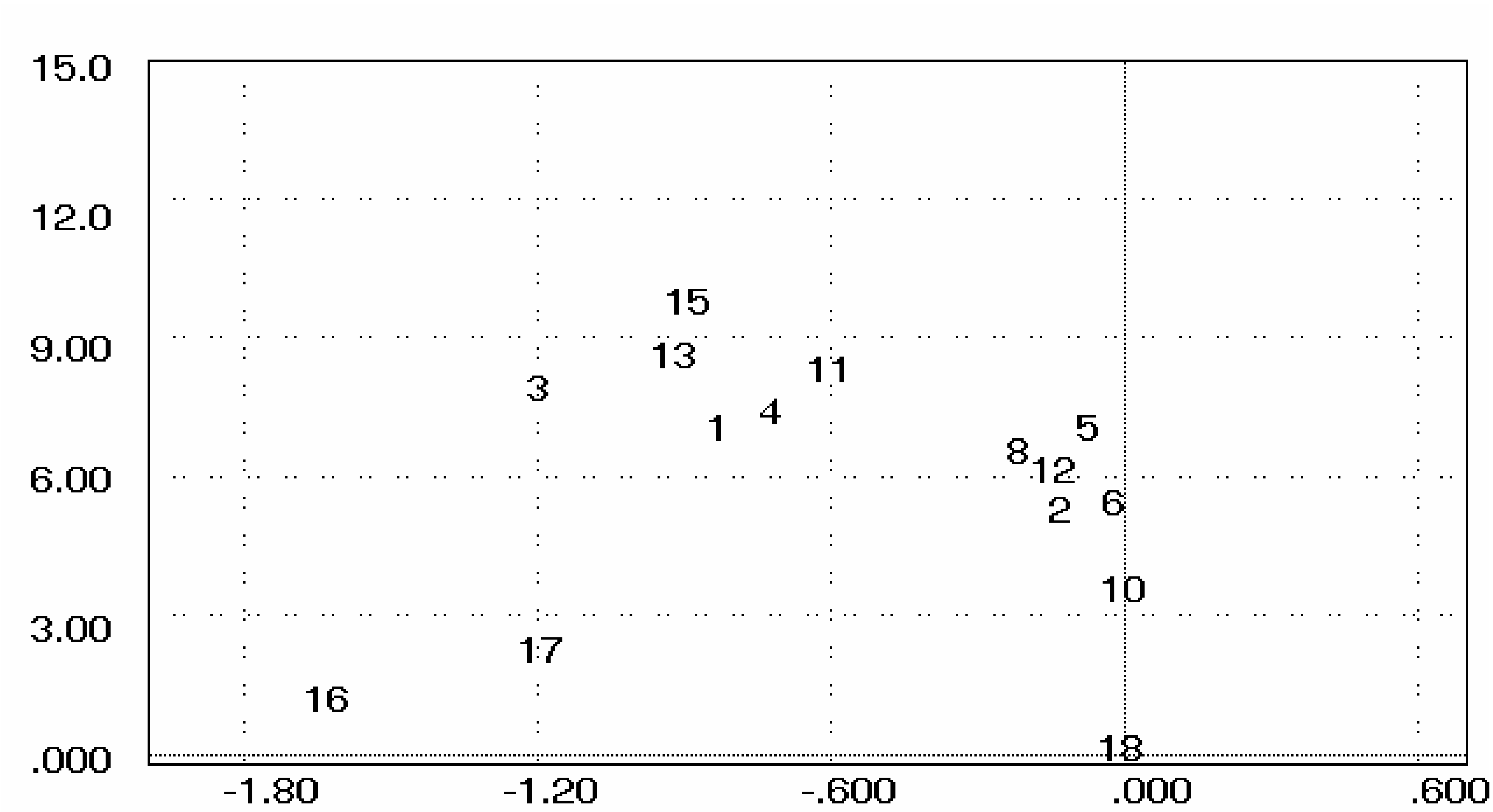
DPSE Results for $F_2(s)$

The 20 Initial Eigenvalue Estimates are Shown as Black Dots in the Right Half Plane



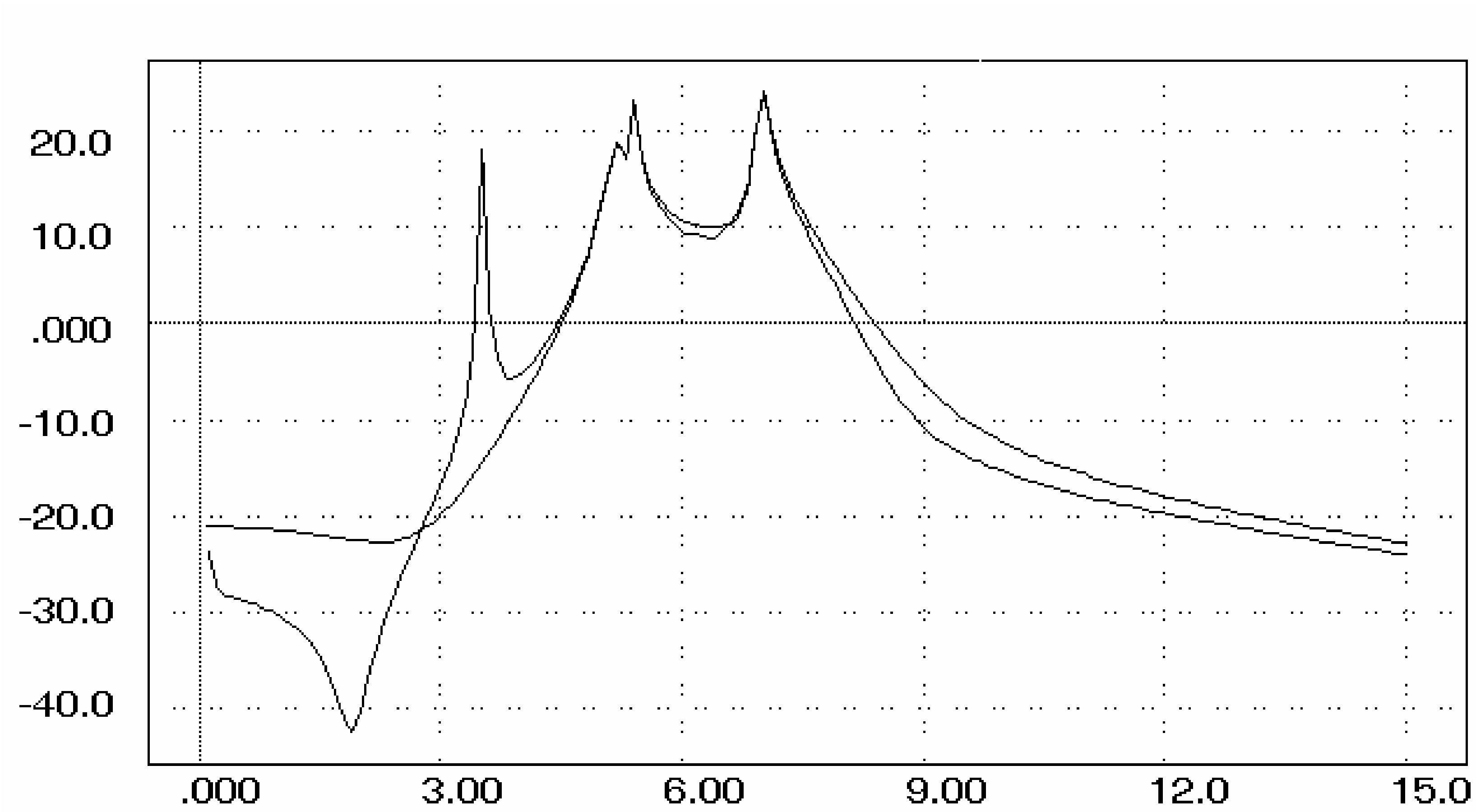
Loci of Dominant Poles in $F_2(s)$ with Information on the Number of Iterations Required for Accurate Convergence of Each Pole

DPSE Results for $F_2(s)$



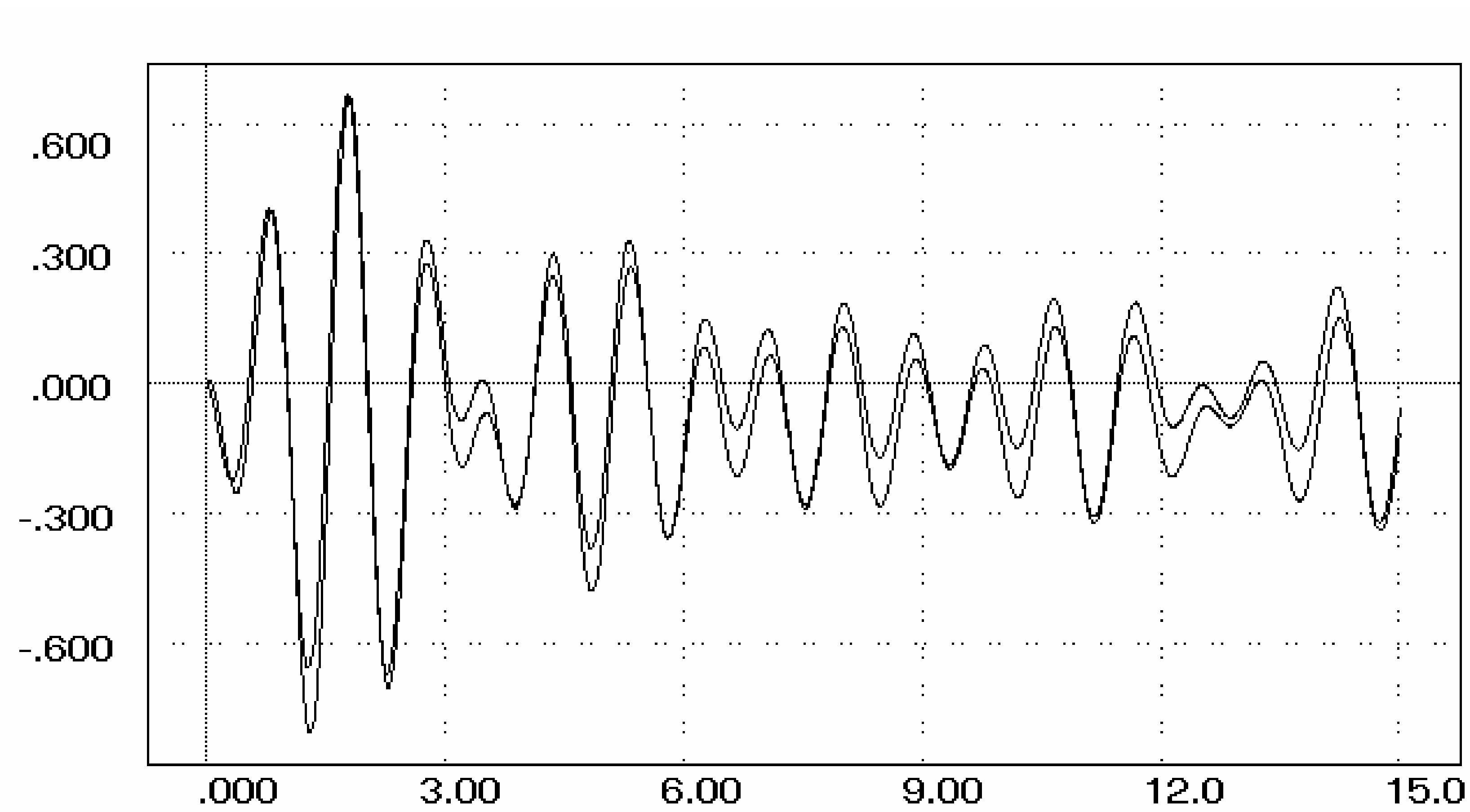
Loci of Dominant Poles in F_2(s) with Information on Ranking Order According to Residue Magnitude

DPSE Results: Modal Equivalent for $F_2(s)$



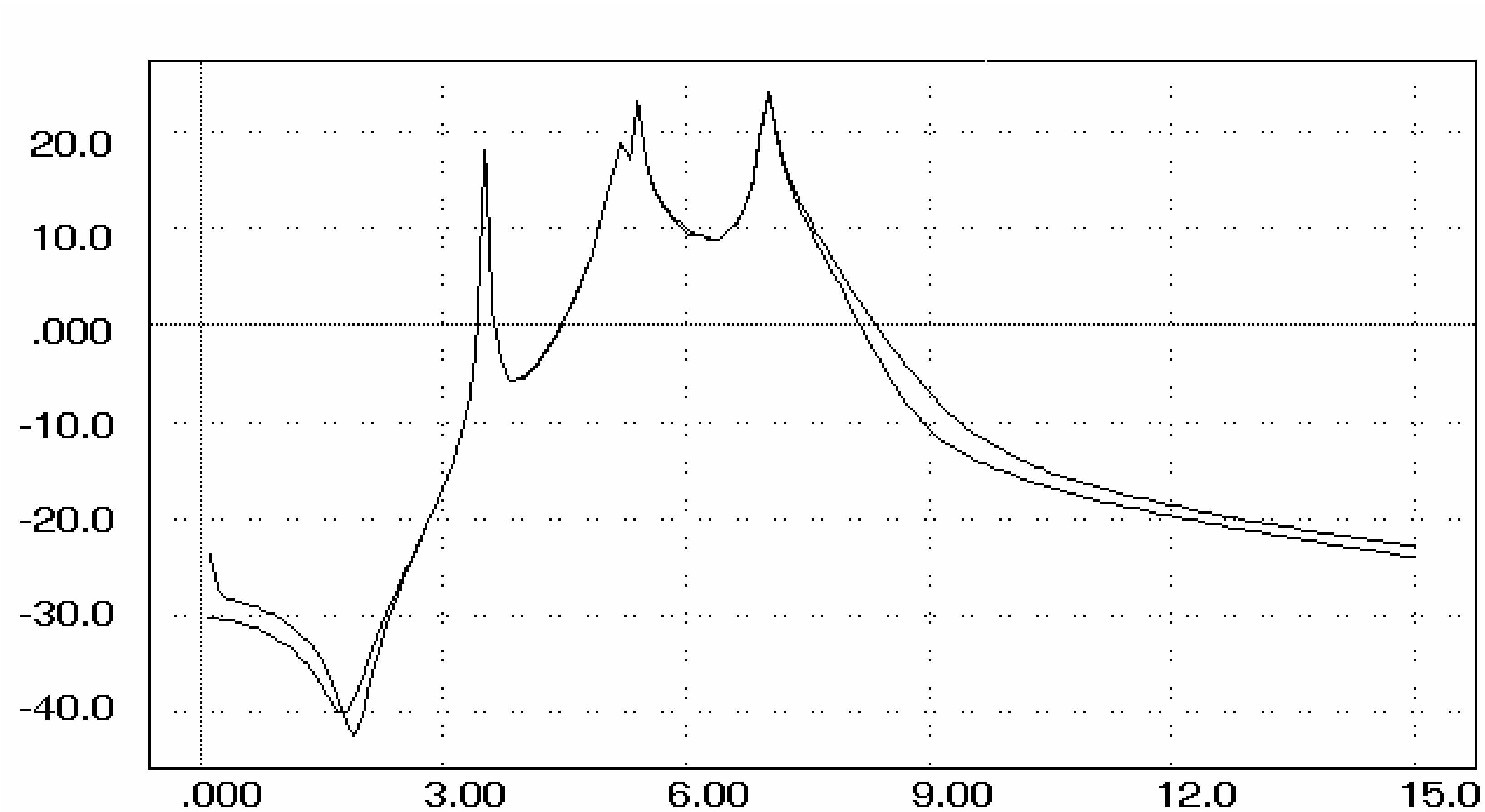
Bode Plots for both $F_2(s)$ and its 12[th] - order Modal Equivalent

DPSE Results: Modal Equivalent for $F_2(s)$



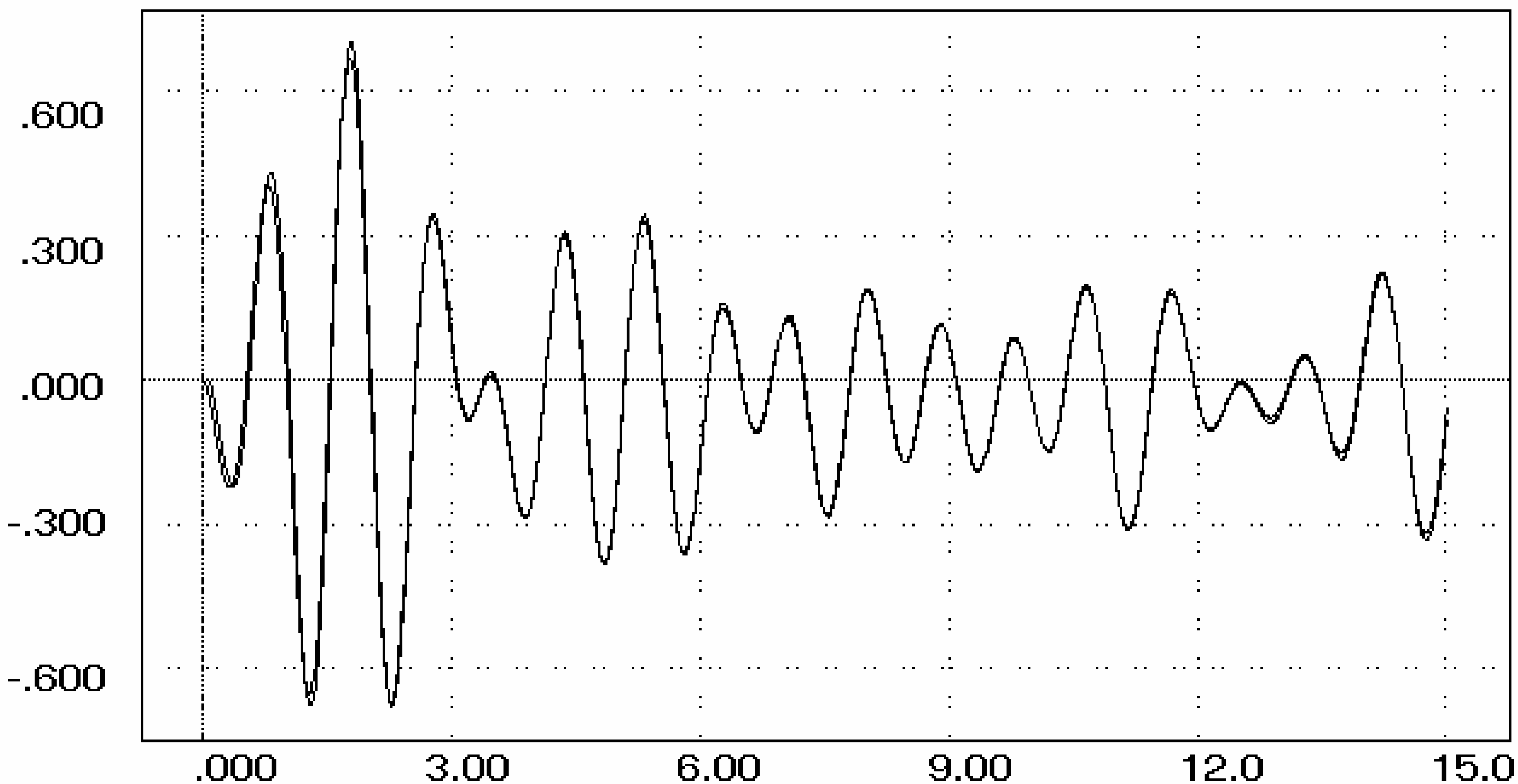
Step Response for both $F_2(s)$ and its 12th - order Modal Equivalent

DPSE Results: Modal Equivalent for $F_2(s)$



Bode Plots for both $F_2(s)$ and its 19th - order Modal Equivalent

DPSE Results: Modal Equivalent for $F_2(s)$



Step Response for both $F_2(s)$ and its19th - order Modal Equivalent

Conclusions

- The Dominant Pole Spectrum Eigensolver (DPSE) operates on the state-space or the sparser descriptor system models of large dynamic systems
- DPSE performs several Newton Raphson eigensolution processes, whose right/left subspaces of eigenvector estimates are re-orthogonalized at every iteration
- Convergence domain of a given eigensolution are larger for poles with high controllability/observability in $F(s)$
- Dominant and subdominant poles of the scalar $F(s)$ are obtained together with their residues
- May automatically produce modal equivalents of any scalar $F(s)$