Lecture 2: Stability Criteria

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ESAC DC Stability Toolbox Tutorial

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Version 2.1

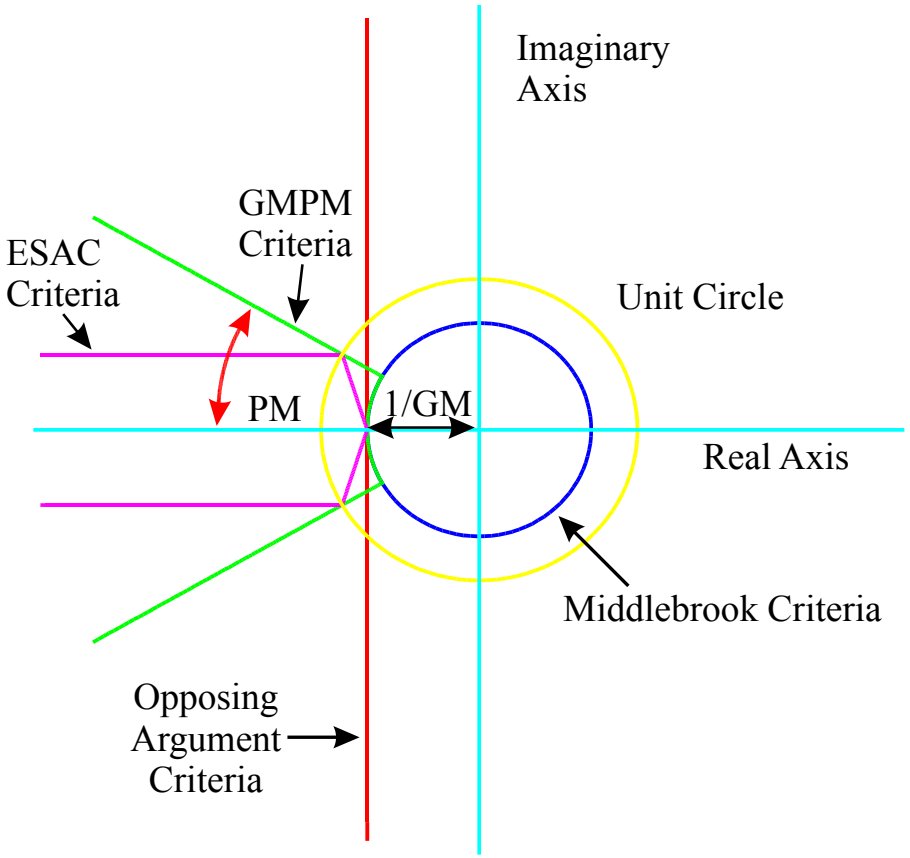
Lecture 2 Outline

- Comparison of Stability Criteria
- Design Specifications From Arbitrary Stability Criteria
- Generalized Impedance / Admittance Concepts

Stability Factoid

The source load system is stable provided that the evaluation of $Z_s Y_l$ along the Nyquist contour does not encircle -1

Stability Criteria



[2] S.D. Sudhoff, "Admittance Space Based Stability Specification," Proceedings of the 1998 ONR - Drexel-NSWC Workshop on Electric Shipboard System Modeling, Simulation and Control, June 22-23, 1998, Philadelphia, PA, USA

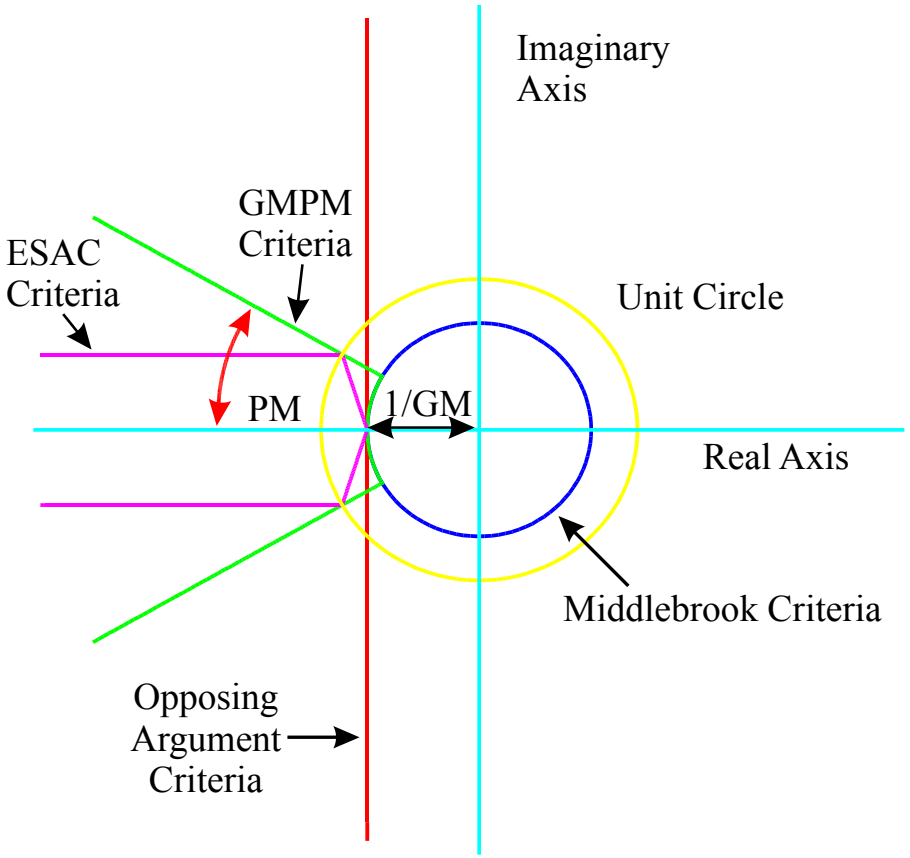
Purpose of Stability Criteria

- Primary
  - Basis for calculating load admittance spec from source impedance; or source impedance spec from load admittance
- Secondary
  - Check of stability

Comparison of Stability Criteria

- Cost of resulting design
- Amenability to arbitrary component grouping
- Amenability to formulation of design specification

Cost of Resulting Design

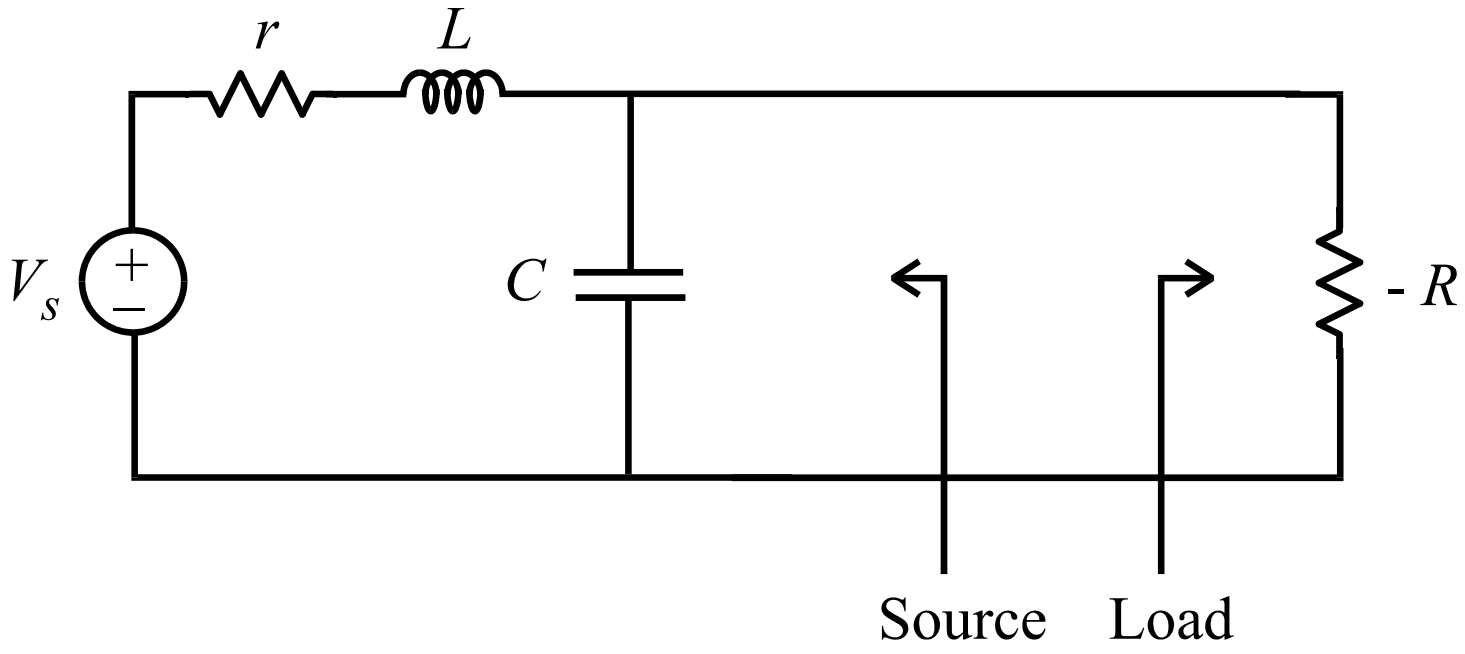


[2] S.D. Sudhoff, "Admittance Space Based Stability Specification," Proceedings of the 1998 ONR - Drexel-NSWC Workshop on Electric Shipboard System Modeling, Simulation and Control, June 22-23, 1998, Philadelphia, PA, USA

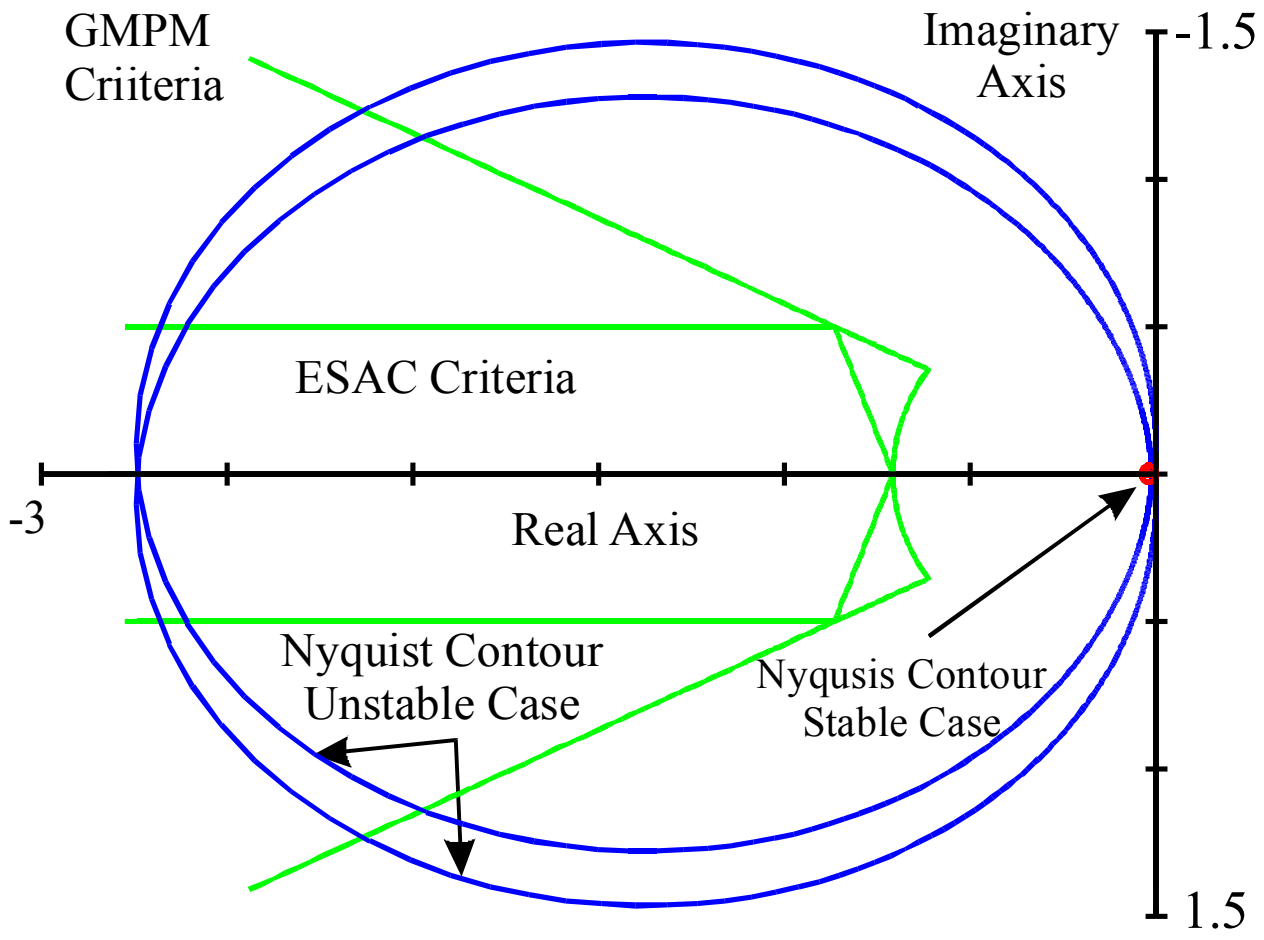
Cost of Resulting Design

- Middlebrook (Highest)
- Opposing Argument
- Gain/Phase
- ESAC (Lowest)

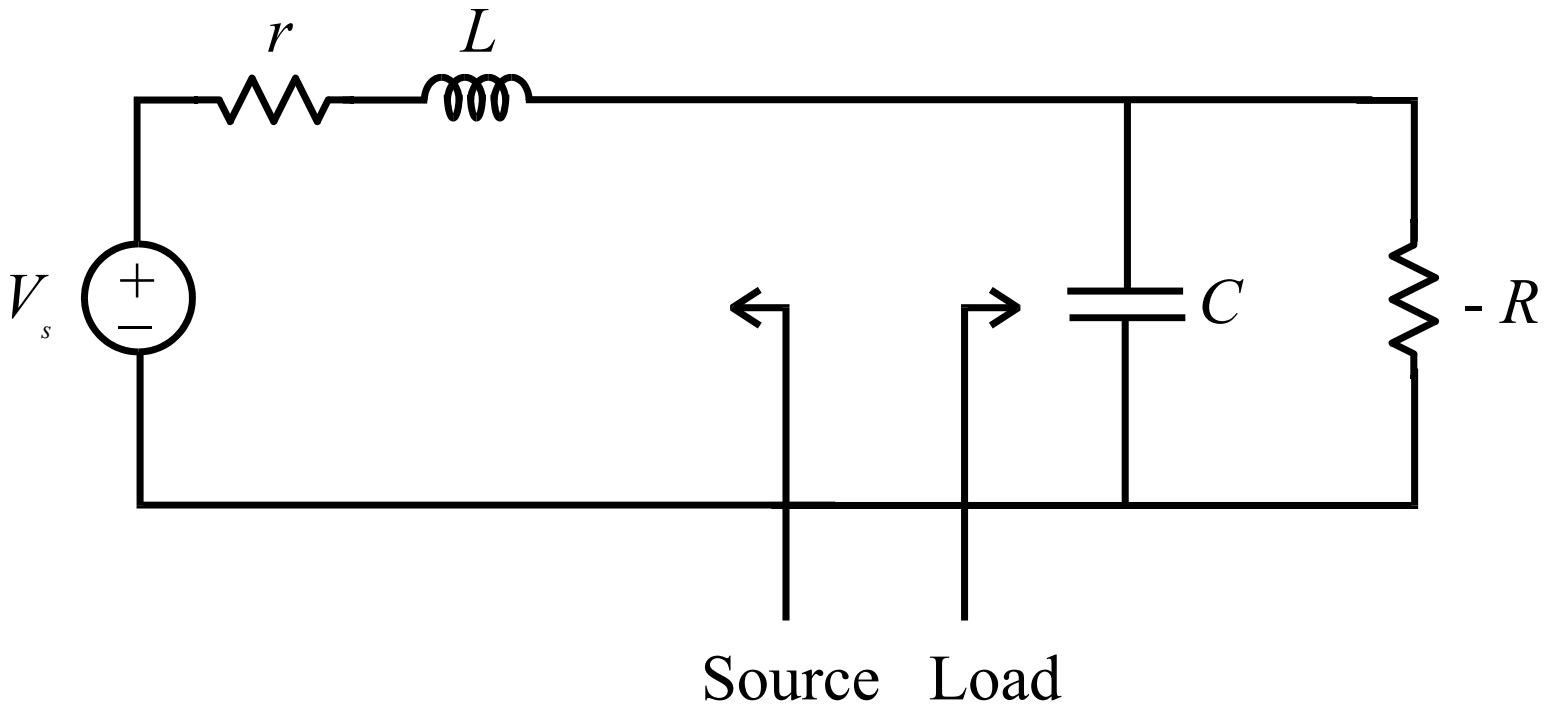
Grouping: Case Study 1



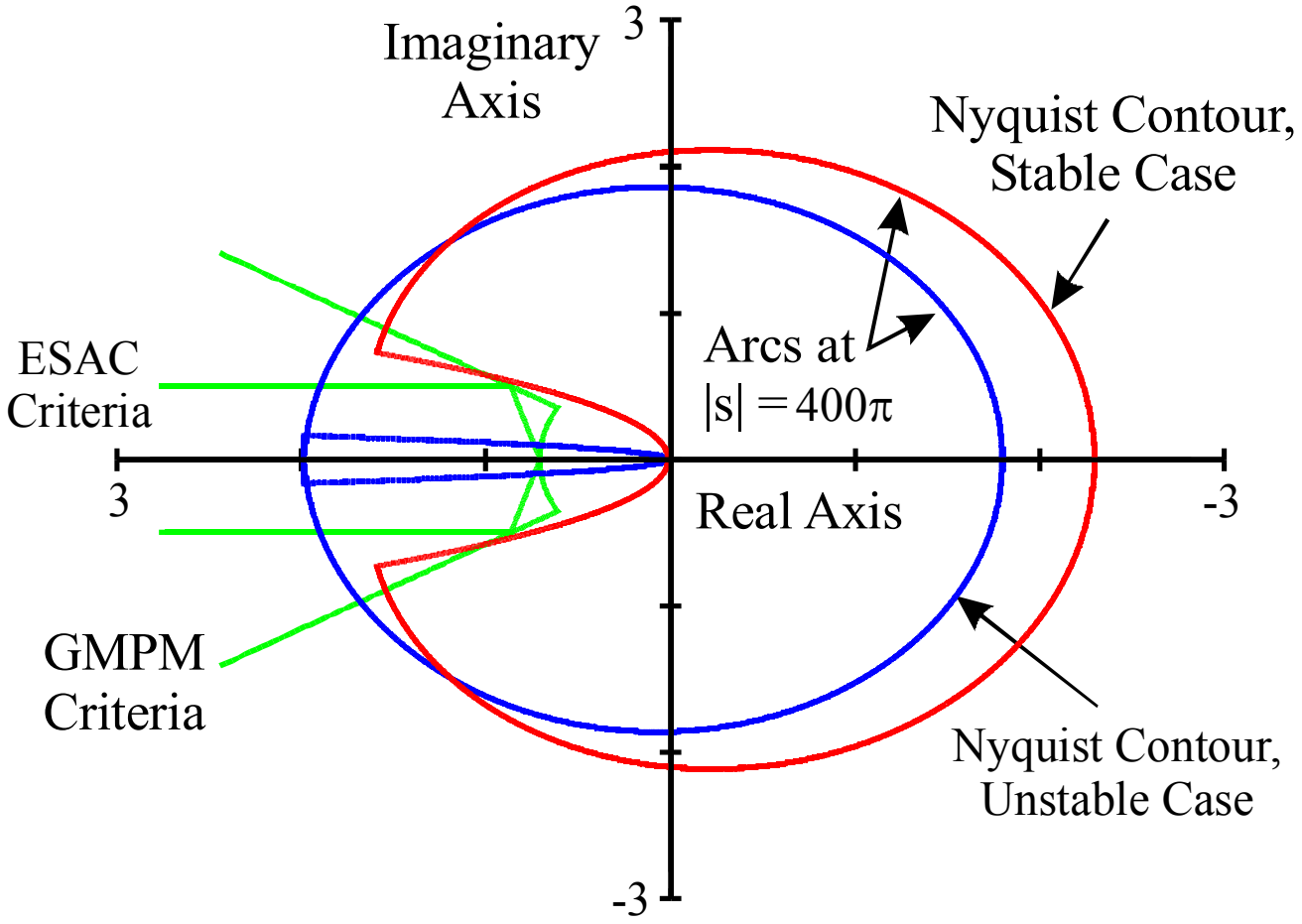
Grouping: Case Study 1 - Nyquist Plane Results



Grouping: Case Study 2



Grouping: Case Study 2 Nyquist Plane Results



Grouping: Summary

- ESAC Criteria much less sensitive to grouping than other proposed criteria

Design Specification: Middlebrook

- Suppose Z_s known
- Design specification on load becomes

$$|Y_l| < \frac{1}{GM\,|Z_s|}$$

- Alternately, could come up with specification on load impedance

Design Specification: Gain and Phase Margin Criteria

- Design specification based on

$$|Y_l||Z_l| < \frac{1}{GM}$$

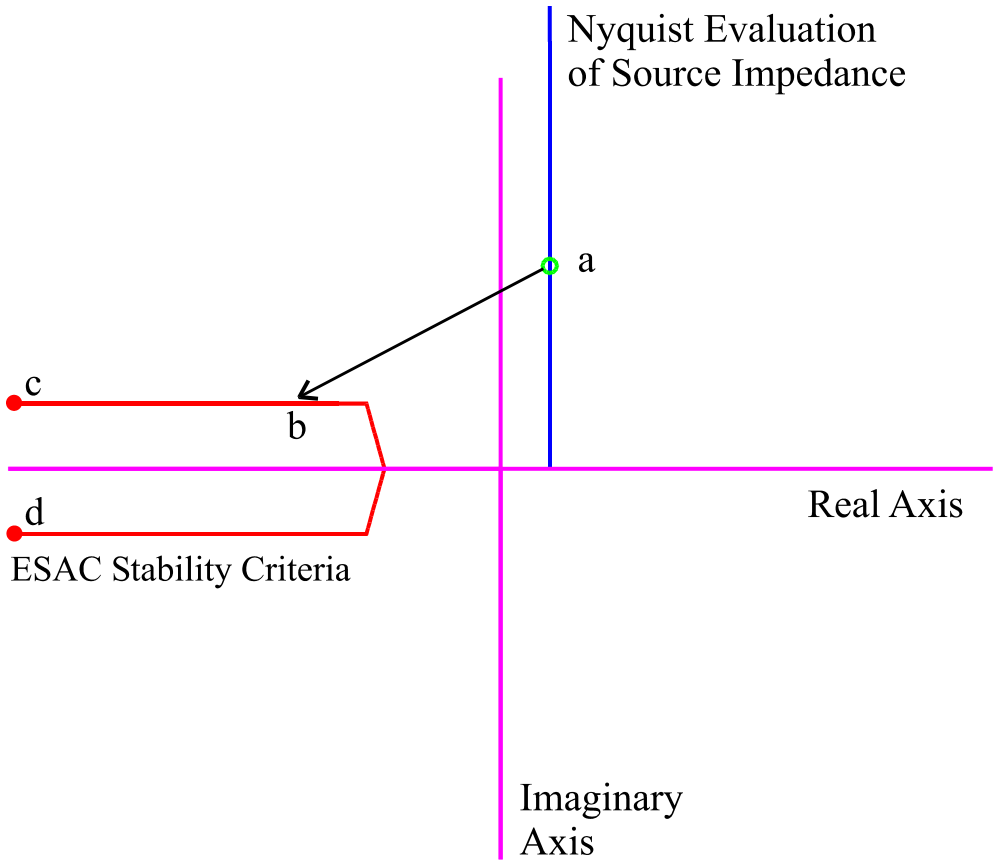
$$\angle Y_l(s) \underset{\angle}{+} \angle Z_s(s) \le \left(180^o - PM\right) \quad \text{and}$$

$$\angle Y_l(s) \underset{\angle}{+} \angle Z_s(s) \ge \left(-180^o + PM\right)$$

$$\angle x \equiv angle(\mathrm{Re}(x) + j\,\mathrm{Im}(x))$$

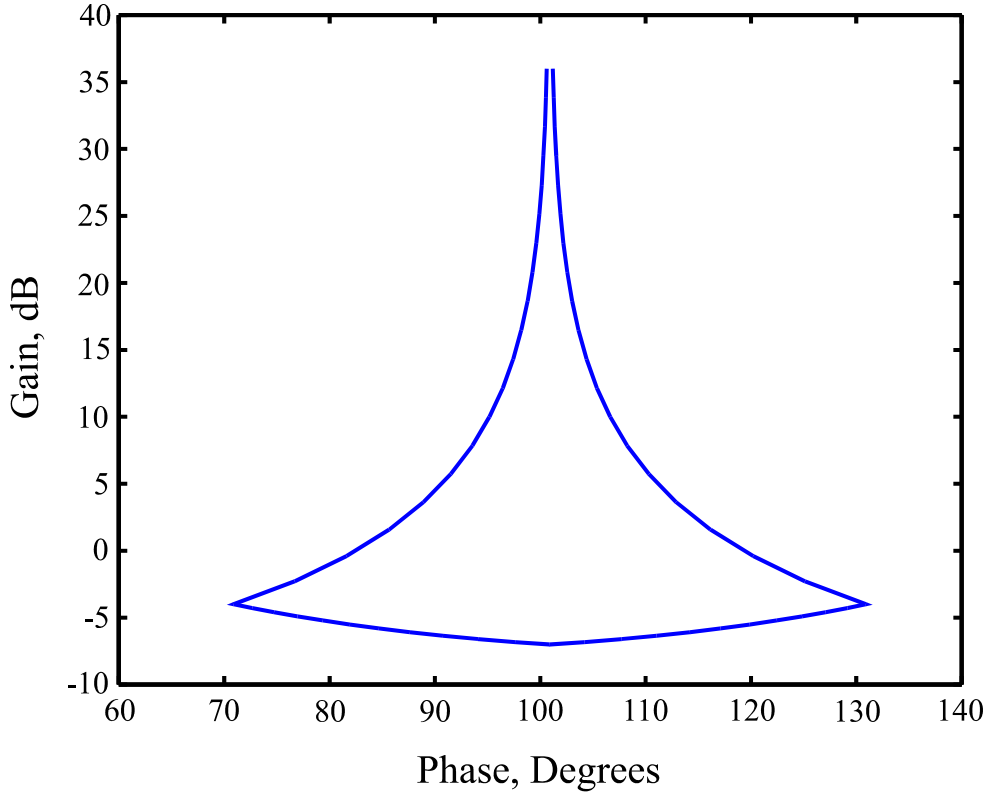
Design Specification: ESAC Criteria

Construction of a load admittance specification at a point

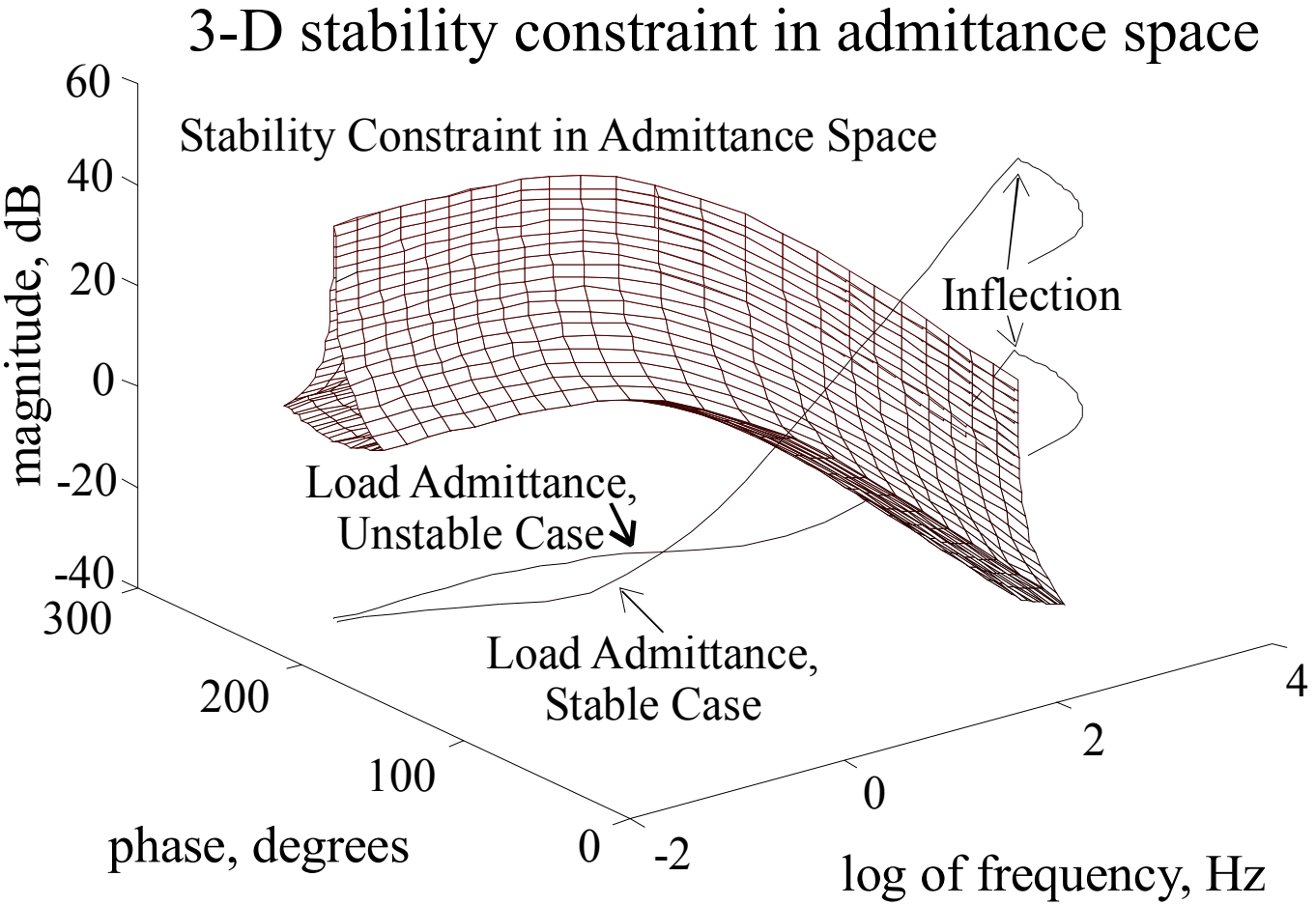


Design Specification: ESAC Criteria

Construction of load admittance constraint at a frequency



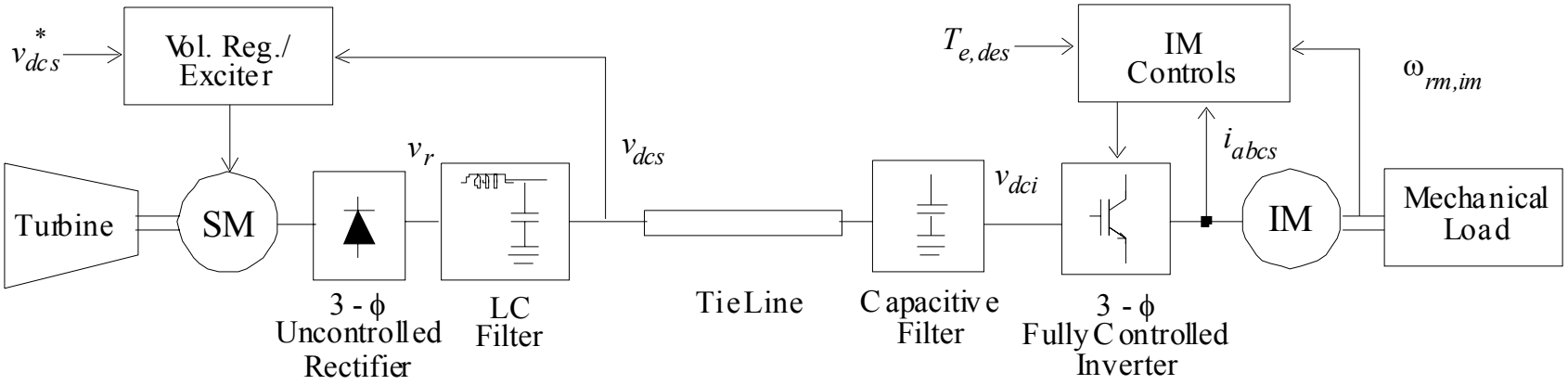
Design Specification: ESAC Criteria



Comments on Stability Criteria

- Design Cost (Highest to Lowest)
  - Middlebrook, Opposing Argument, GMPM, ESAC
- Component Grouping
  - ESAC criteria much less sensitive to grouping
- Translation to Design Specification
  - Middlebrook most readily used
  - GMPM not bad
  - ESAC requires toolbox

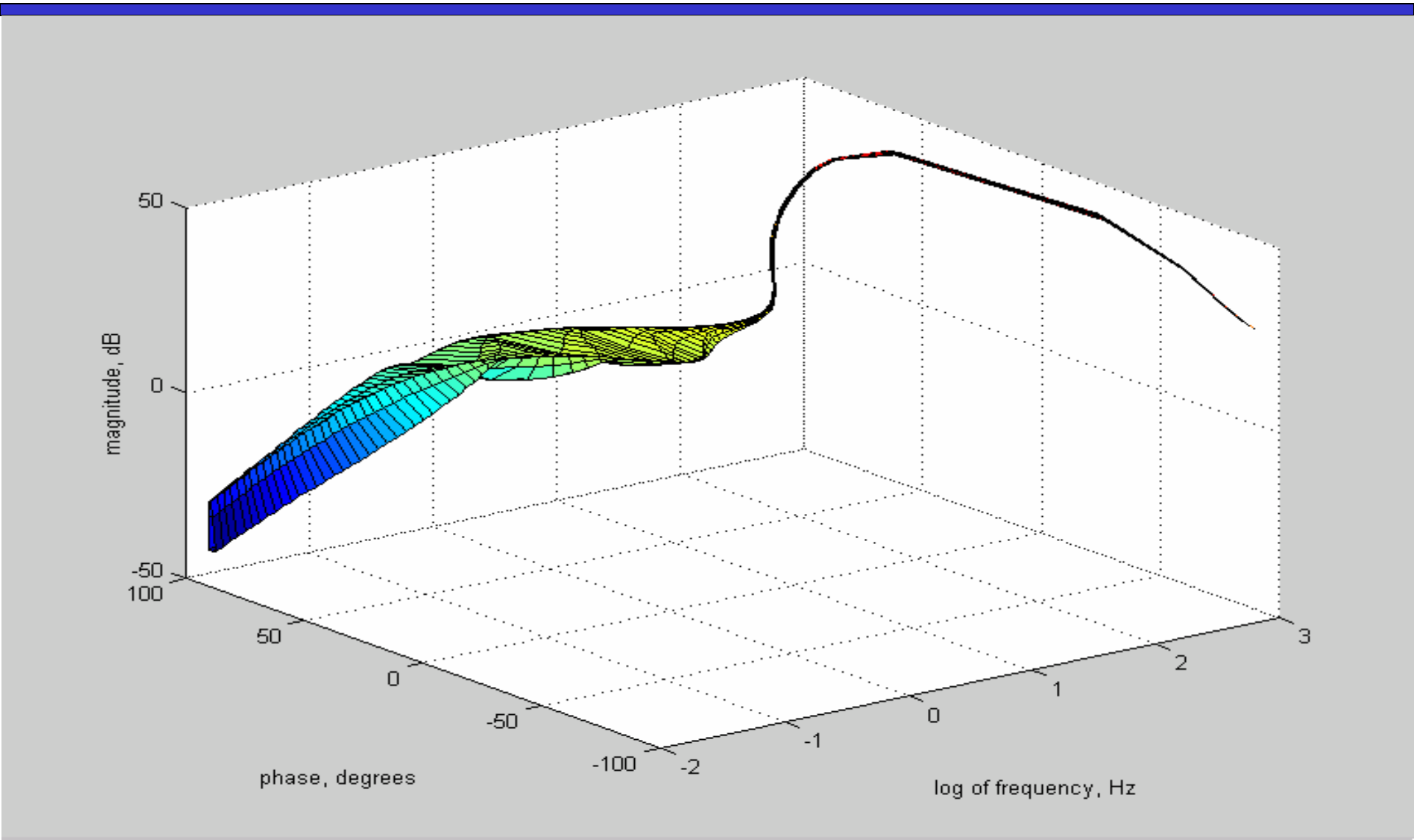
Dealing with Reality: Example System



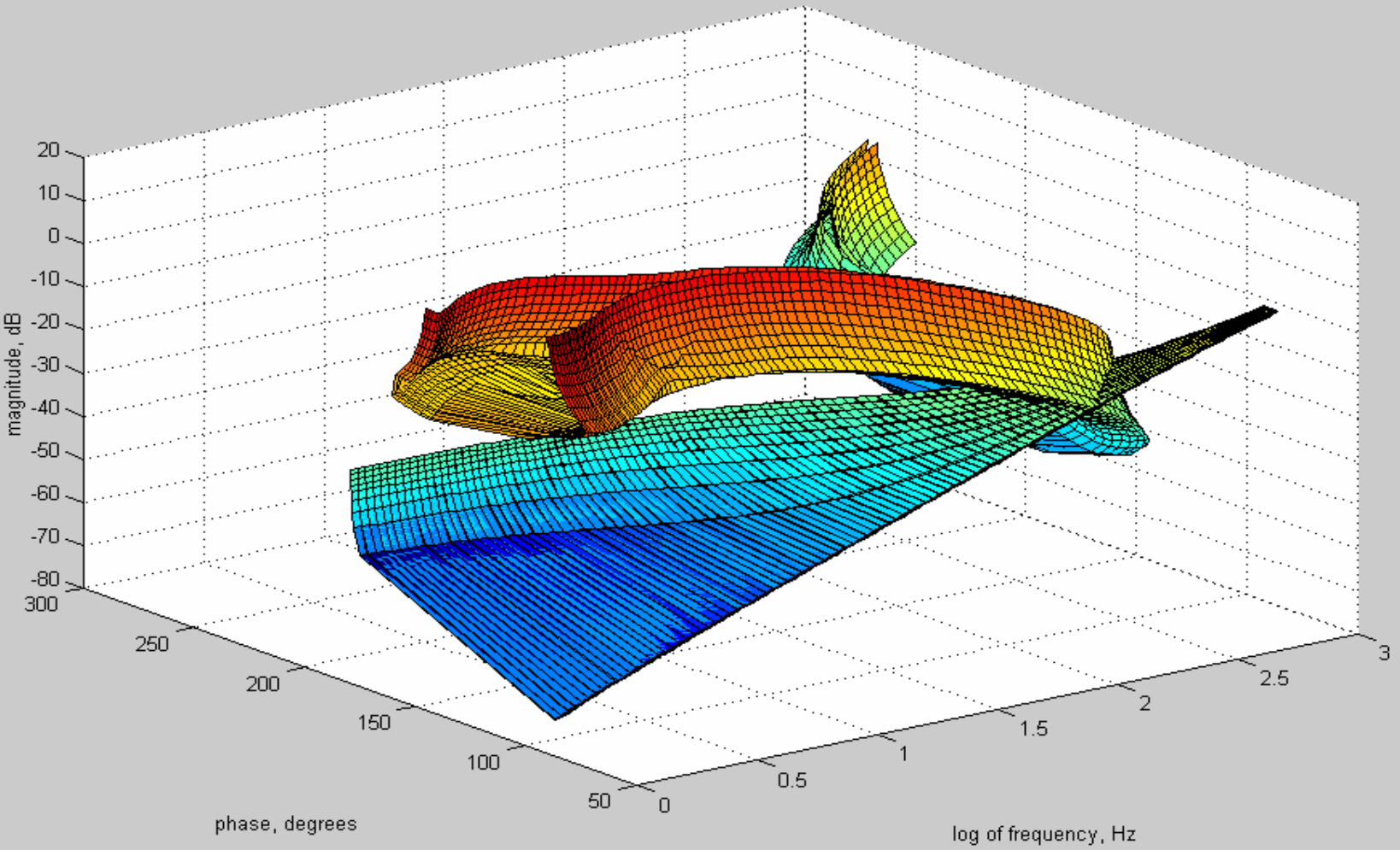
Generalized Source Impedance

- Speed: 0.9-1.1 p.u.
- Power: 0-1.1 p.u.
- Voltage: 0.95-1.05 p.u.
- Number of Plants Considered: 125

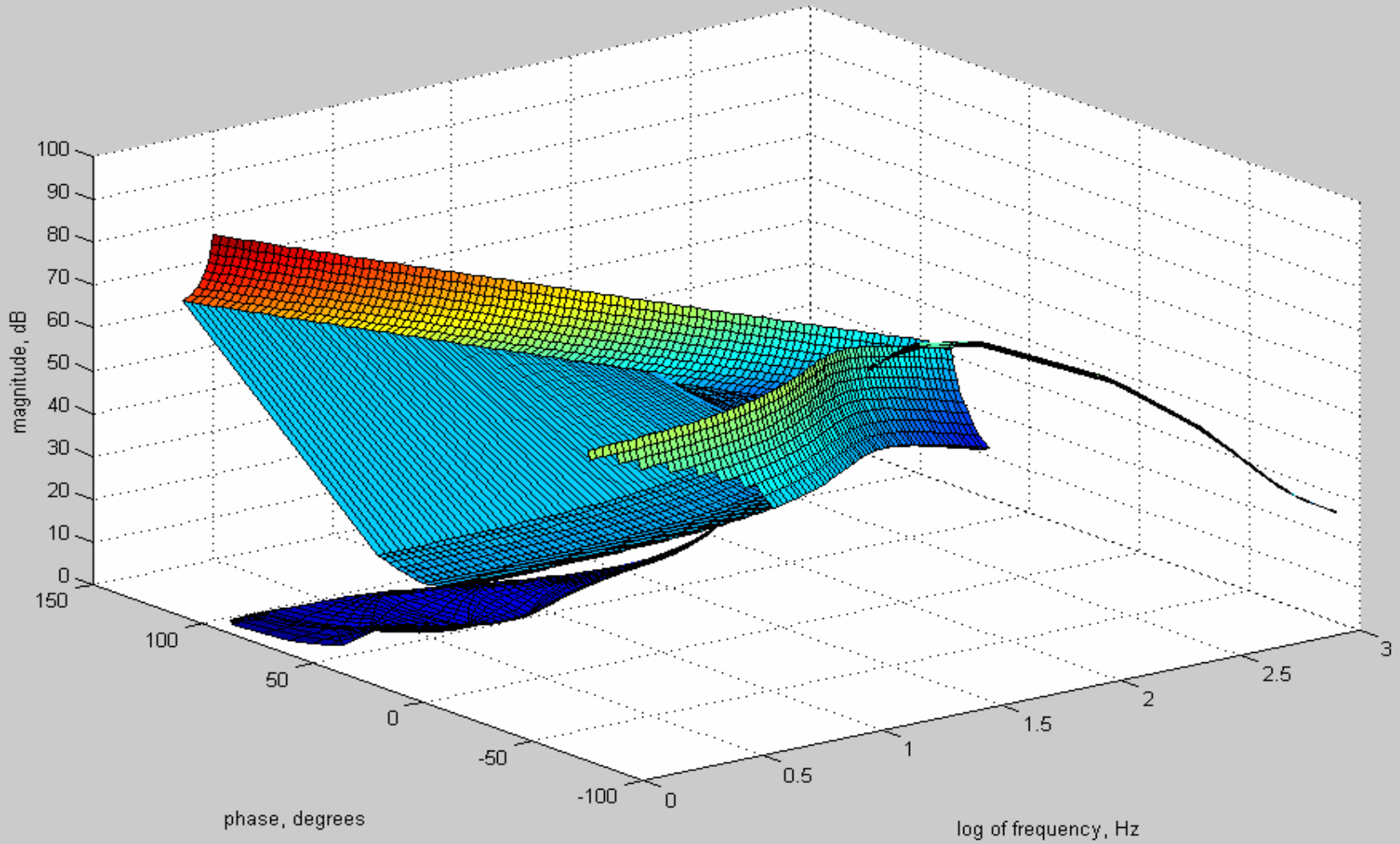
Generalized Source Impedance



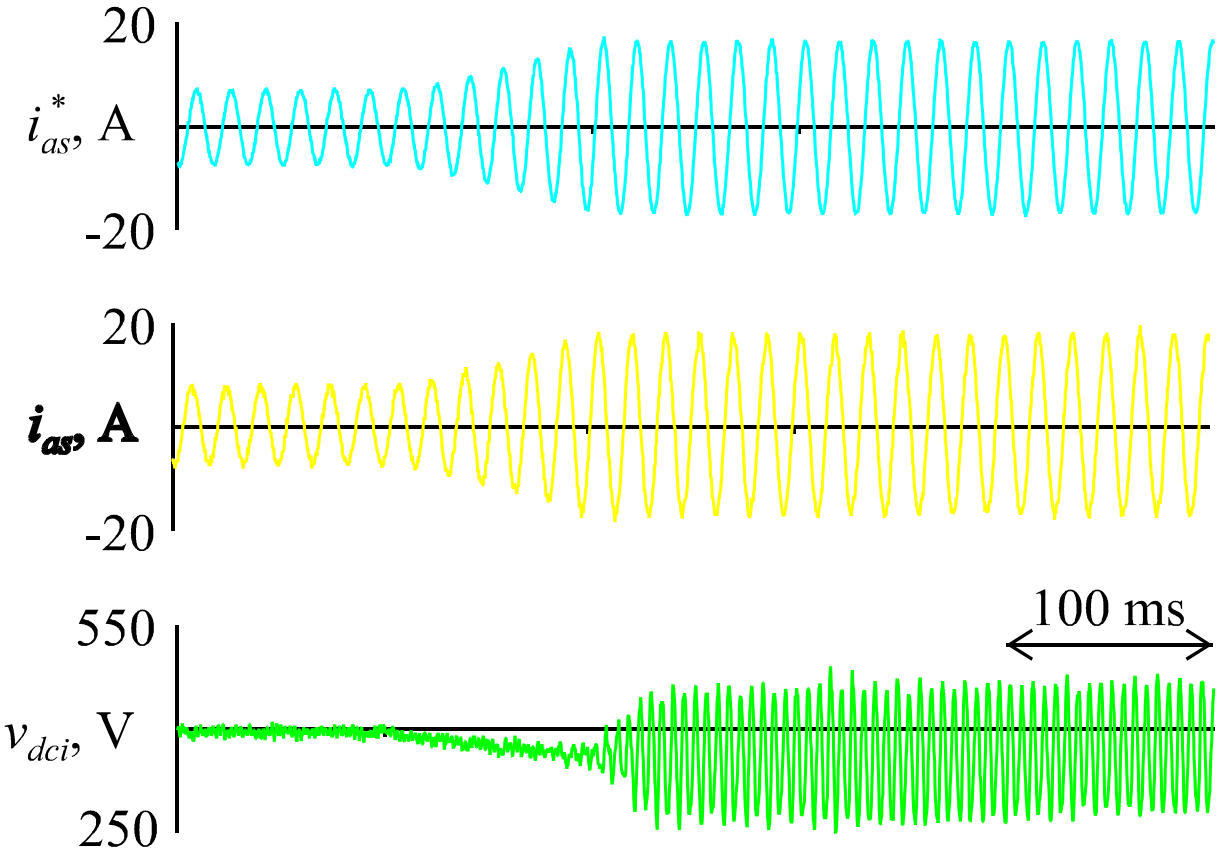
Generalized Load Admittance and Load Admittance Constraint



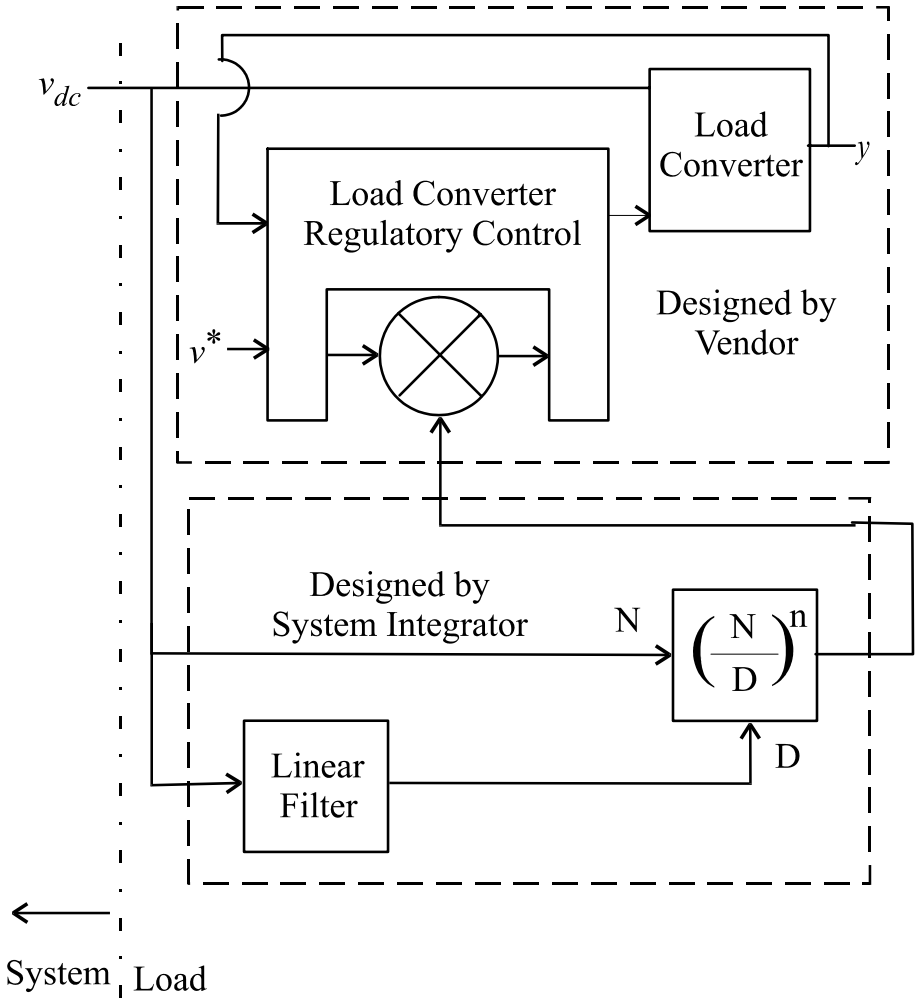
Generalized Source Impedance and Source Impedance Constraint



Measured Performance



Mitigation: The Nonlinear Stabilizing Control Architecture (NSCA)

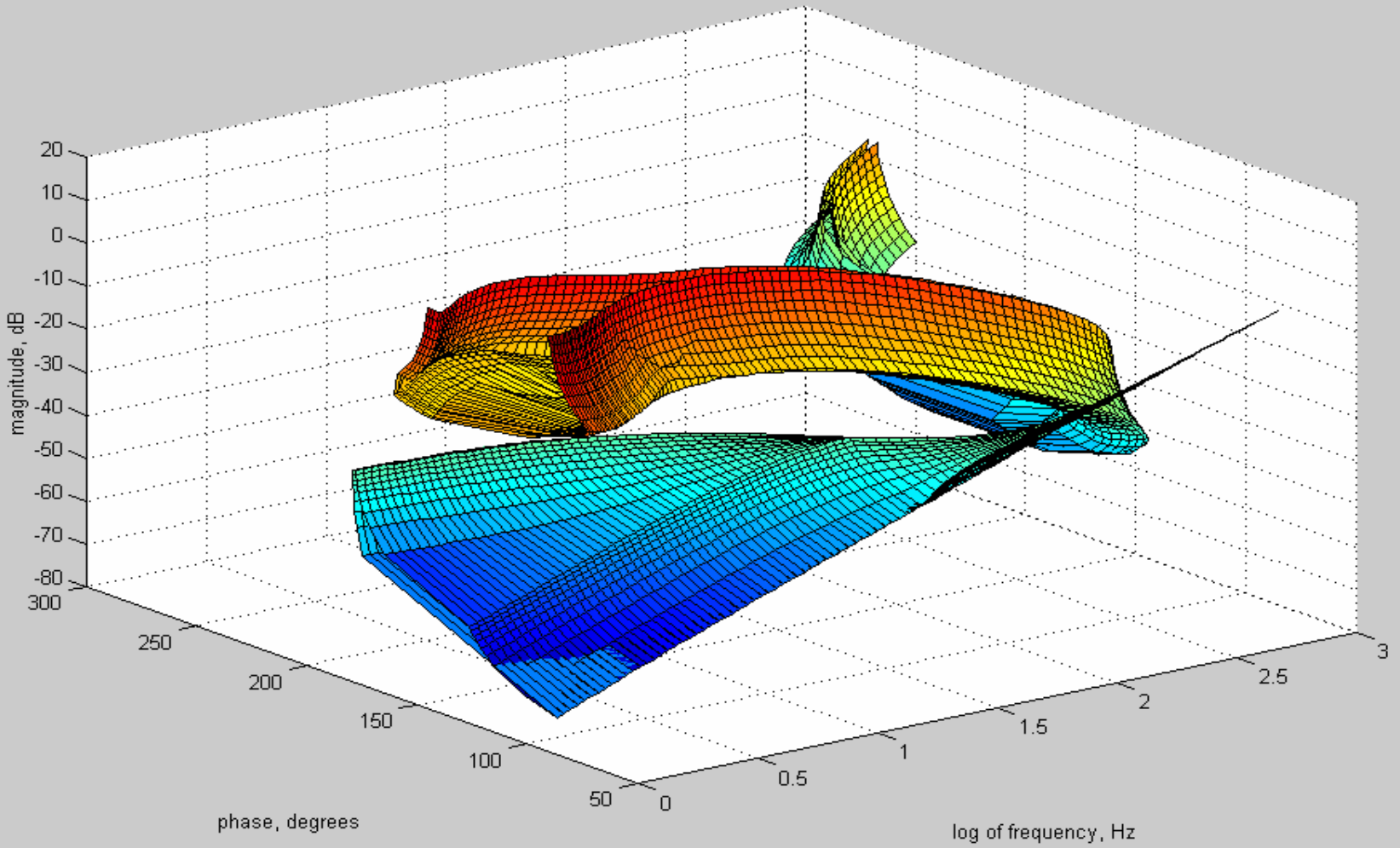


[3] S.D. Sudhoff, K.A. Corzine, S.F. Glover, H.J. Hegner, and H.N. Robey, "DC Link Stabilized Field Oriented Control of Electric Propulsion Systems," *IEEE Transactions on Energy Conversion,* Vol. 13, No. 1, March 1998.

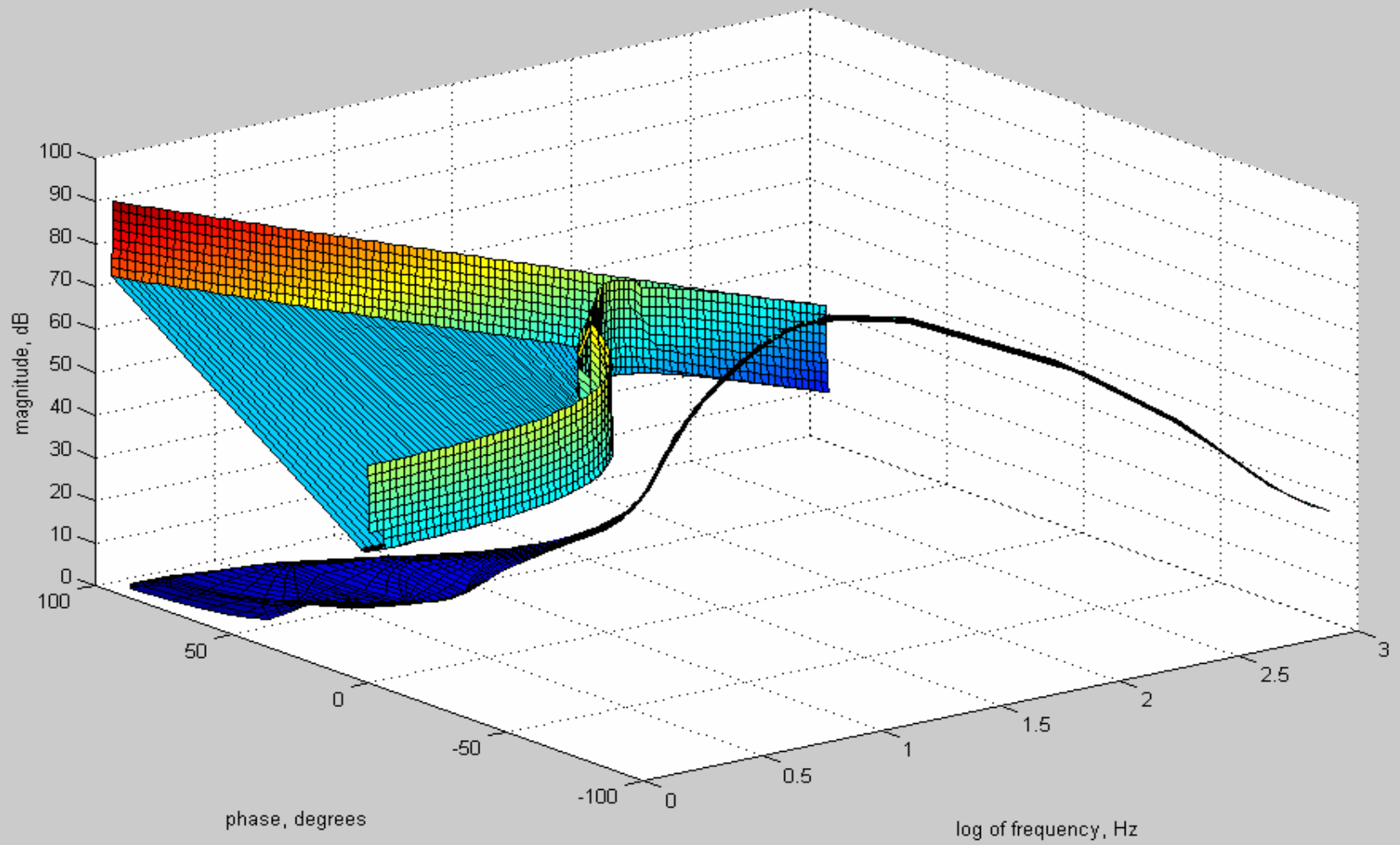
[4] S.D. Sudhoff, "Control of Power Electronics Based Systems" Proceedings of the 1998 ONR -Drexel-NSWC Workshop on Electric Shipboard System Modeling, Simulation and Control, June 22-23, 1998, Philadelphia, PA, USA

[5] S.D. Sudhoff, S.F. Glover, "Nonlinear Stabilizing Control for Power Electronic Based Systems," U.S. Patent No. 6,051,941, April 18, 2000. International Patents Applied For.

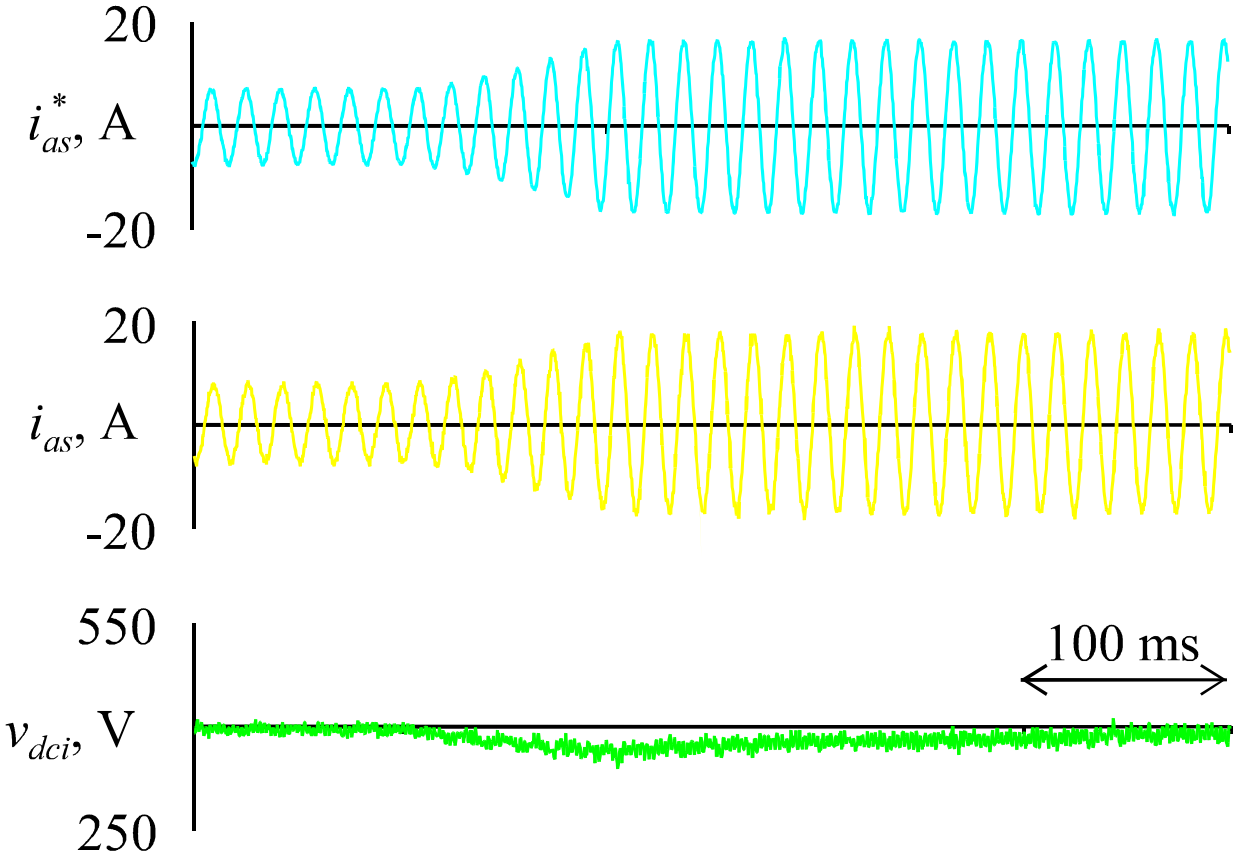
Generalized Load Admittance and Constraint with NSCA



Generalized Source Impedance and Constraint with NSCA



Measured Performance with NSCA



Conclusions

- ESAC Criteria
  - Leads to Less Expensive / Higher Performance Designs
  - Facilitates Modularity in Design Process
- 3-Dimensional Admittance/Impedance Space Approach
  - Allows ESAC (and Arbitrary) Stability to Be Used
  - Facilitates Specification of Source Given Load
  - Facilitates Specification of Load Given Source