



# Outlines

## STABILITY ANALYSIS OF NONLINEAR SYSTEMS (EEEN50100)

Prof. Federico Milano

Email: [federico.milano@ucd.ie](mailto:federico.milano@ucd.ie)

Tel.: 01 716 1844

Room 157a – Engineering & Materials Science Centre

School of Electrical & Electronic Engineering

University College Dublin

Dublin, Ireland



## Contents

- Basic stability concepts
- Power flow analysis (numerical stability)
- Voltage stability
- Angle stability
- Frequency stability
- Impact on stability of distributed generation and other devices
- Advanced stability concepts



## Basic Stability Concepts

- Nonlinear autonomous systems
- Equilibrium points
- Stability regions
- Bifurcation theory



## Power Flow Analysis

- Power system model and background
- Equations and solution techniques
- Numerical vs. system stability
- Modal analysis
- Contingency analysis



# Voltage Stability

- Definitions
- Basic concepts:
  - Saddle-node bifurcation
  - Limit-induced bifurcation
- Homotopy methods and Continuation Power Flow (CPF)
- Direct methods (based on optimization techniques)
- Indices
- Protections and controls
- Impact of wind generation
- Real case example: August 2003 North American blackout



## Angle Stability (I)

- Small-signal stability analysis:
  - Definitions
  - Hopf Bifurcations
  - Control and mitigation
  - Practical applications
- Real case example: August 1996 WSCC blackout



## Angle Stability (II)

- Transient Stability (large-disturbance):

Definitions

Time domain analys

Direct Methods:

Lyapunov's function (energy function)

Equal Area Criterion

- Impact of wind generation
- Impact of energy storage devices
- Real case example: November 1965 Northeast US and Canada clackout
- Real case example: May 1997 Chilean blackout



## Frequency Stability

- Definitions
- Basic concepts
- Protections and controls
- Impact of wind generation
- Impact of energy storage devices
- Impact of frequency-controlled loads
- Real case example: September 2003 Italian blackout
- Real case example: November 2006 European blackout



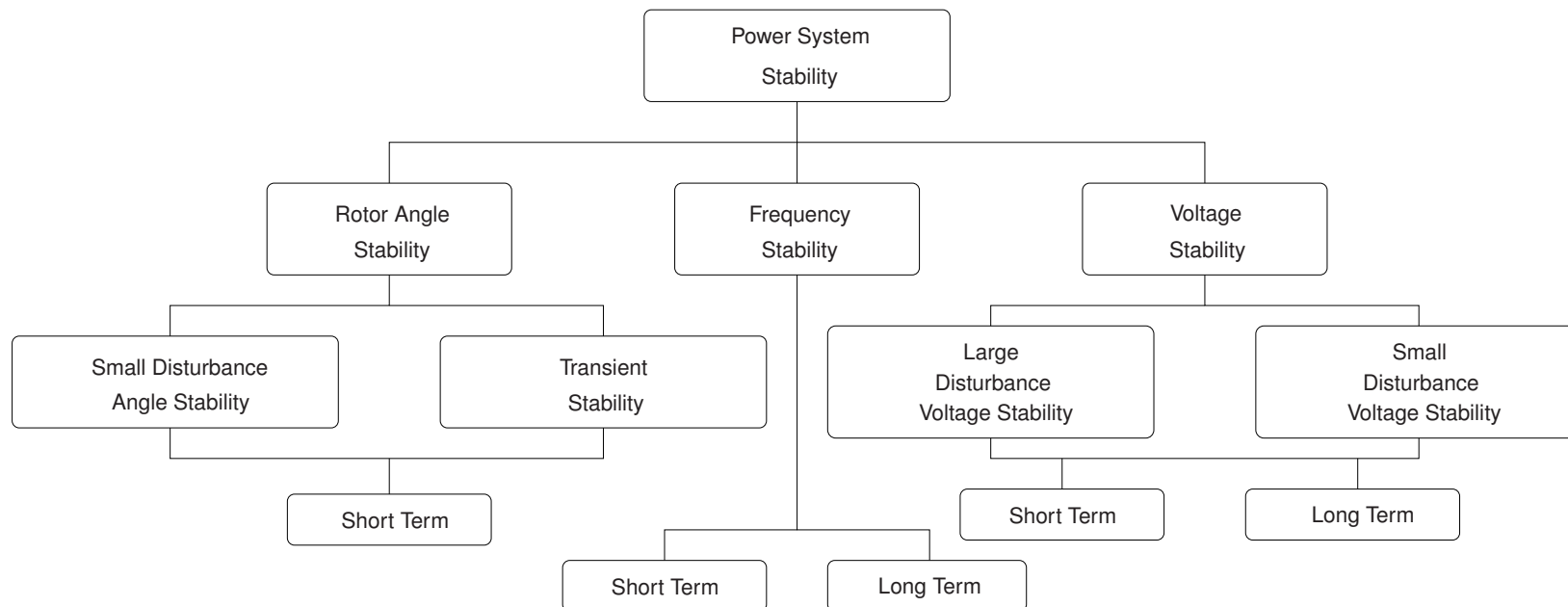


## Advanced Stability Concepts

- Fundamental matrix solution
- Monodromy matrix and Floquet's multipliers
- Limit cycles and routes to chaos
- Spectral analysis and Lyapunov exponents
- Stability of non-autonomous systems
- Hybrid-systems (both continuous and discrete variables)
- Impact of delays on power system stability
- Impact of stochastic processes on power system stability

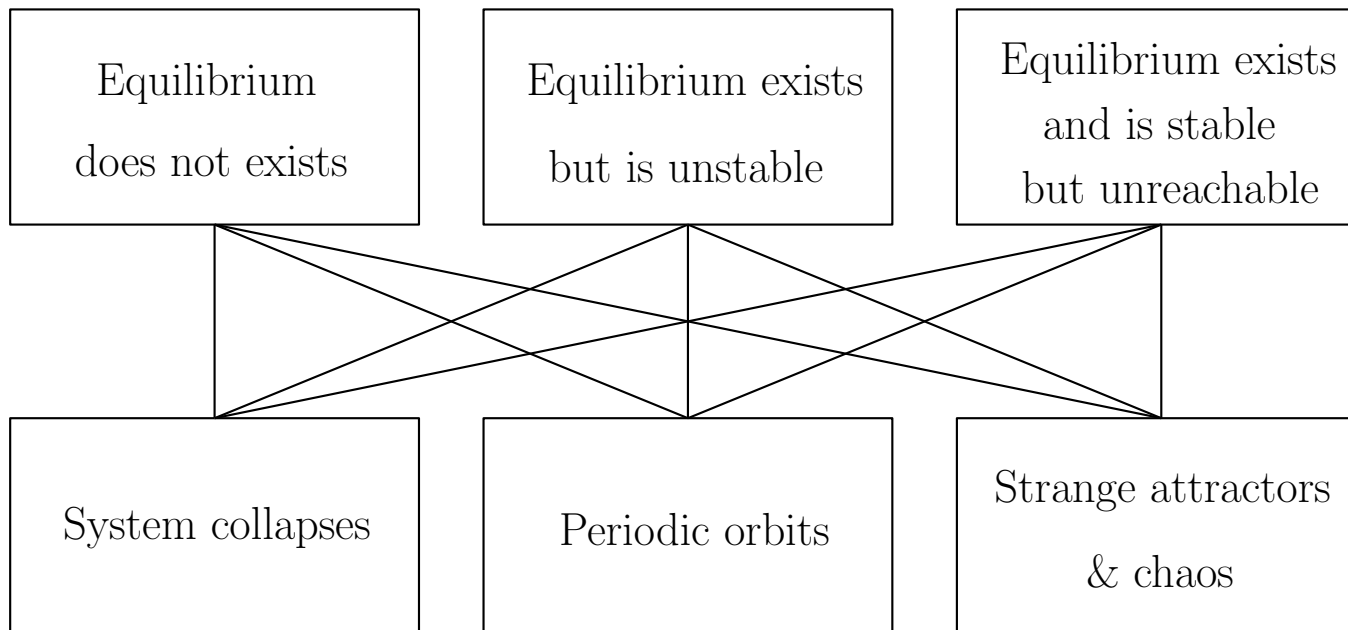
## Taxonomy of Power System Stability Phenomena

- IEEE-CIGRE classification (IEEE/CIGRE Joint Task Force on Stability) Terms and Definitions, “Definitions and Classification of Power System Stability”, *IEEE Trans. Power Systems and CIGRE Technical Brochure 231*, 2003:



## Taxonomy of Nonlinear System Stability

- Classification based on the equilibrium and following trajectory.





## Evaluation

- The evaluation will be based on reports prepared individually and autonomously by each student.
- The outlines of the assignments are provided on the webpage of the module.
- A tutorial on the software tool and on how to prepare the reports will be given during the lectures.



## Bibliography (Power Systems)

- P. Kundur, *Power System Stability and Control*, Mc Graw Hill, 1994.
- C. A. Cañizares, Editor, *Voltage stability assessment: concepts, practices and tools*, IEEE-PES Power System Stability Subcommittee Special Publication, SP101PSS, May 2003.
- M. Ilić and J. Zaborszky, *Dynamics and Control of Large Electric Power Systems*, Wiley, New York, 2000.
- EirGrid & Soni, *All Island TSO Facilitation of Renewables Studies*, 2012. Available at [www.eirgrid.com/media/FacilitationRenewablesFinalStudyReport.pdf](http://www.eirgrid.com/media/FacilitationRenewablesFinalStudyReport.pdf)
- Journal papers and technical reports.
- Module slides available on line.



## Bibliography (Stability Analysis)

- J. Stoer and R. Bulirsch, *Introduction to Numerical Analysis*, Second Edition, Springer-Verlag, 1993.
- R. Seidel, *Practical Bifurcation and Stability Analysis*, Springer-Verlag, New York, 1994.
- Journal papers and technical reports.
- Module slides available on line.



## Links

- Web page of the course:

<http://faraday1.ucd.ie/stability.html>