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School of Engineering
IEFE Institute of Energy Systems and Fluid Engineering

Dynamic stability of power systems

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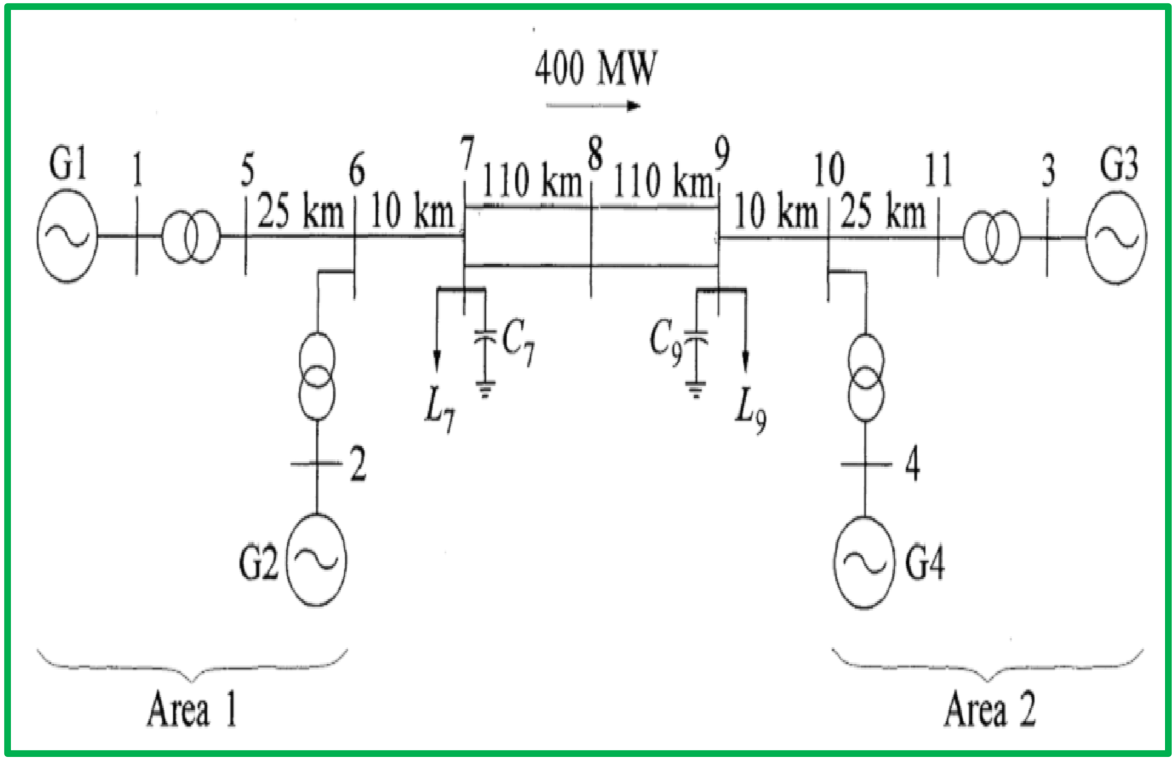
Agenda

- Fundamentals of Dynamic Stability
- Oscillation Effects in Power Systems
- How to Deal with this Problem

Fundamentals on Dynamic Stability

Dynamic Power System Model

- The behaviour of a power system can be described by
  - A set of n first order nonlinear ordinary differential equations
  - The outputs of interest to be observed



$$\dot{x}_i = f_i(x_i, u_j, t) \qquad i = 1, 2, \ldots, n$$

$$y_k = g_k(x_i, u_j) \qquad j = 1, 2, \ldots, r$$

$$k = 1, 2, \ldots, m$$

where

n order of the system

r number of inputs

m number of outputs

Linear Model and its Modes

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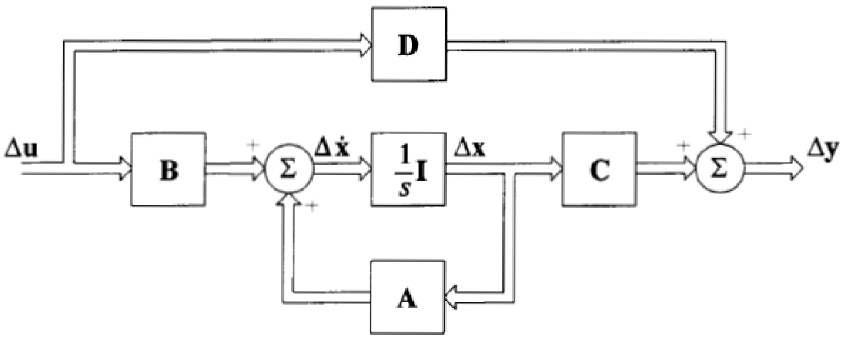
$$\dot{x}_i = f_i(x_i, u_j, t)$$
$$y_k = g_k(x_i, u_j)$$

Linearization

$$\Delta\dot{x} = A\Delta x + B\Delta u$$
$$\Delta y = C\Delta x + D\Delta u$$



A state matrix *nxn*

B control or input matrix *nxr*

C output matrix *mxn*

D feedforward matrix *mxr*

The poles of the transfer function are the roots of the equation

$$det(sI - A) = 0$$

The values of s which satisfy the above are known as **eigenvalues** or **modes** of the A matrix

$$\lambda_i = \sigma_i \pm j\omega_i$$

$$f_i = \frac{\omega_i}{2\pi} \qquad \xi_i = \frac{-\sigma_i}{\sqrt{\sigma_i^2 + \omega_i^2}}$$

Types of Stability

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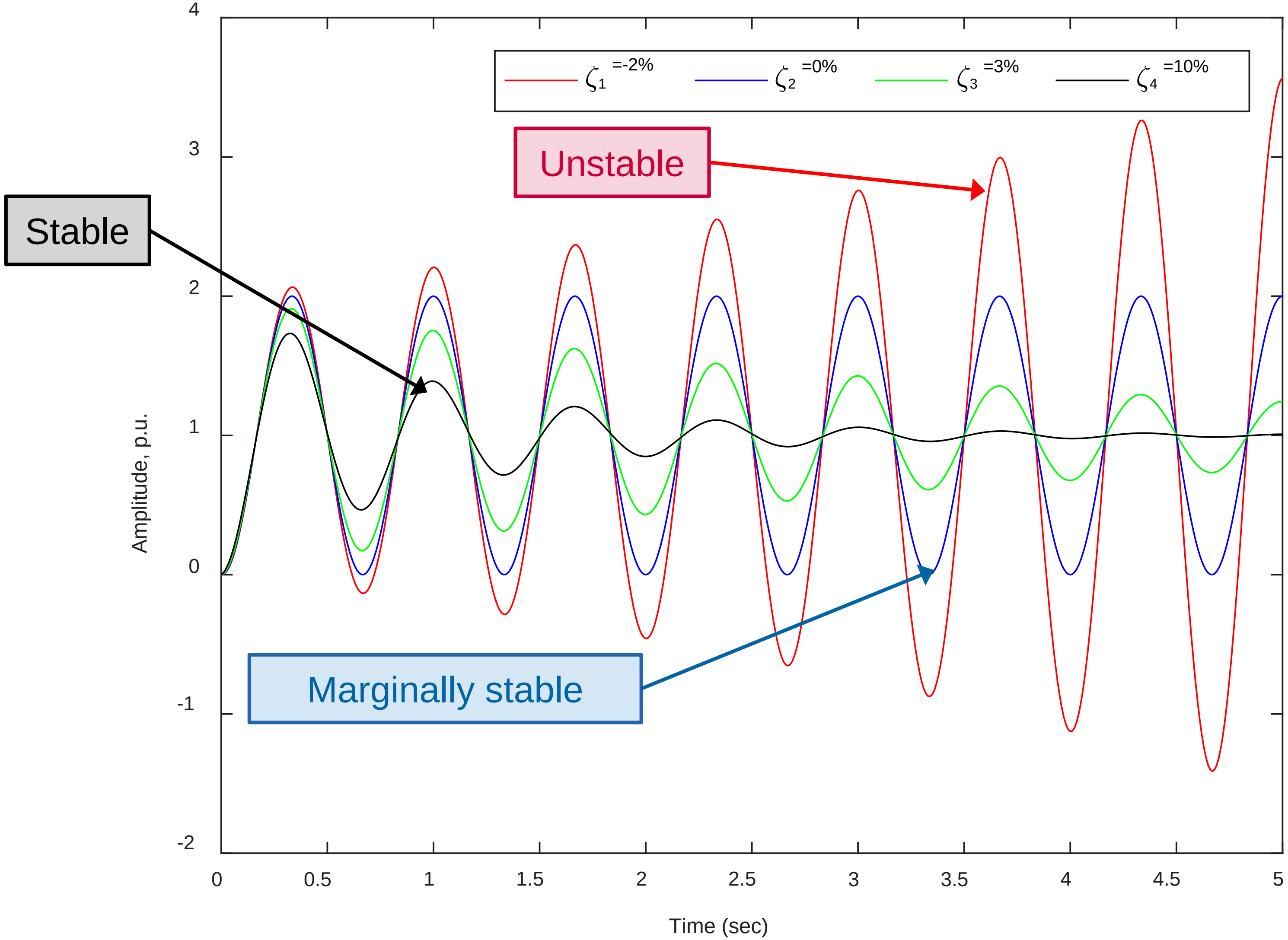

Time-scales of Power System Events

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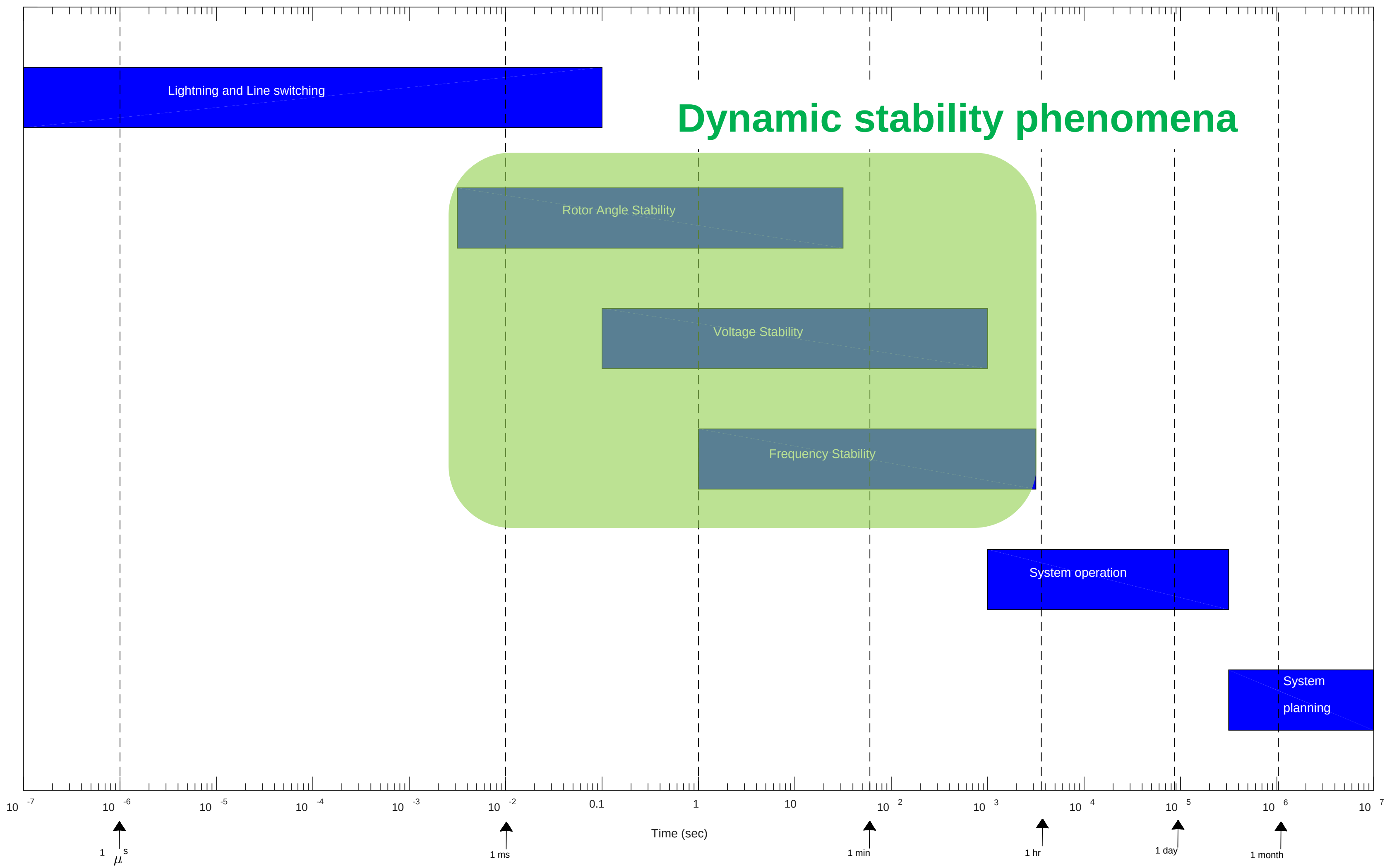
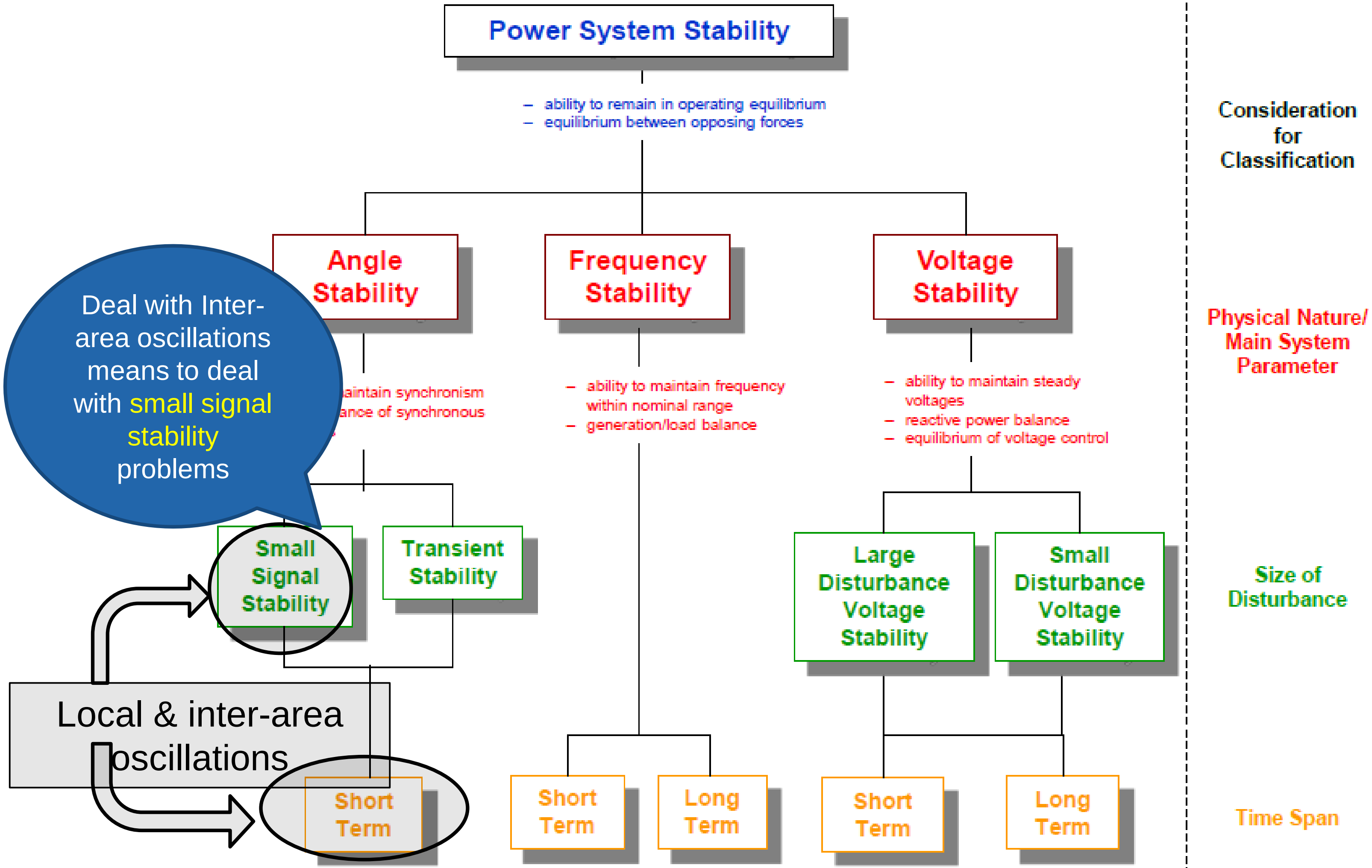


Classification of Power System Stability



P. Kundur ; J. Paserba ; V. Ajjarapu ; G. Andersson, et all,
"*Definition and classification of power system stability IEEE/CIGRE joint task force on stability terms and definitions*",
IEEE Transactions on Power Systems, Volume 19, Issue 3, 2004

Question 1

The eigenvalues or modes of an electric power system are unique? ([online survey]())

a) Yes, they are defined by the nature of the system itself

b) No, they are related to a particular operating condition

c) There are unique but under certain conditions might change

Answers:

b) Was correct:
- Eigenvalues are derived from the sate matrix A of the linear system
- The system can be linearized around multiple operating conditions and hence, **eigenvalues are not unique**

a) and c) are not correct!

Question 2

Inter-area oscillations are a dynamic stability phenomena derived from? (online survey)

a) A sudden drop or rise in the buses voltages

b) A mismatch between generation and consumption

c) Speedup or slowdown of a synchronous generation unit

Answers:

c) Was correct:

- Inter-area oscillations are rotor speed problems originated in the shaft of the synchronous generators
- Therefore they are classified as **angle stability >> small-signal problems**

a) Is not correct!

- Inter-area oscillations might affect voltage levels, but voltage problems are not directly related to inter-area modes.

b) Is not correct!

- Mismatch between generation and consumption cause frequency issues (drop or rise) but not necessary oscillations

Oscillation Effects in Power Systems

Type of Oscillations

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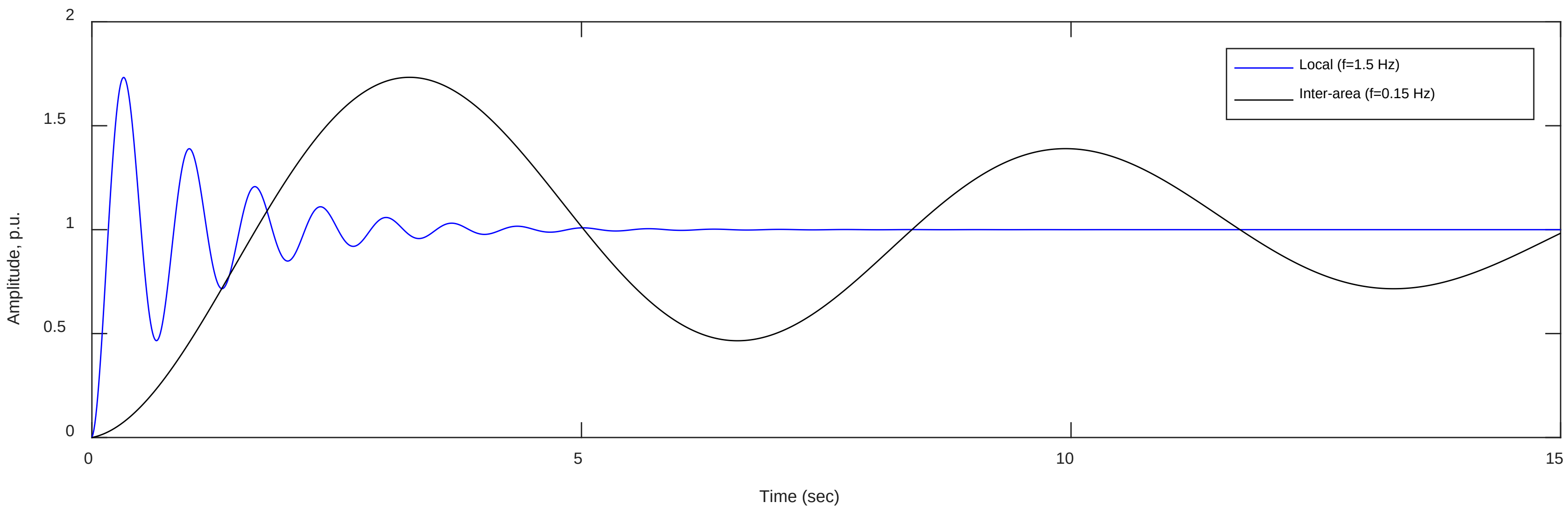
Due to local modes

- Oscillations with frequency in the range of **1.0 to 2.0 Hz**
- Swing of a single generator against rest of the power system

Due to inter-area modes

- Oscillations with frequency in the order of **0.1 to 1.0 Hz**
- Generators in one part swing against generators in the other part
- System is essentially split into two parts



Inter Area Oscillation Effects

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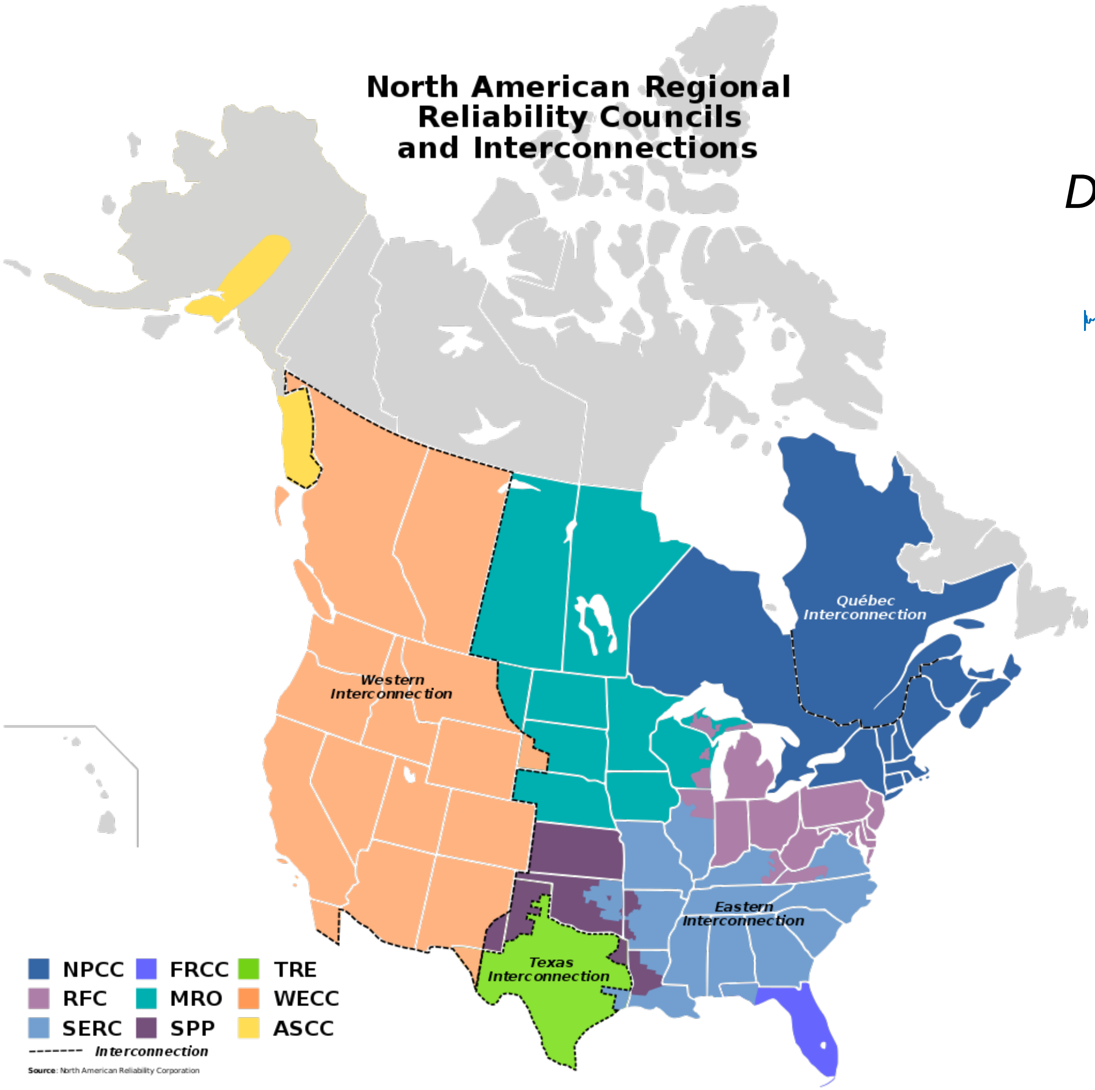
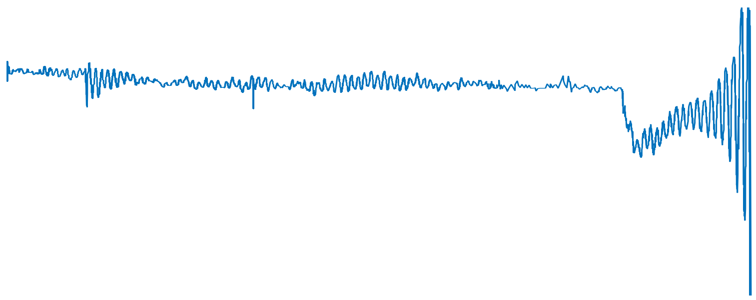
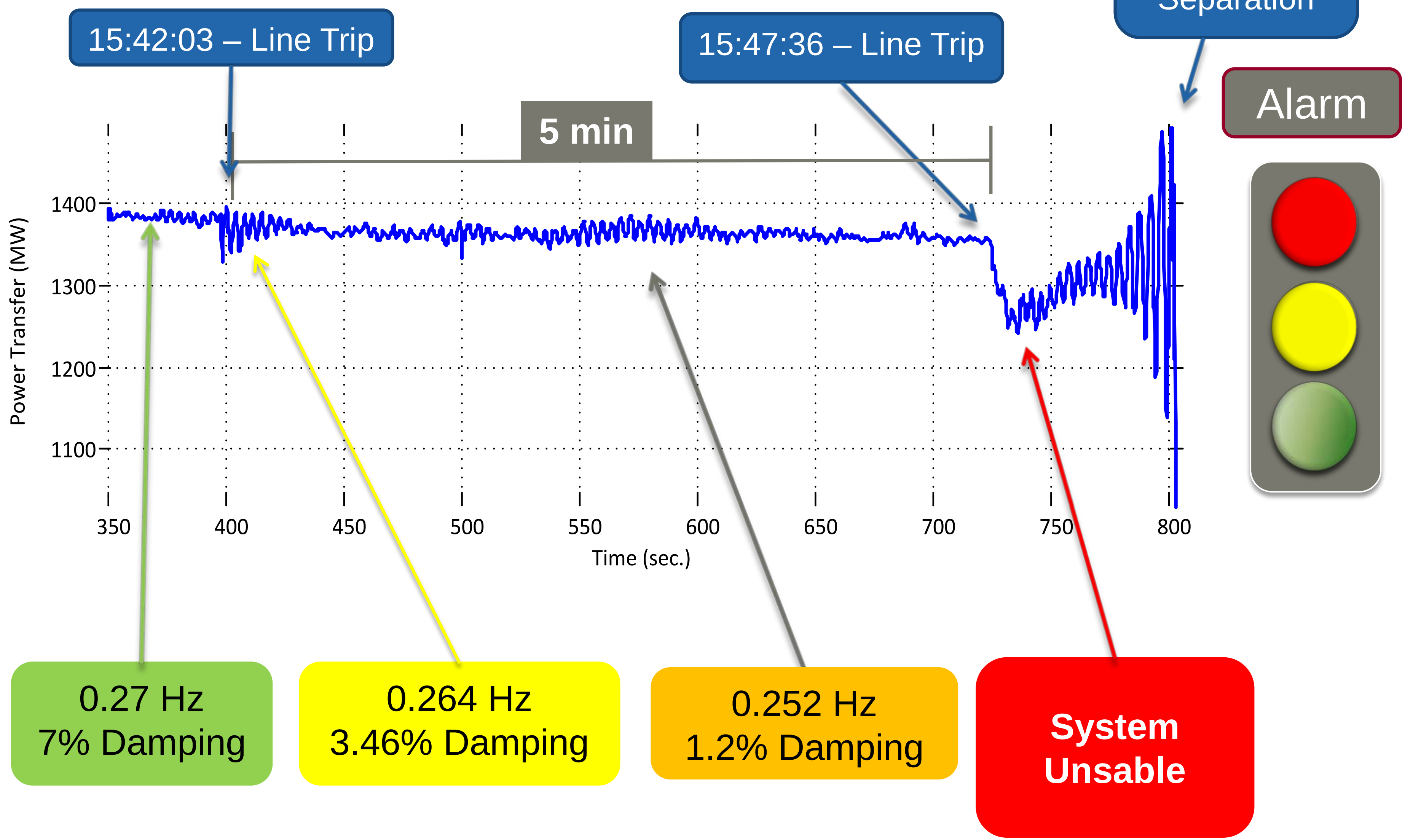


Data from the 1996 WECC Break-up



Courtesy of Prof. Luigi Vanfretti (RPI, USA)

Inter Area Oscillation Effects



Oscillations in the Pan-European Power System

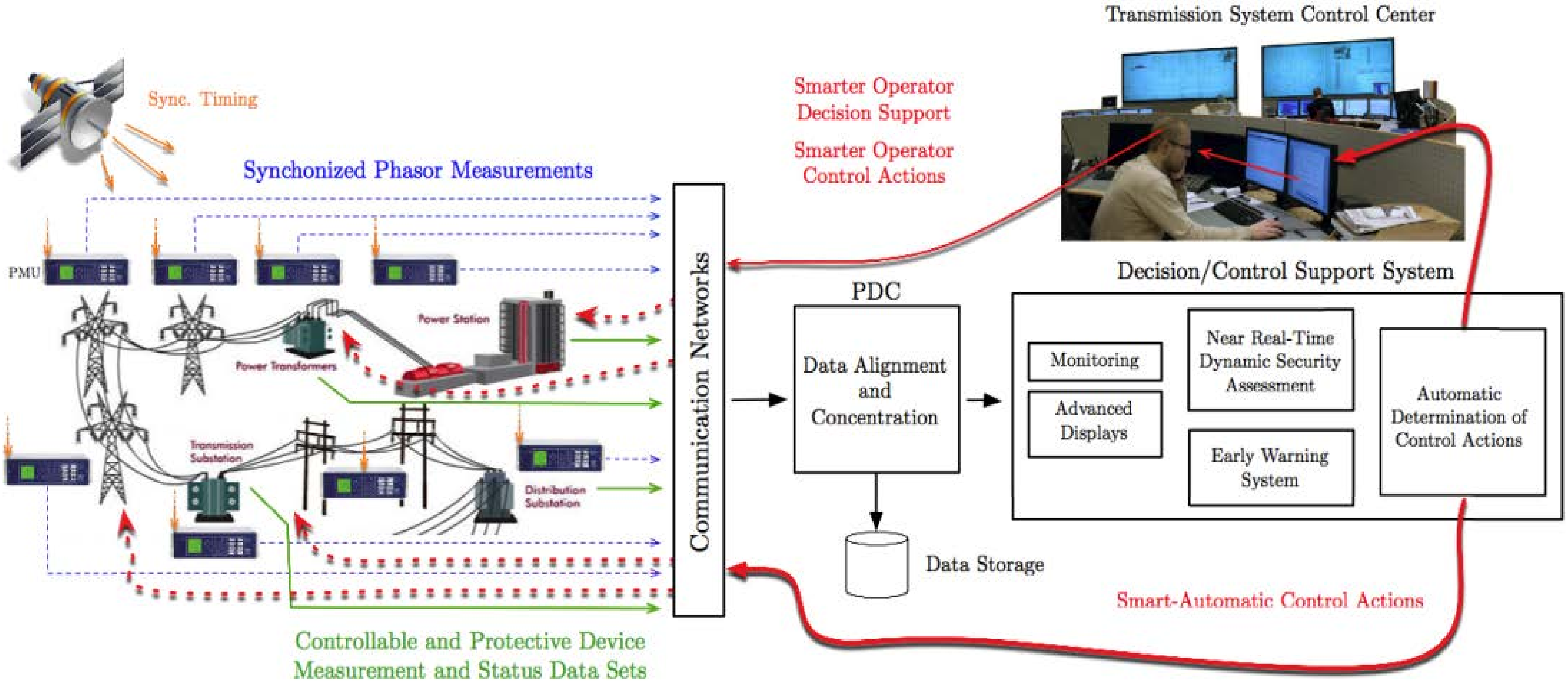
In February 2011

- Poorly damped inter-area oscillations between Italy and the rest of the Europe were observed
- Oscillations resulted in power swigs of 25 MW in the North-South corridor lines through Switzerland with large frequency oscillations
- Power system in central Europe is becoming stability-constraint: in the Nordic region this is already a reality
- Big challenge considering the continuous expansion of the Pan European Power System: integration of Turkey in 2015

Courtesy of Swssgrid

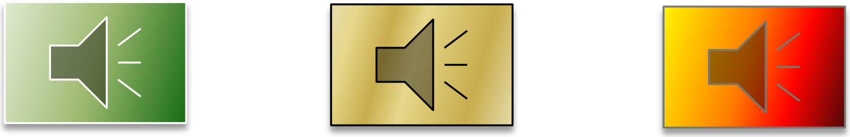
Monitoring Oscillations

- Use of Wide Area Monitoring System (WAMS) for monitoring oscillations

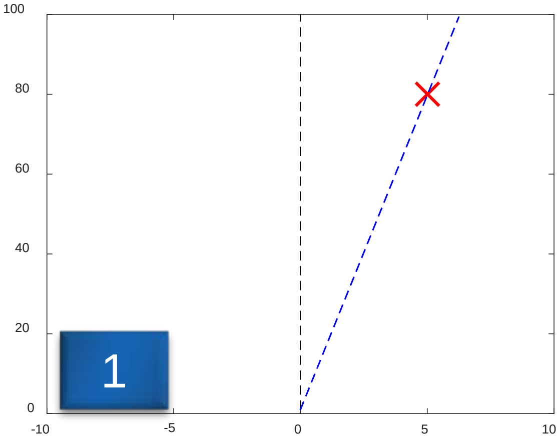


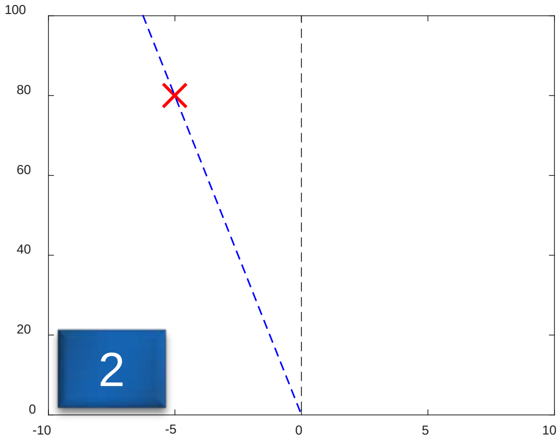
Question 3

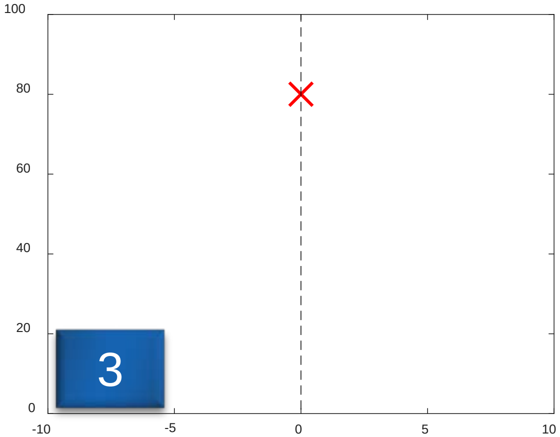
Three audio clips will be played next.



They are all oscillations of different types. What is the sequence of the eigenvalue plots below corresponding to oscillations in the sequence in which the audio clips where played? (online survey)







a) 2, 3, 1

b) 1, 2, 3

c) I cannot hear any difference

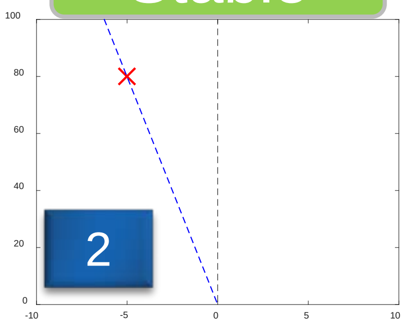
Answers:

a) Was the correct sequence: 2, 3, 1

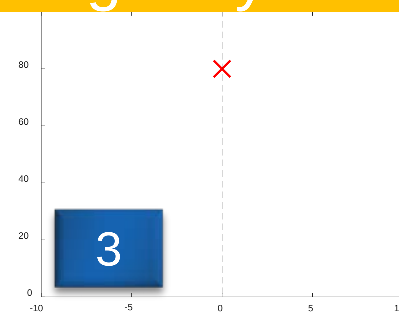
– All of the signals have the same frequency: 82.4069 Hz (E flat)

– Only the damping of the signals was changed, the correct order was

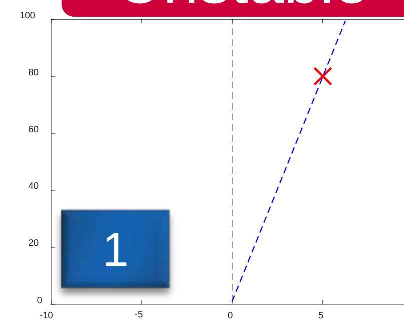
Stable

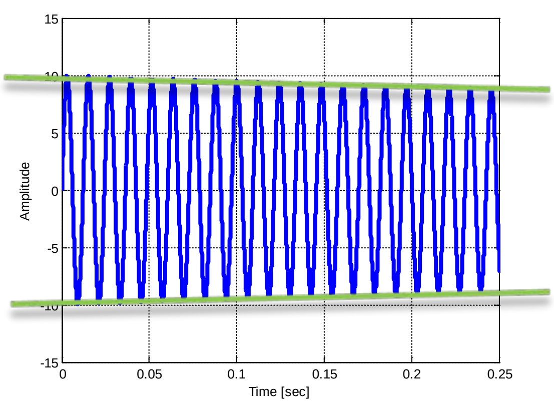


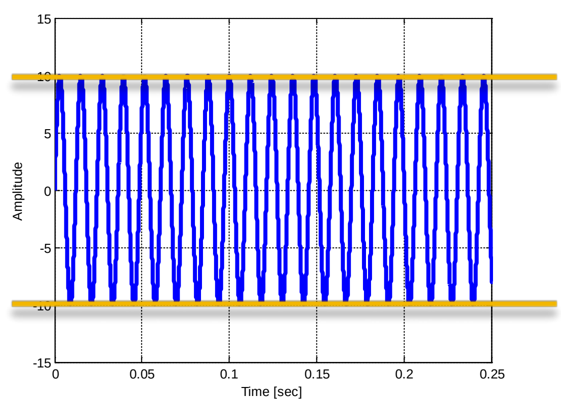
Marginally Stable

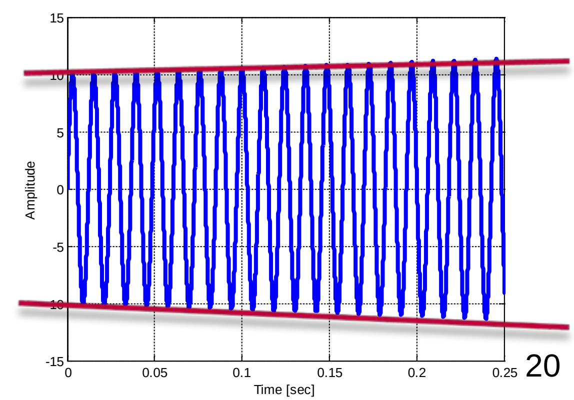


Unstable









How to Deal with this Problem

Measures to Improve Damping

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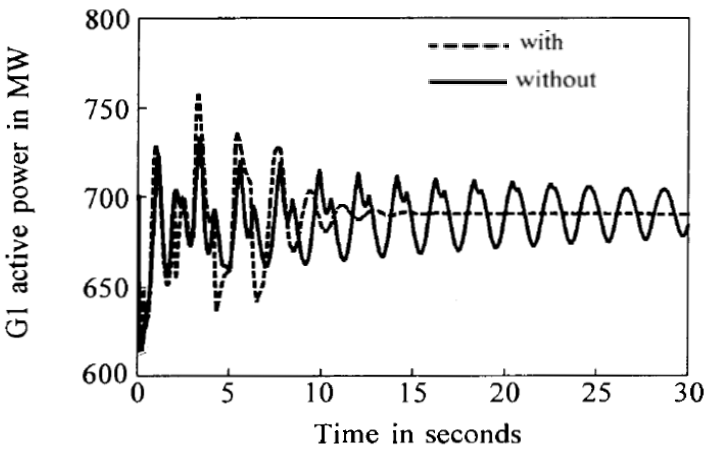
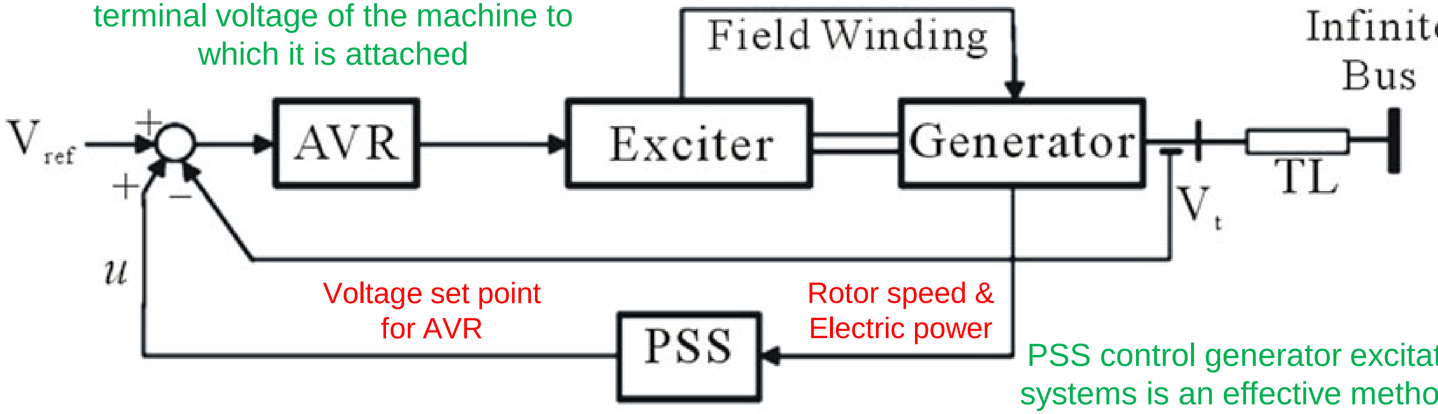
Installation and proper tuning of:

- Power Systems Stabilizers (PSS)
  - Most cost-effective method by adding damping to the generator rotor
- Flexible AC Transmission Systems (FACTS)
  - Rapidly controlling the voltage and reactive power with a supplementary control in devices such as Static Var Compensators (SVCs) equipped with power oscillation damper (POD).
- Supplementary control of High Voltage DC links (HVDC)
  - Modulating the power electronic components (current or voltage at the rectifier).



Power Systems Stabilizers (PSS)

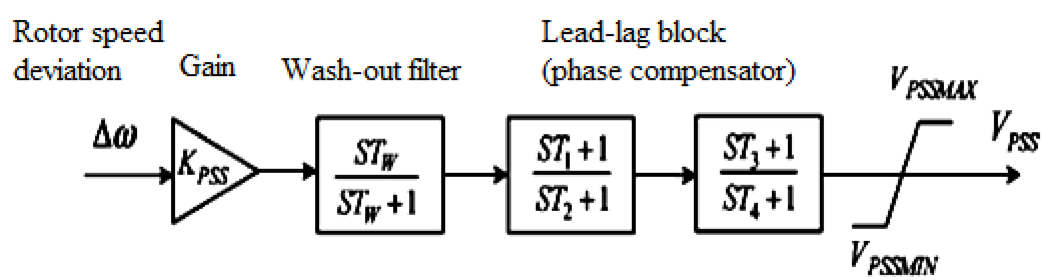
The AVR provides regulation of the terminal voltage of the machine to which it is attached



PSS control generator excitation systems is an effective method to enhance small-signal stability

Objectives

- Maximize damping of local and inter-area modes without compromising the stability of the other modes
- Enhance transient stability



Challenges

- Parameters design
- Selection of location

Challenges to Design Controllers

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- Accurate measure of the current status of the system (damping estimation).
- Location of the controller
  - Hundreds of machines (PSS), hundreds of buses (SVCs)
- Signal Selection
  - Local signals available, global signals from PMUs also available (thousands)
- Method for control design
  - Pole placement, lead-lag compensation, robust control (H-inf), etc.
- Satisfactory closed loop performance without destabilizing the rest of the system

Thank you for your attention !