

Adaptive and AI Controls – A panacea in one aspect in the march to a smarter grid

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Smart Grid Engineering

Developments in Power Systems

- Technology level in power systems is a moving target
- Power systems engineers have always been on the forefront of exploring and utilizing any new enabling technology, as it became available, to improve the operation of power systems,
- i.e. making it smarter since 1882

Power System Keeping up with Changes

Every aspect of the electric power systems:

- Infrastructure (hardware)
- Planning
- Operation
- Control
- Protection

has made tremendous advances over the past 130 years.

Catalysts for Advances

- New developments in the electric power area
- Continuous technological advances in other relevant technologies:
 - Information and Communications technology
 - Satellites
 - SCADA, IEDs, novel sensors and measurement principles
 - PMUs, GPS, WAMS
 - Solid state devices and Computers
 - Power Electronics Devices

Recent Developments in Power Systems

- Increased demands of a digital society
- Increased renewable power generation
- Restructured electricity marketplace
- Electric vehicles and electricity storage
- Vulnerability to security threats

The present electric power infrastructure is not designed to meet many of these needs because

Electricity flows predominantly in one direction

Desired Characteristics of a Grid

- Improved reliability
- Quick power restoration with substation equipment control by the operator
- Monitoring and faster reaction to changes in the delivery system by adjusting the power flow and voltage optimization on the transmission network
- Energy and customer cost savings by advanced metering

Features of a Smart Grid

- Smart grid is based on a very extensive monitoring system whereby each and every aspect of the grid is constantly monitored
- The basis for all this is the sensors specially designed to deliver and perform at high speed
- It is an electric delivery network from electricity generation to the end user that makes use of the latest advances in wireless communication and intelligent information management systems

Description of a Smart Grid

- The term “smart grid” has become ubiquitous, but its definition is flexible.
- A generic description, as good as any, is:
“A smart grid is a digitally enabled electric grid that gathers, distributes and acts on information about the behavior of all components in order to improve the efficiency, reliability and sustainability of electricity services”. [1]

Smart Grid - Vision

Provide enhancements to ensure:

- high level of security, quality, reliability and availability of electric power
- improve economic productivity and quality of life
- minimize environmental impact while maximizing safety and sustainability.

Smart Grid Vision –Who's

- The European Union model:
 - Driven primarily by environmental concerns
- The North American Model:
 - Motivated primarily by desire for reliability improvements. Desirable characteristics include: self-healing network architectures resistant to intentional attacks and natural disasters, high power quality.
- China, Japan and other countries according to their national needs and priorities

Control for the Smarter Grid

Three aspects of how control can be applied to improve power system operation, security and reliability to make power system smarter have been discussed. These are:

- Wide area control
- Adaptive and AI control at a local level
- Renewable sources of generation

One Aspect in the March to a Smarter Grid

Adaptive and Artificial Intelligence
Control at the local level, i.e. Power
System Stabilizer

Commonly Used PSS (CPSS)

An illustrative example:

Take IEEE type PSS1A PSS

Its transfer function is

$$TF = K_s \frac{1}{1 + sT_6} \cdot \frac{sT_5}{1 + sT_5} \cdot \left[\frac{1 + sT_1}{1 + sT_2} \cdot \frac{1 + sT_3}{1 + sT_4} \right]$$

Characteristics of Conventional Controller

- Designed for each specific application
- Needs to be tuned during commissioning
- Settings are a compromise that provide acceptable, though not optimal, performance over a wide range of operating conditions
- Needs retuning if the system configuration has changed.

Desirable Controller Features for Power Systems

- Power systems are non-linear
- Their characteristics and parameters depend upon the operating conditions
- Desirable to track the system parameters on-line during operation
- Determine the control based on the actual parameters.

Adaptive Control

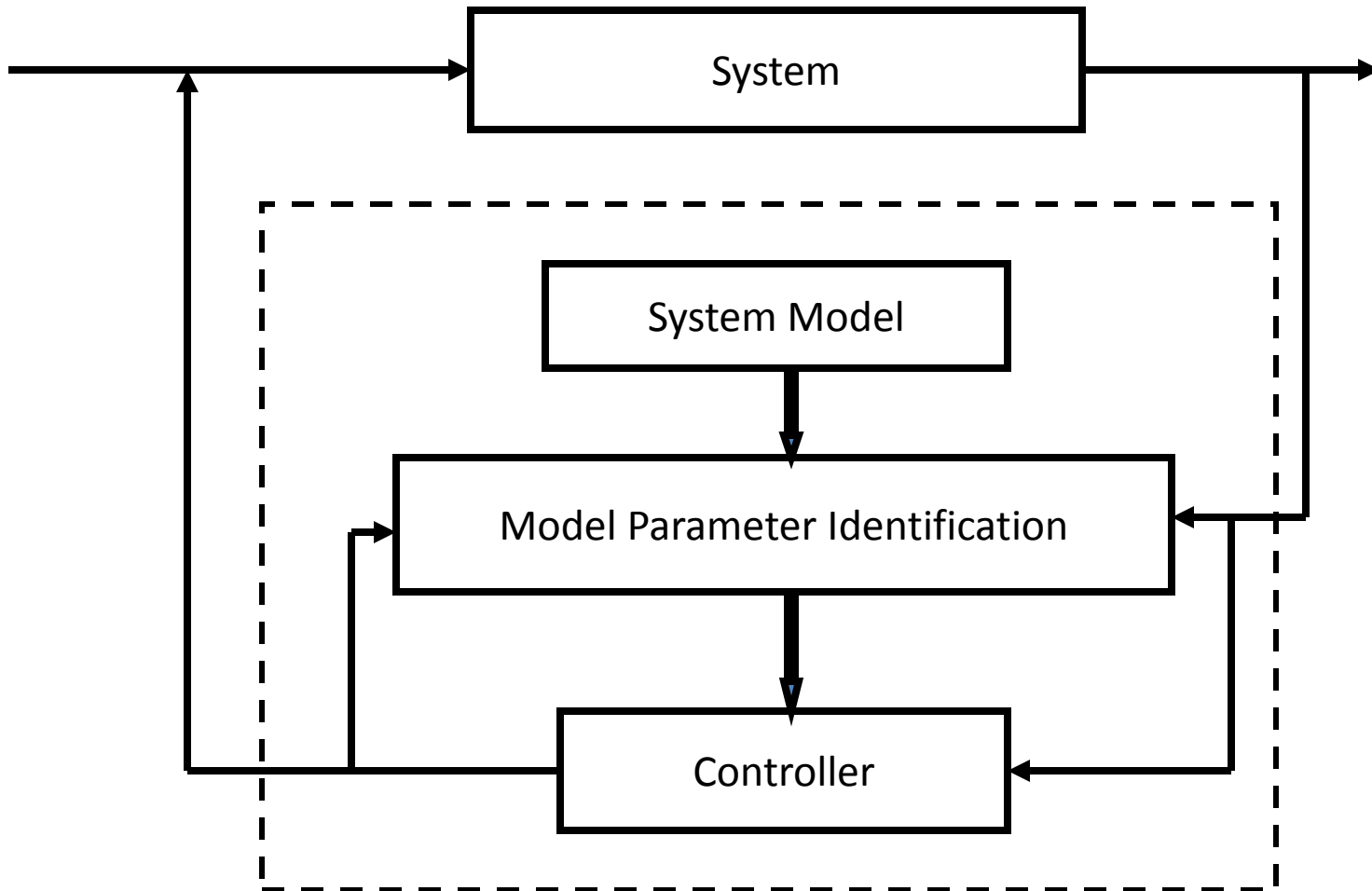
Changing of controller parameters based on changes in the system operating conditions

Whenever changes in system operating conditions are detected, an adaptive controller responds by determining a new set of control parameters

Self-tuning Adaptive Control

- Estimate the parameters of the plant at any instant in time, say k .
- Adapt the controller parameters based on the estimated plant parameters vector

General Configuration of a Self-tuning Adaptive Controller



Adaptive Controller

Various types of identification and control techniques can be combined to form a variety of controllers:

- Fully analytical
- Fully AI based
- Mixed analytical and AI

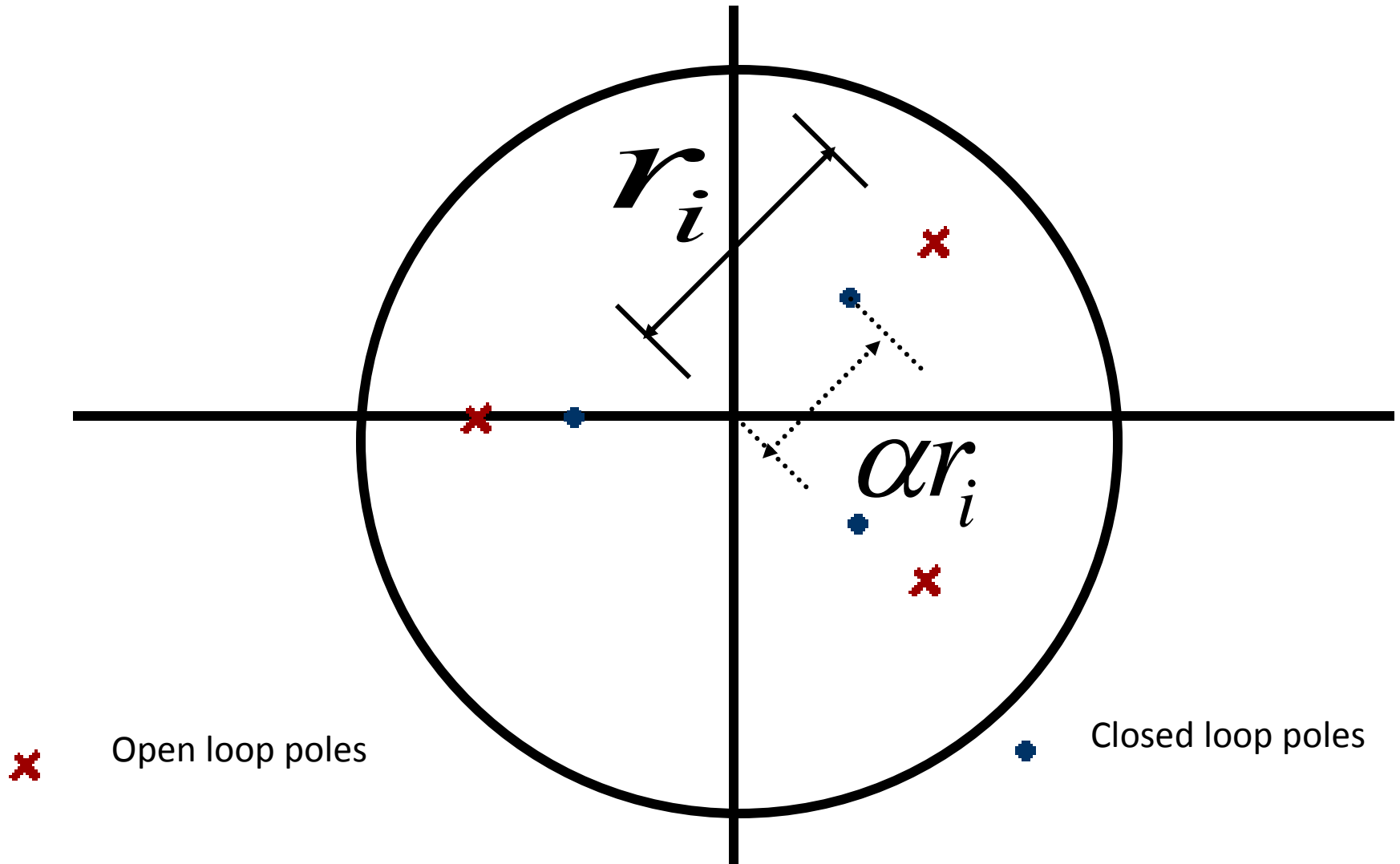
Analytical Self-tuning Adaptive PSS

- Recursive least-squares identification algorithm to determine the system model parameters, $A(z^{-1})$ and $B(z^{-1})$.

Open-loop poles of the system are the roots of the characteristic equation; $A(z^{-1}) = 0$.

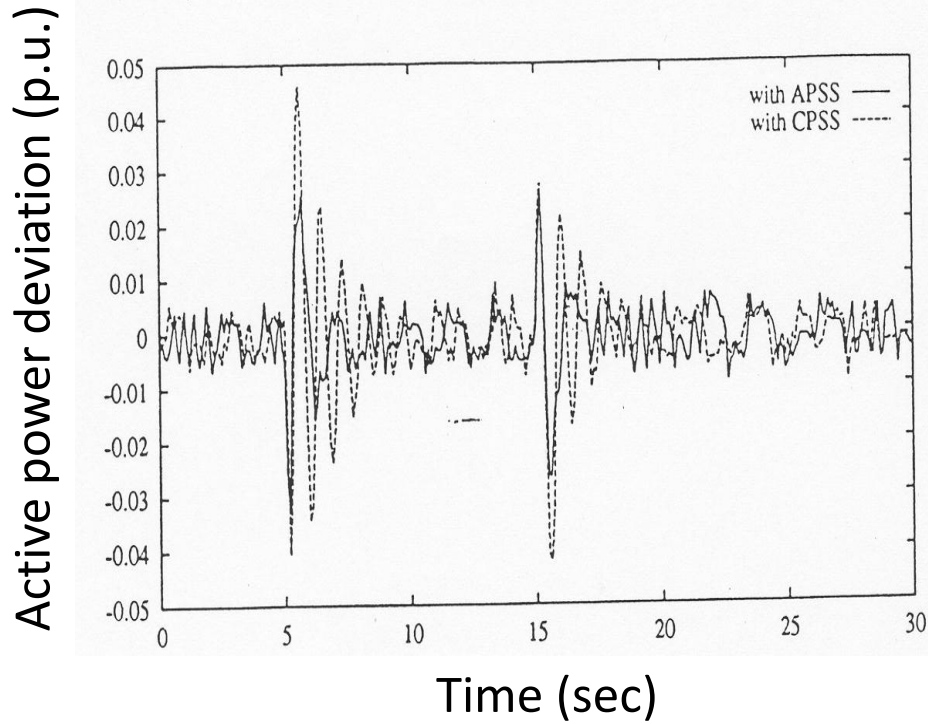
- Pole-shifting control shifts the roots (closed-loop poles) towards the origin of the unit circle by a factor α .

Positioning The Closed Loop Poles

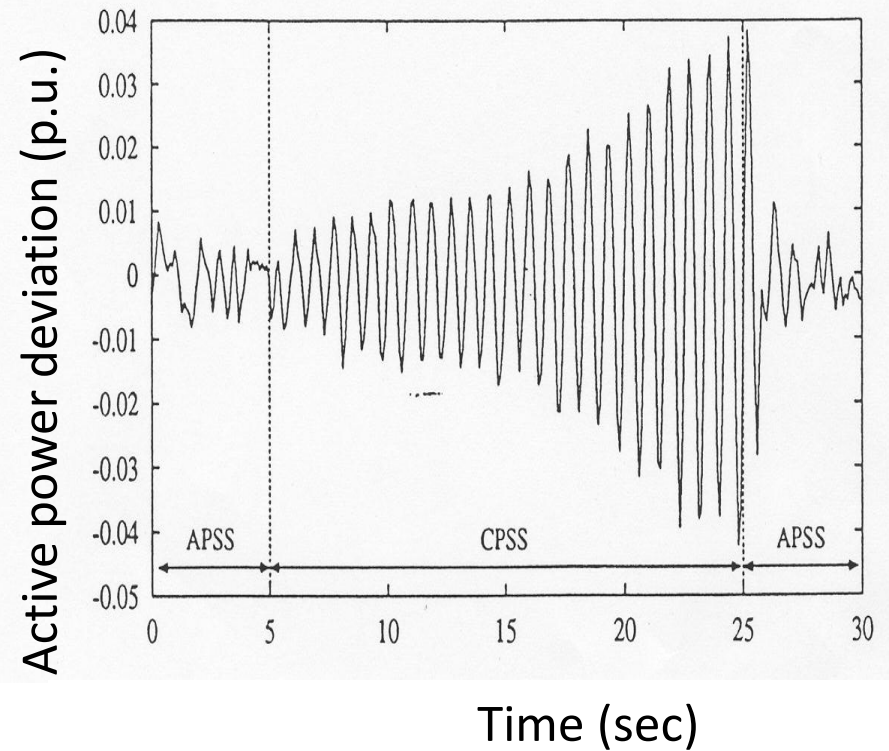


Comparison of APSS & CPSS

For $P = 1.26\text{pu}$, $\text{pf} = 0.94$ lag



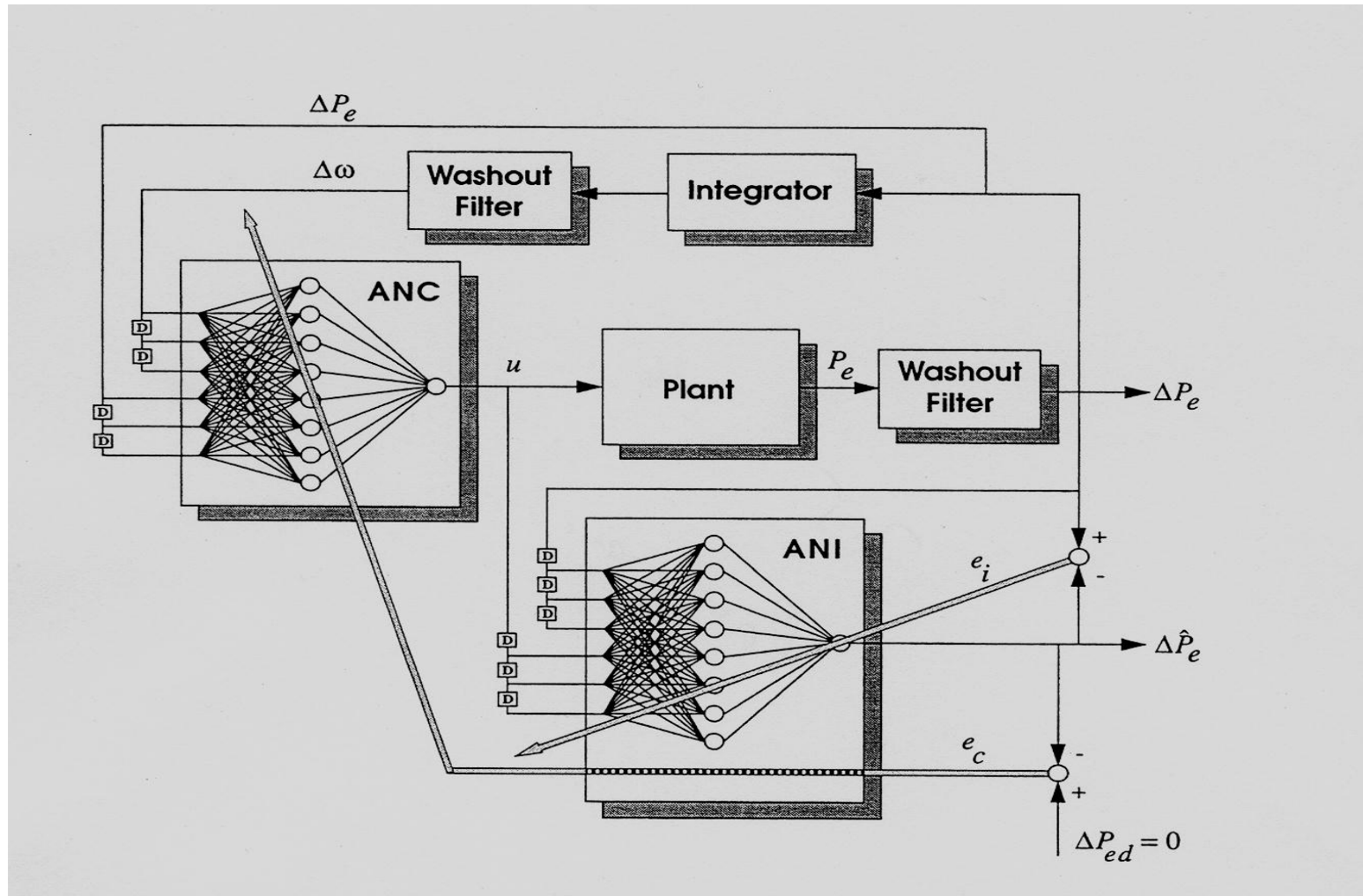
Dynamic Stability Improvement by APSS



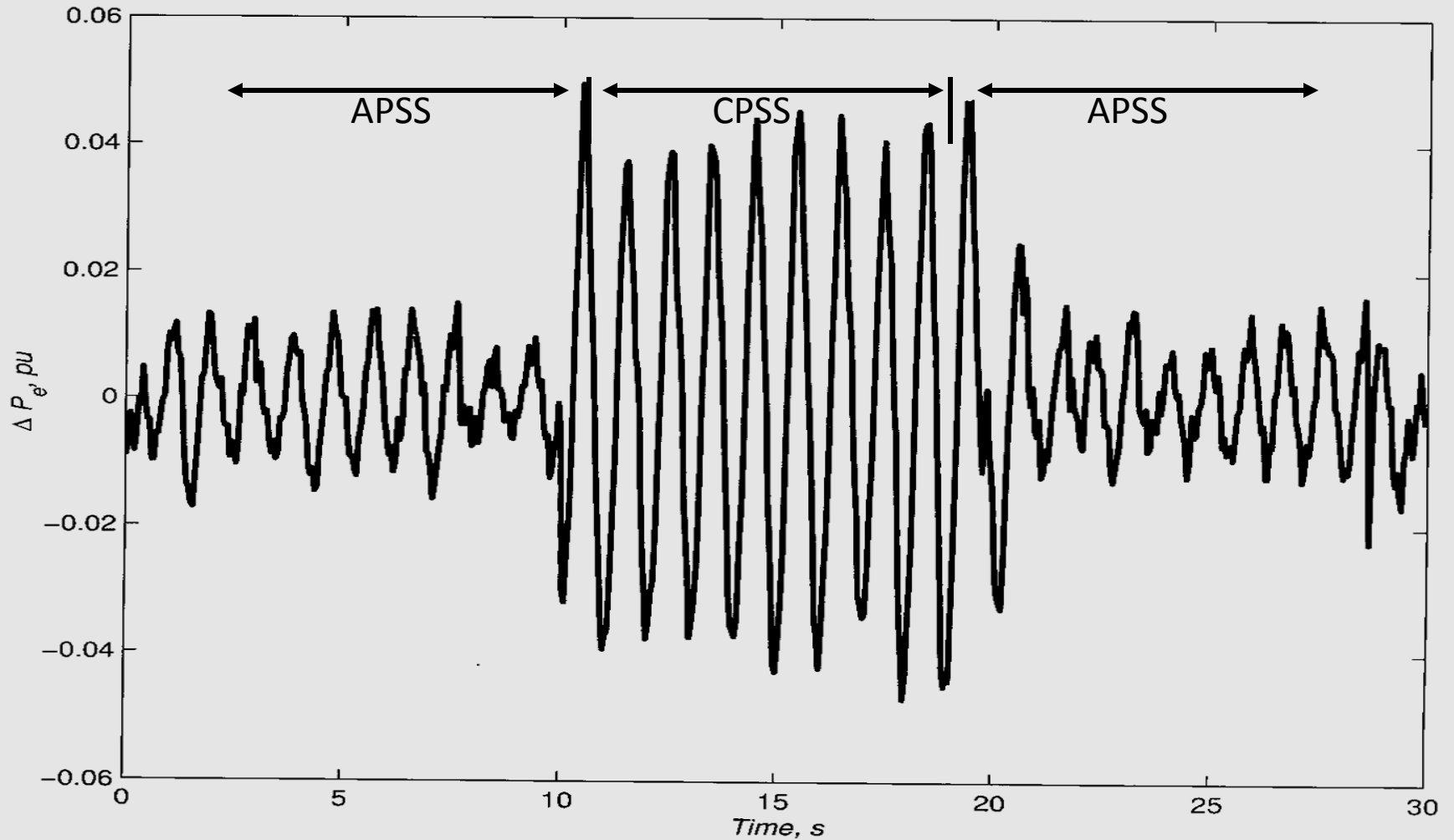
Installations

- Retrofitted on eleven 280 MW hydro-generators at Porto Primavera hydro-station in Brazil and in operation since 1999.
- One turbo-generator in a nuclear generating station in Latvia

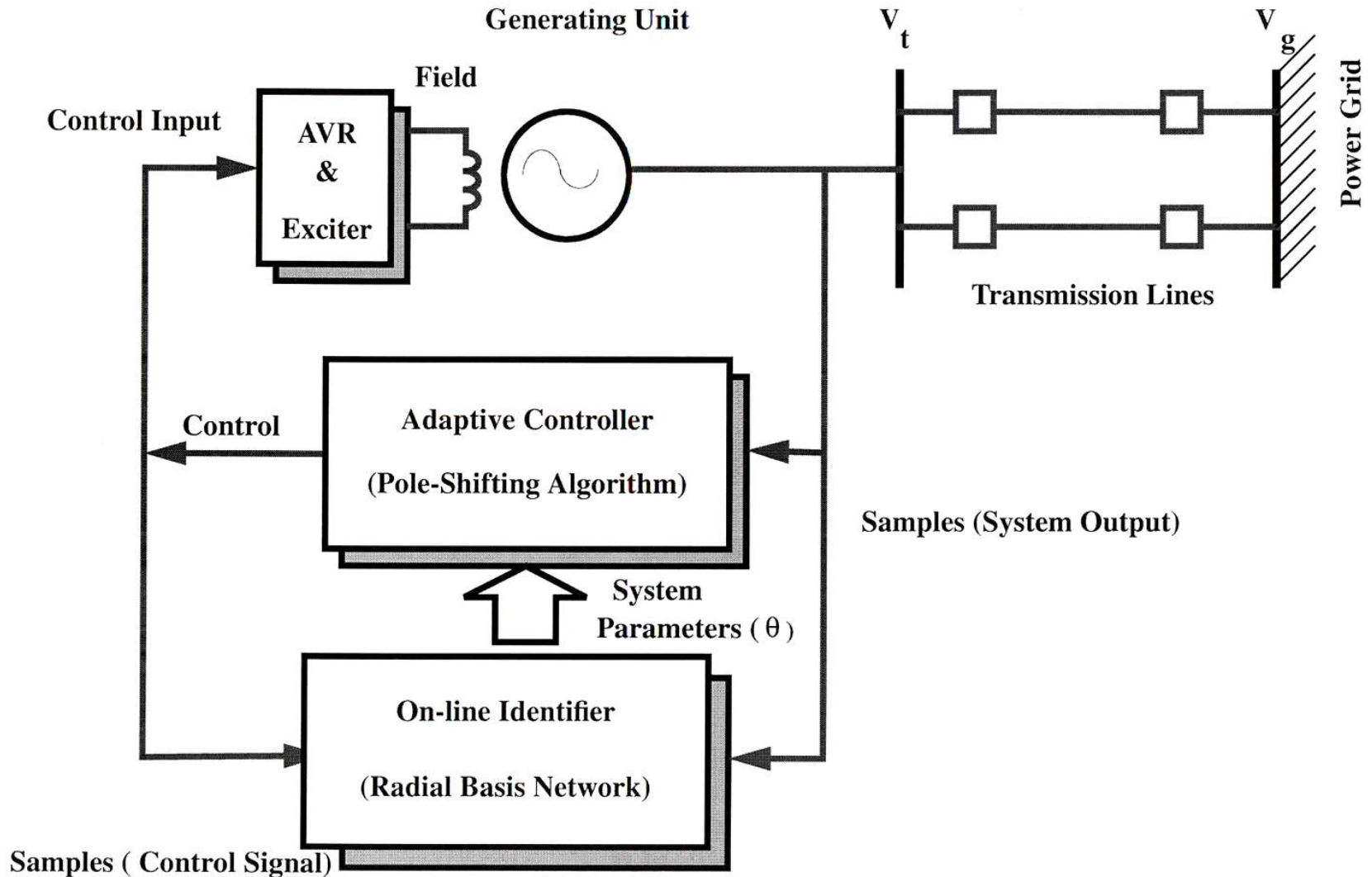
Neuro Adaptive PSS



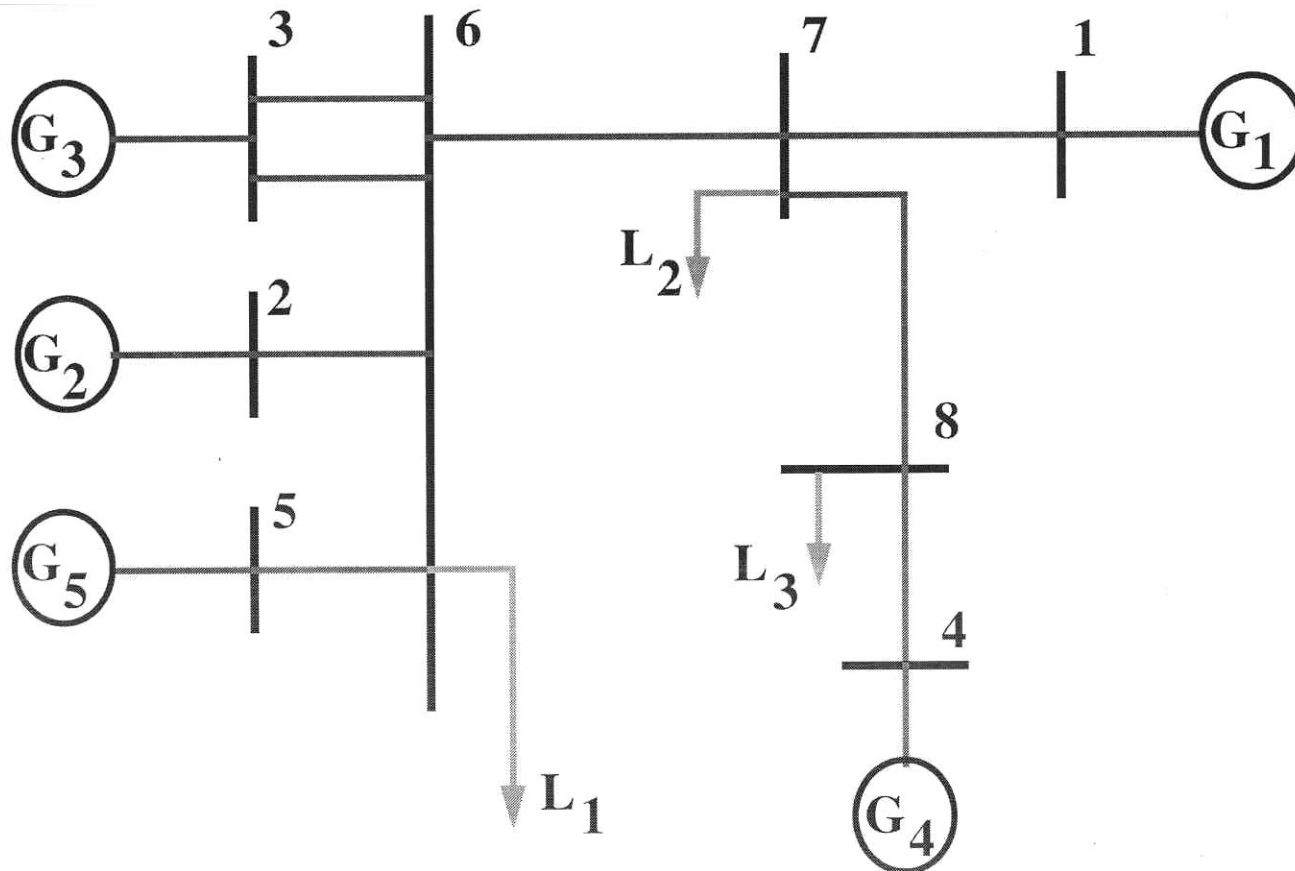
Stability Margin Test



RBF-Identifier & Pole-Shifting Controller



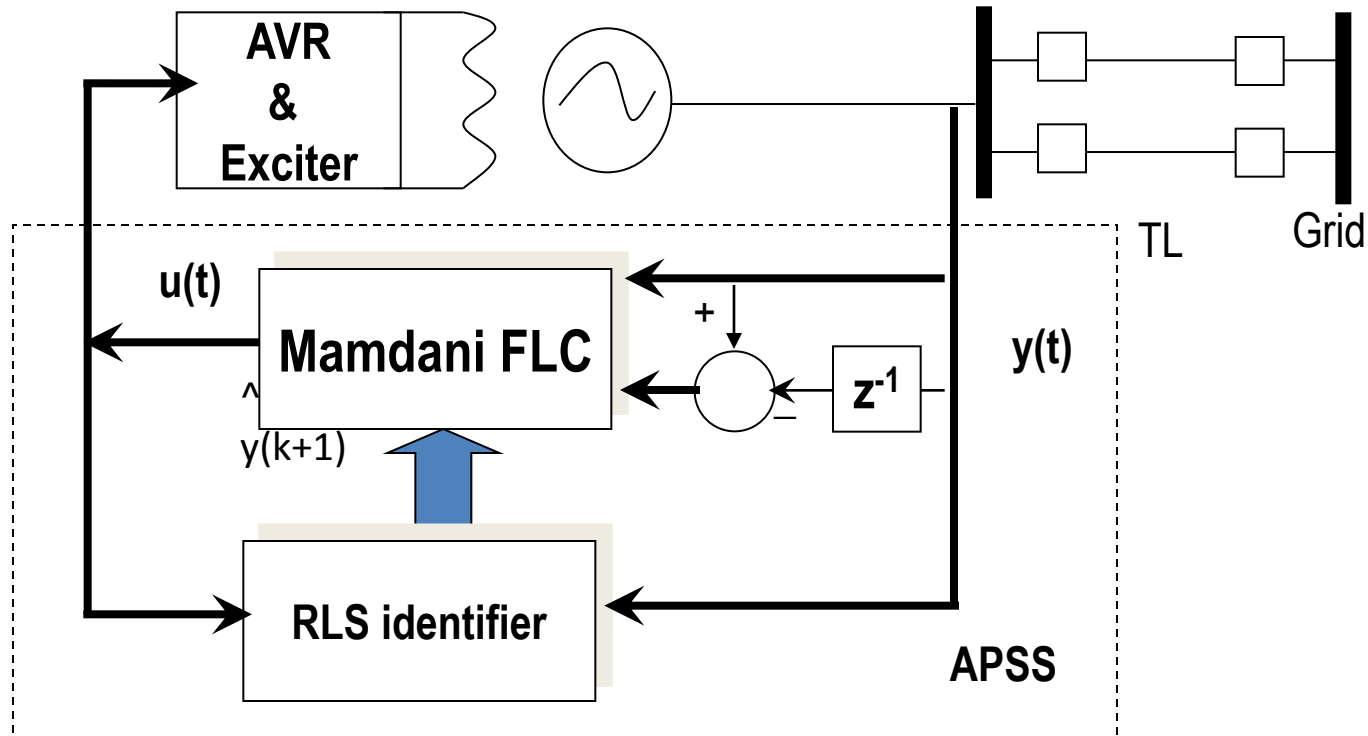
Five Machine System Configuration



Identified System Oscillation Frequency

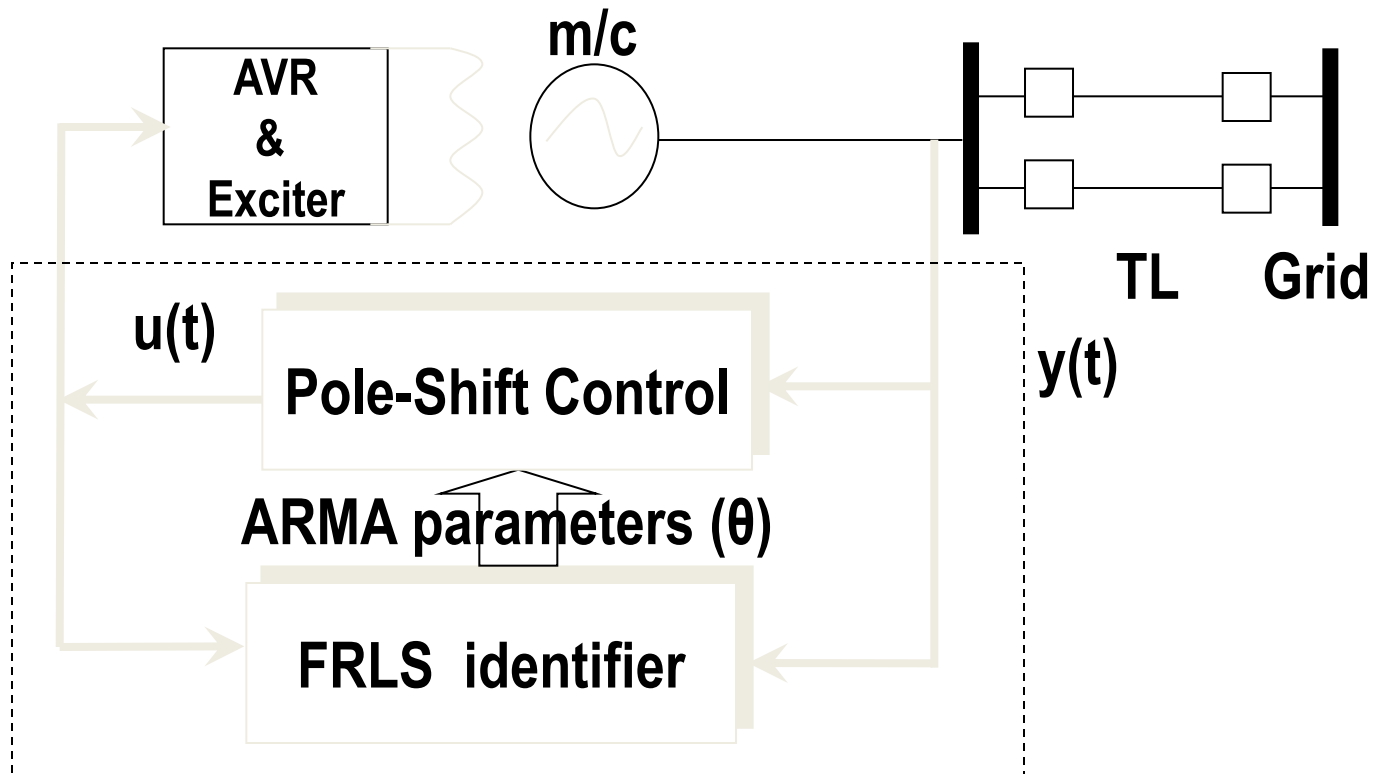
Time after disturbance s	Identified frequency Hz
2.5	1.024
5.0	0.737
7.5	0.583
10.0	0.537
12.5	0.501
15.0	0.475
17.5	0.452
20.0	0.433

Fuzzy Adaptive Control PSS



RLS identifier and a self-learning Mamdani fuzzy logic controller.

Adaptive Takagi-Sugeno PSS (ATSPSS)



Takagi-Sugeno identifier and a pole-shift controller.

Advantages of an Adaptive PSS

- Does not require to be redesigned for each new application.
- Needs no tuning during commissioning.
- Provides optimal response to suit the system operating conditions.
- Tracks the system characteristics.
Therefore, needs no retuning over time.

Concluding Remarks

In the area of electric power generation, adaptive and AI controls can make the grid smarter by;

- (i) collecting information in real-time about the behaviour of the synchronous machine, and
- (ii) acting on this information to improve the stability and thus the reliability of the grid, i.e. 'electricity services'.