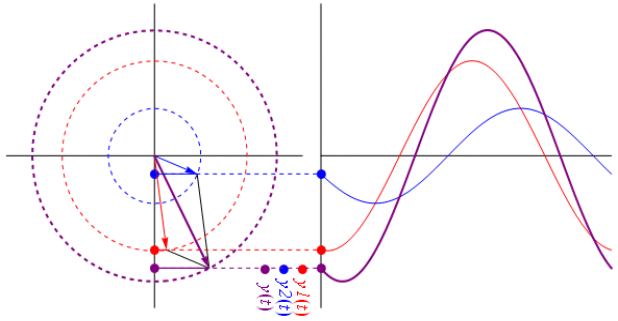
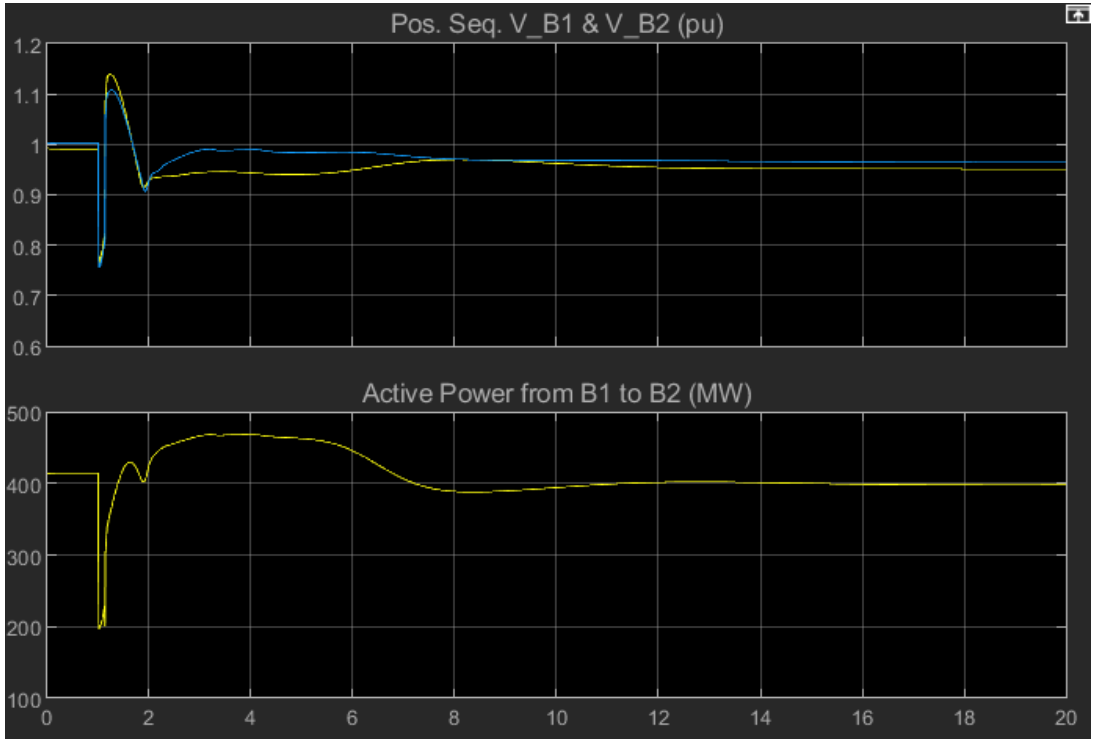
Applications of Real-Time Digital Twin Simulation along with WAMS for improving the power system dynamic security

DynPOWER 2022

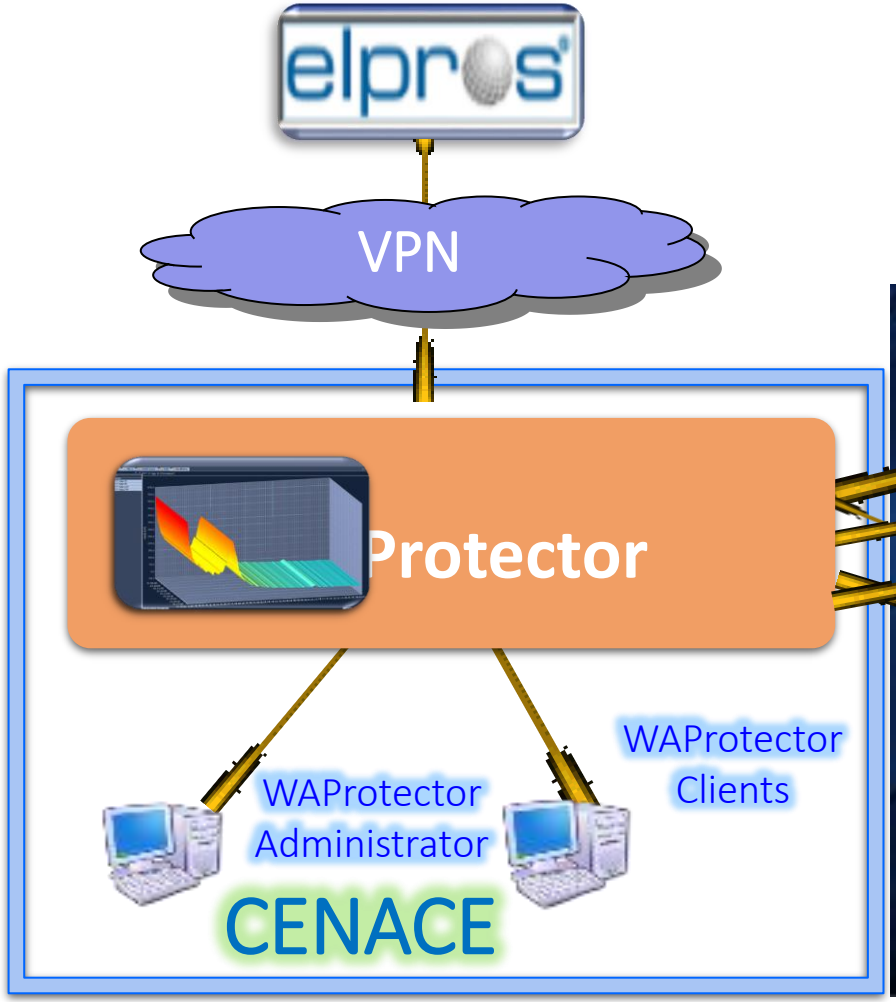
Jaime Cepeda, Ph.D.



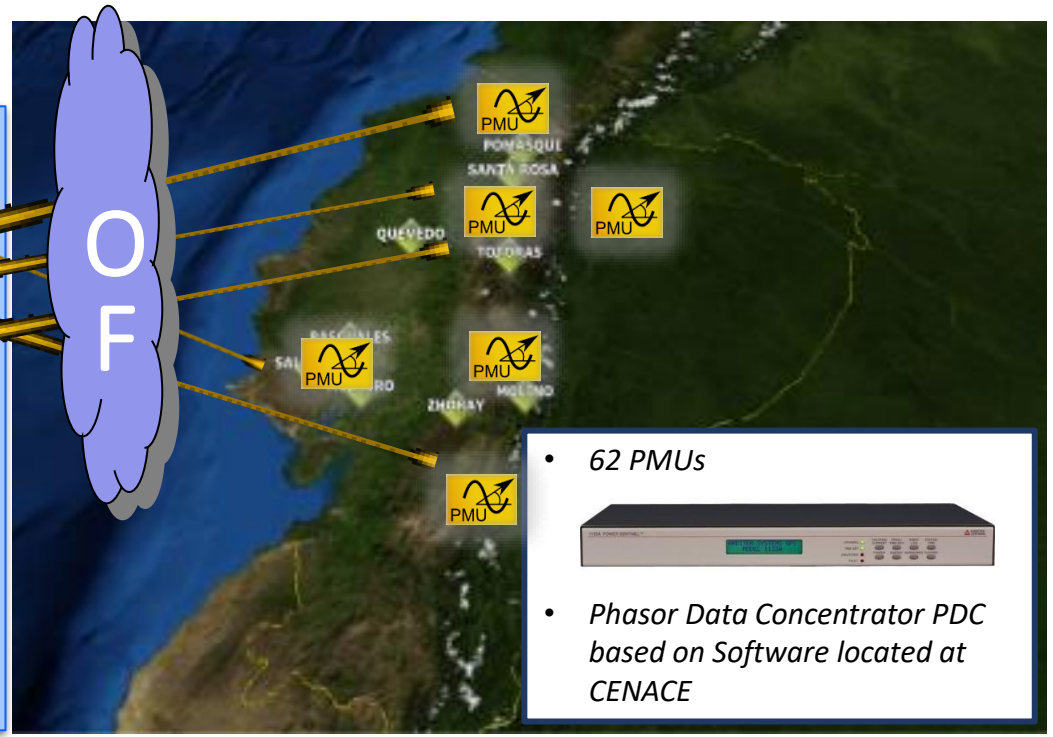


September 19, 2022

Ecuadorian WAMS



- **TCP/IP Protocol**
- **Standard IEEE C37.118**



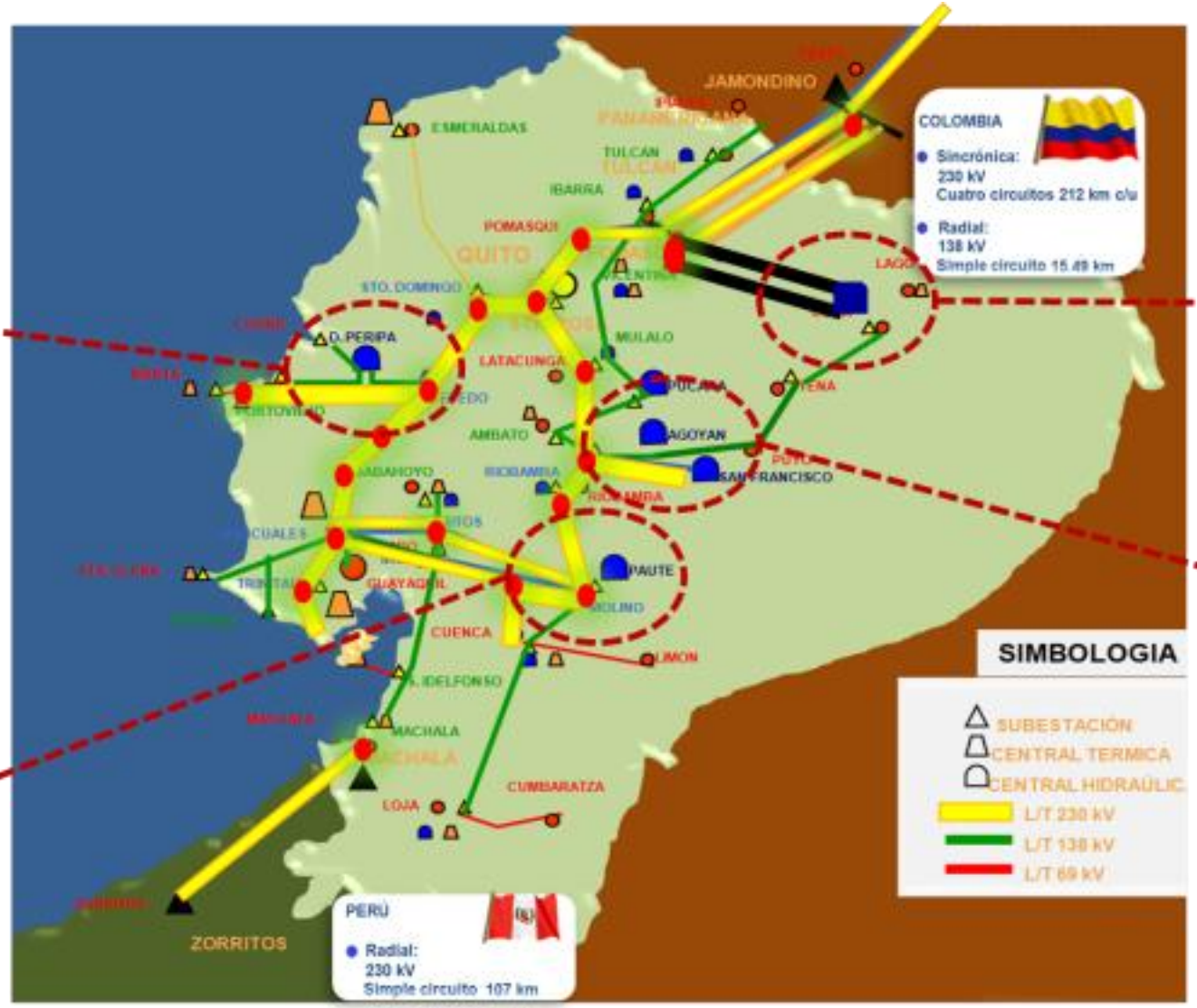
- *62 PMUs*

- *Phasor Data Concentrator PDC based on Software located at CENACE*

Oscillatory Modes determined via Statistics from WAProtector

1.0 – 1.8 Hz Local Mode

0.34 – 0.45 Hz Inter-area Mode



0.7 – 1.2 Hz Local Mode

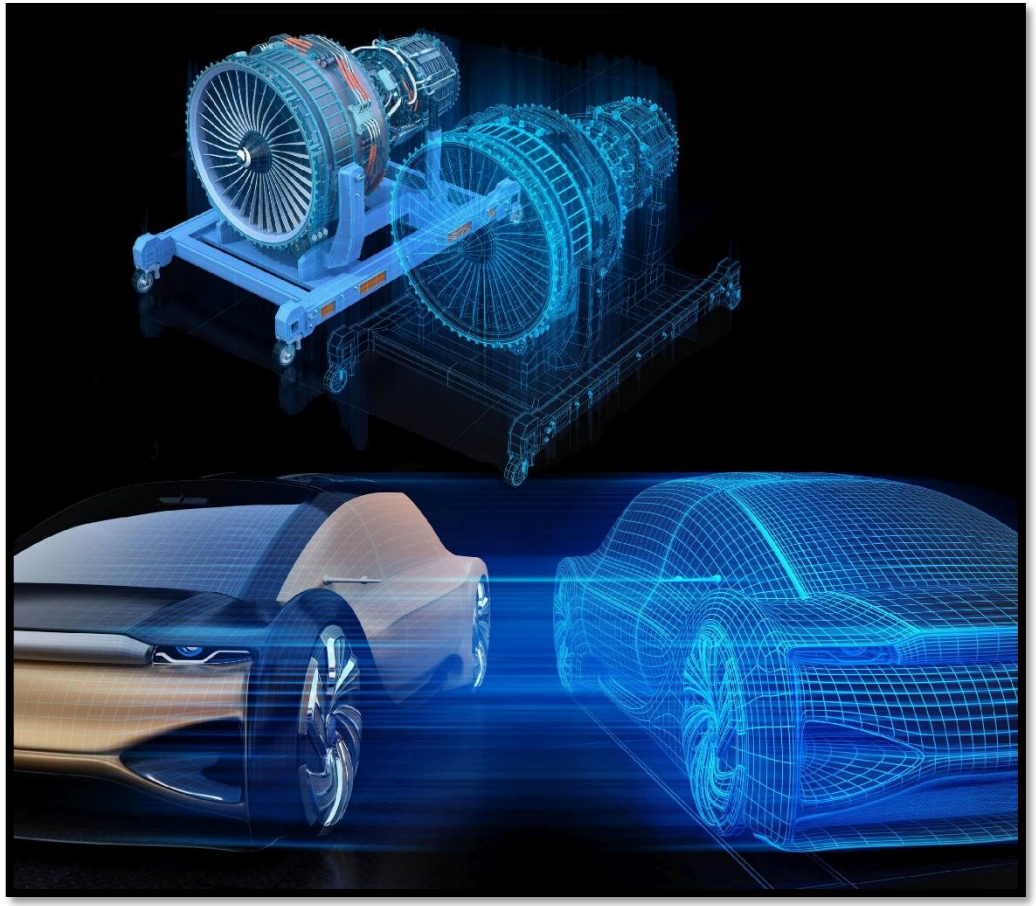
0.34 – 0.45 Hz Inter-area Mode

0.8 – 1.1 Hz Local Mode

0.34 – 0.45 Hz Inter-area Mode

Local Oscillation mode at CCS: 0,75 Hz with negative damping

Digital Twin Concept



A digital twin is a virtual representation that serves as the real-time digital counterpart of a physical object or process.

Digital twins are the result of continual improvement in the creation of product design and engineering activities.

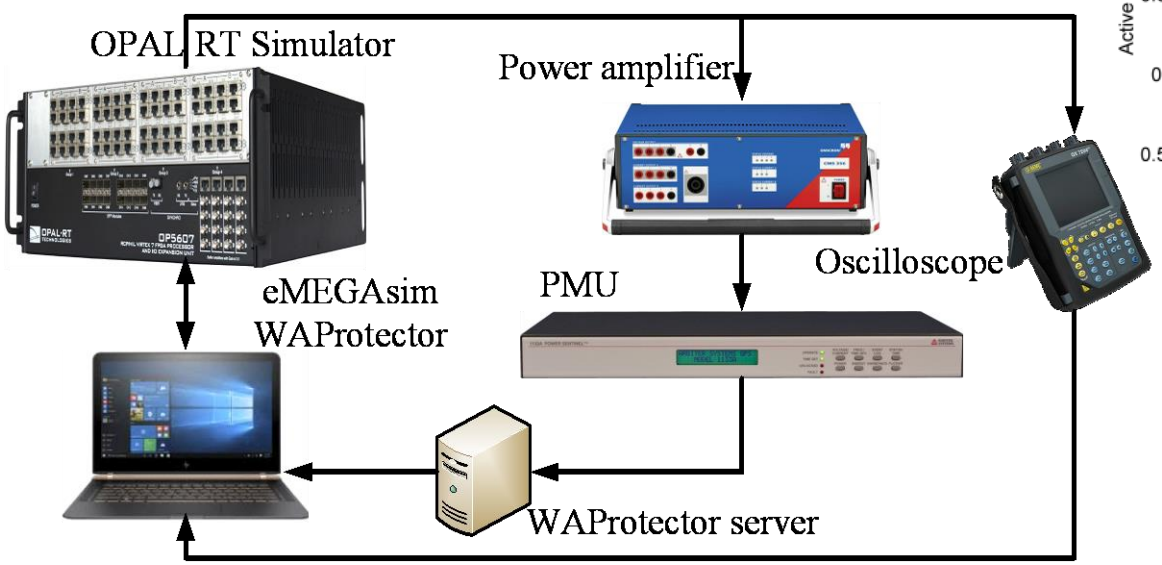
The digital twin concept consists of three distinct parts: the physical product, the digital/virtual product, and connections between the two products. The connections between the physical product and the digital/virtual product is data that flows from the physical product to the digital/virtual product and information that is available from the digital/virtual product to the physical environment.

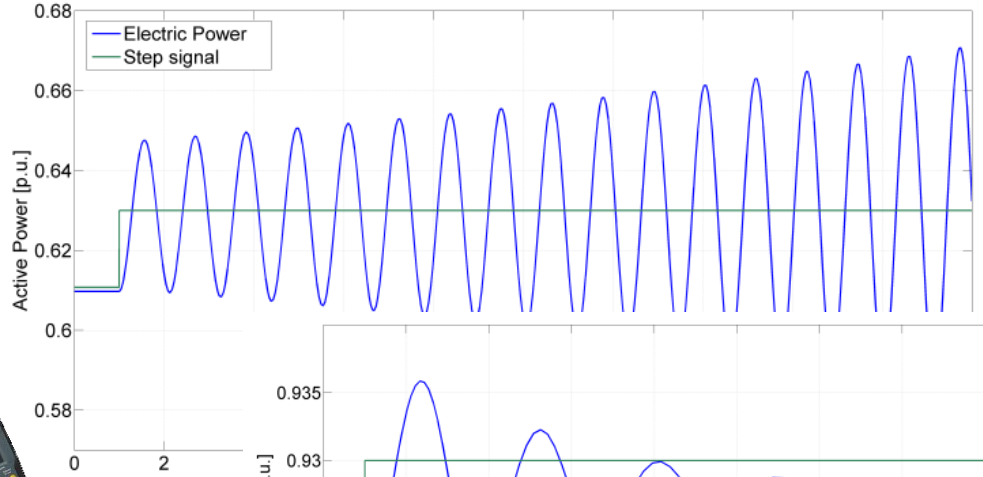
Real-Time Digital Simulation and Smart Grid Laboratory

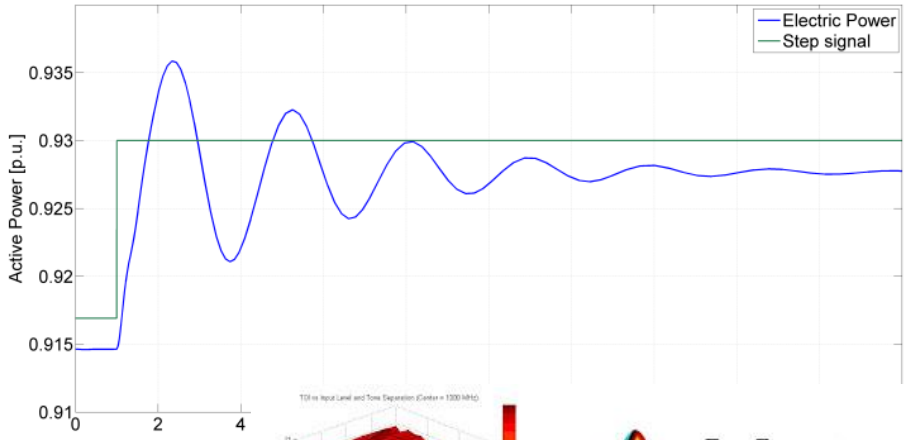
cenace
OPERADOR NACIONAL DE ELECTRICIDAD

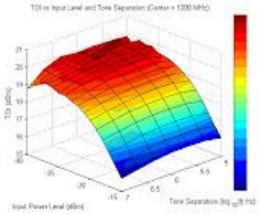
- *OPAL-RT Real-Time Digital Simulator*
- *Low-power Amplifier*
- *Medium-power Amplifier*
- *PMUs*
- *Digital Twin of PDC (WAProtector)*
- *Protection Relays*
- *Scope*
- *Perturbation recorder*
- *Signal injector*
- *Video Wall*
- *Training environment*

PSS Tuning using eMEGAsim and WAMS



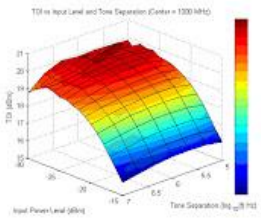






MATLAB SIMULINK

PSS Tuning Methodology



MATLAB SIMULINK

Installation of monitoring devices in the Generation power Plant: PMUs

Modeling of key system elements: generator, AVR and simplified network.

Model validation through field tests and real-time records (WAProtector)

Probabilistic Oscillatory analysis:

Modal Analysis

Frequency response

Time domain Simulation

Multiple scenarios (Monte Carlo)

PSS Tuning.- Robust Methodology:

- Multiple scenarios (Monte Carlo)

- Heuristic optimization algorithm

- Frequency response (constraints)

- TestBed for PSS Tuning (Laboratory)

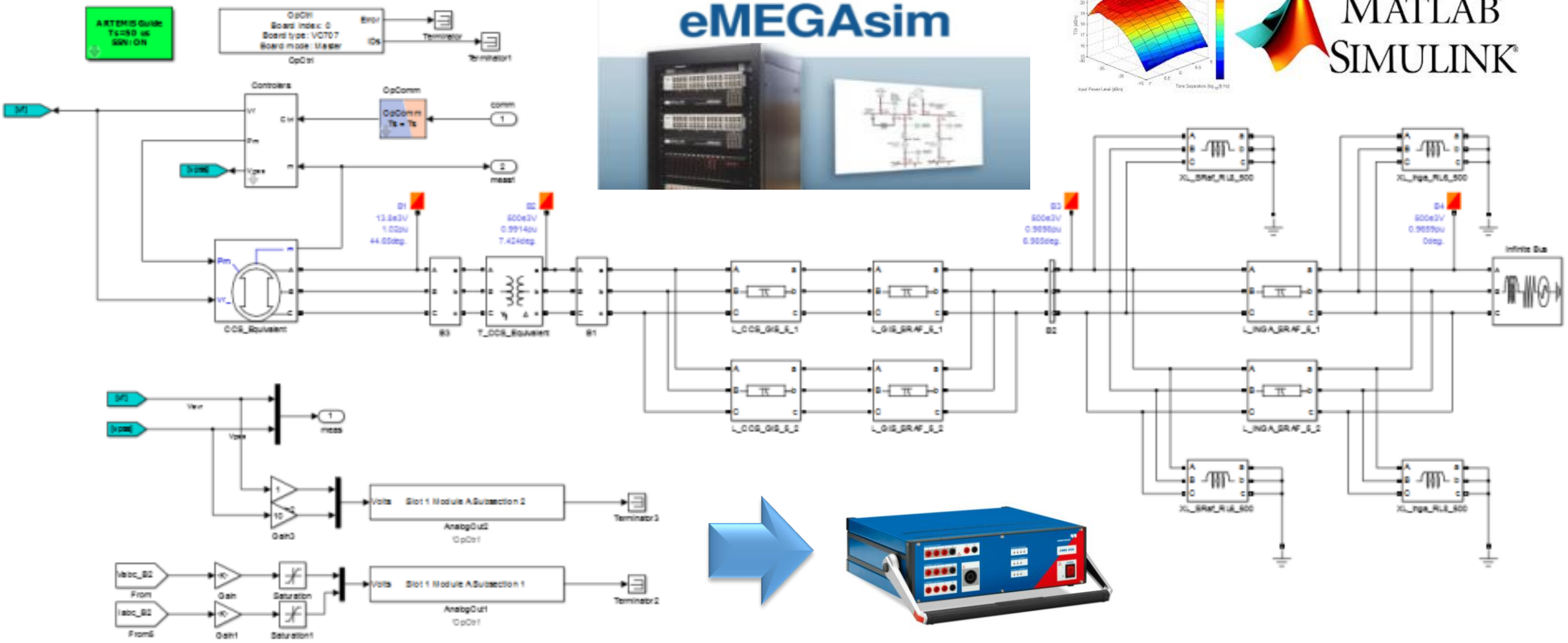
Field PSS tuning

Tuning validation tests

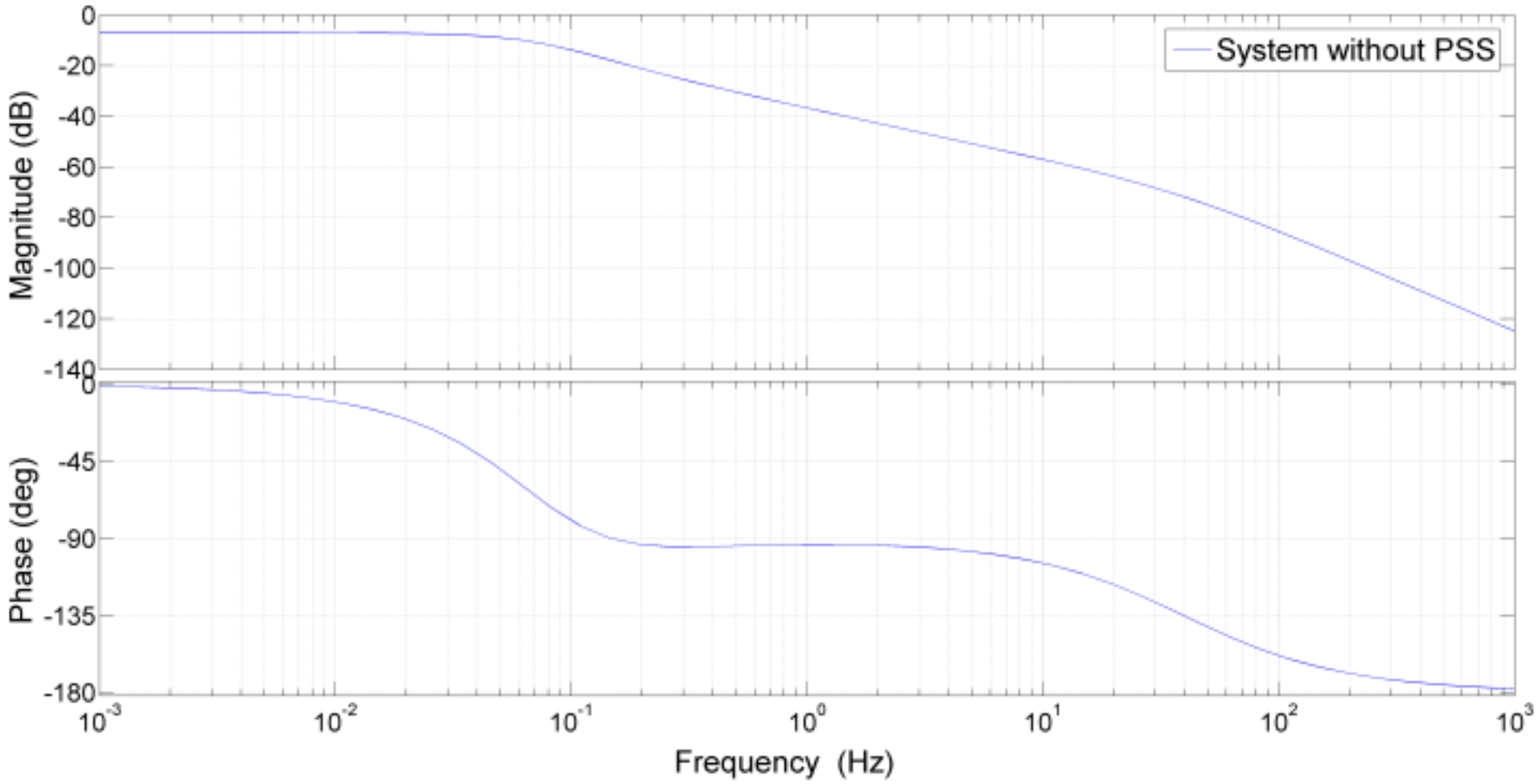
(WAProtector)

eMEGAsim

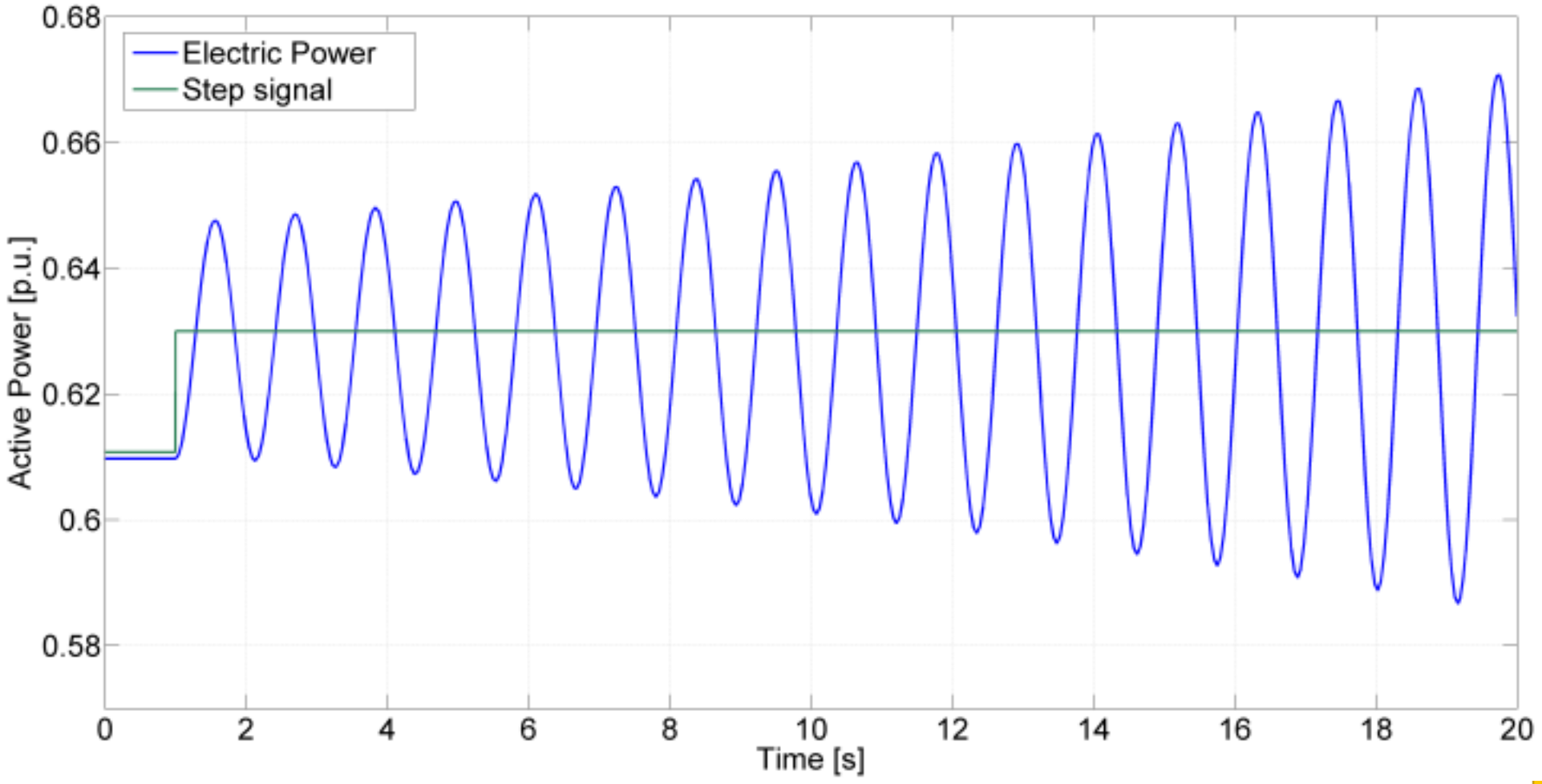
Modeling the Electric Power System



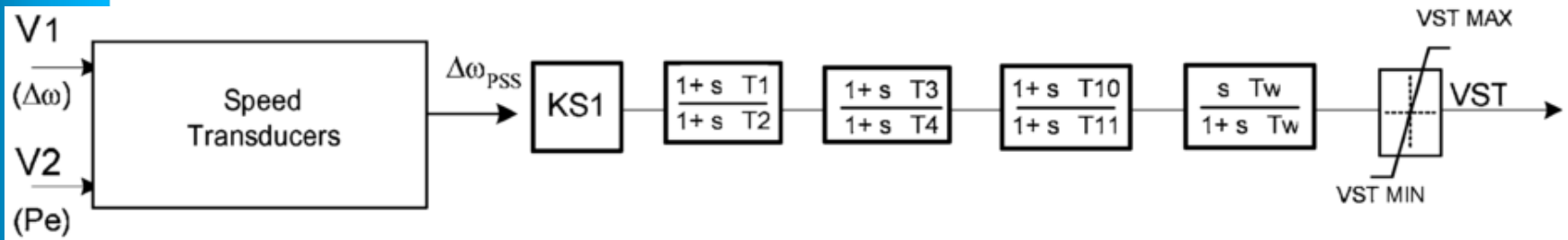
Bode diagram without PSS

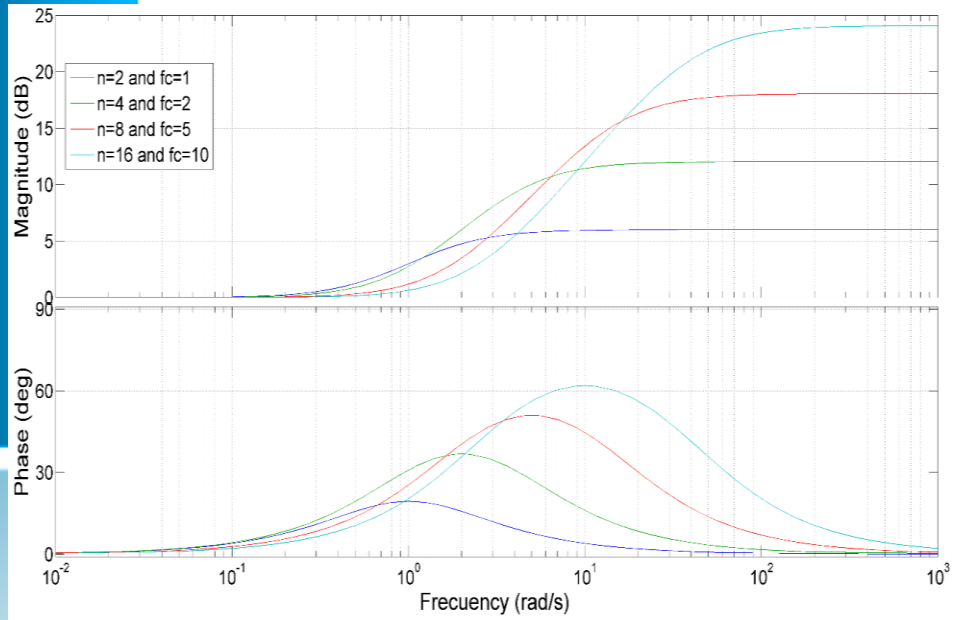


Oscillations detected by eMEGAsim - 1000 MW generation



PSS Tuning



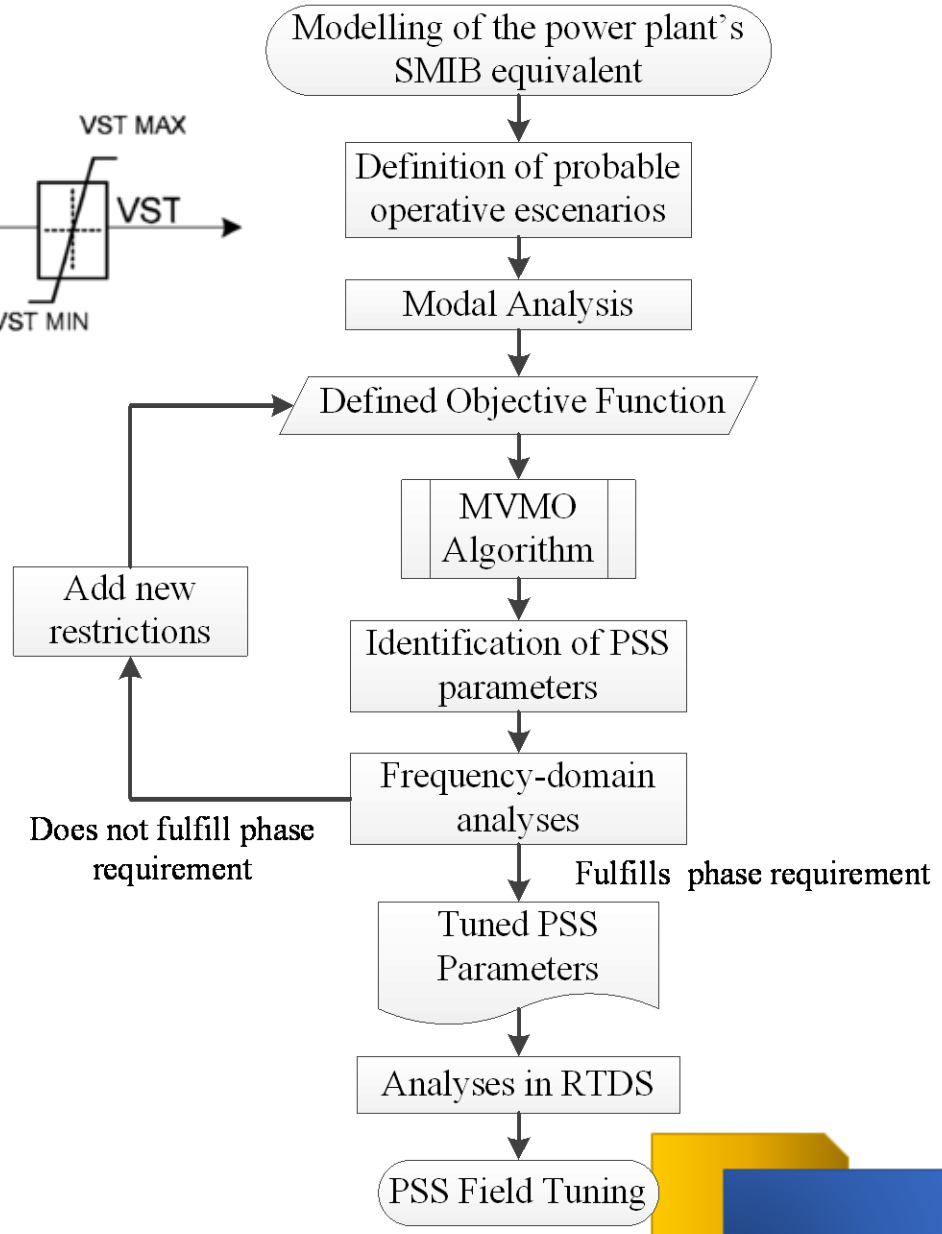


$$\min OF = \left|\xi_{th} - \xi_{sys}\right|$$

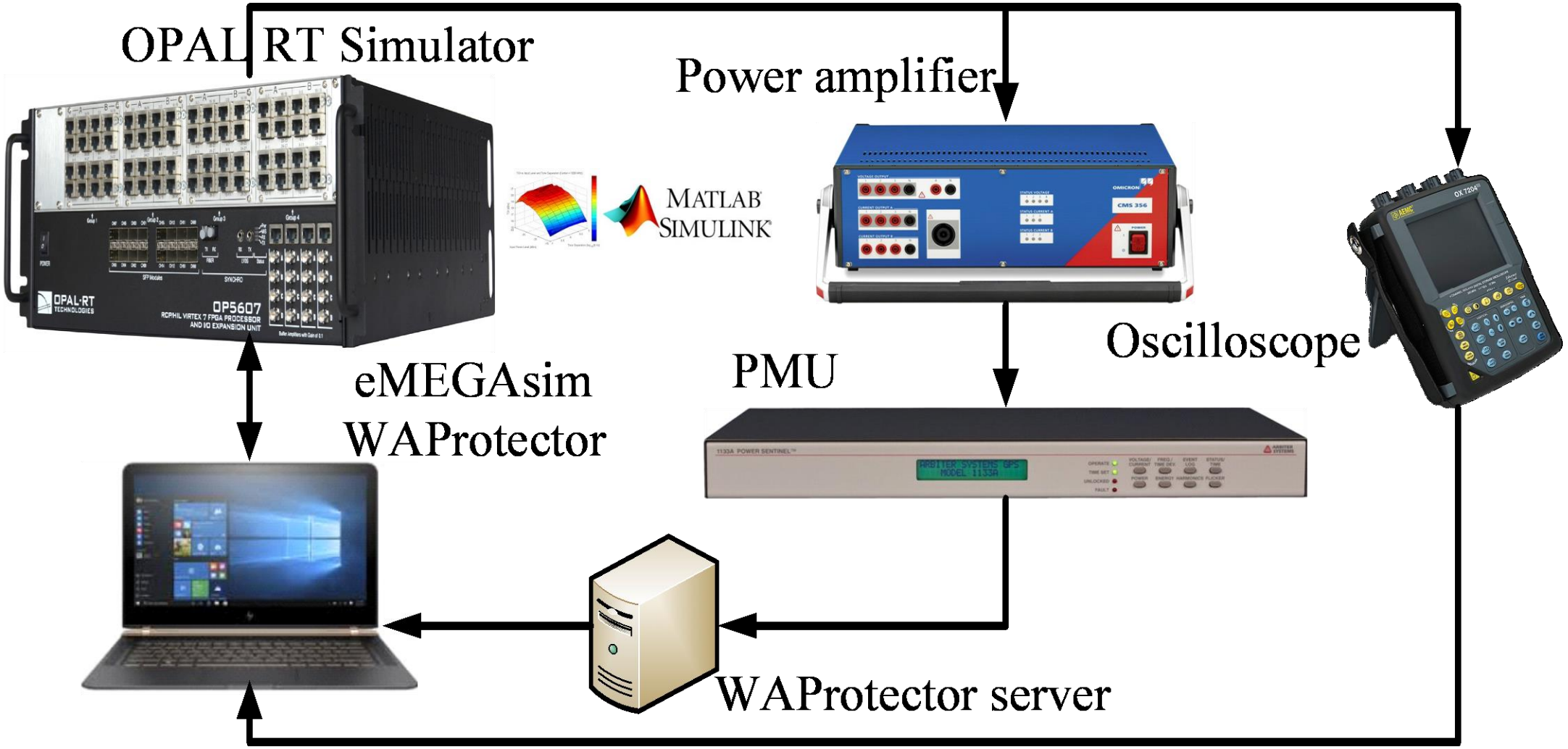
$$\xi_{sys} = \min_{p=1\ldots nm}\left(\xi_p\right)$$

$$\mathbf{x}_{j-\min} \le \mathbf{x}_j \le \mathbf{x}_{j-\max}$$

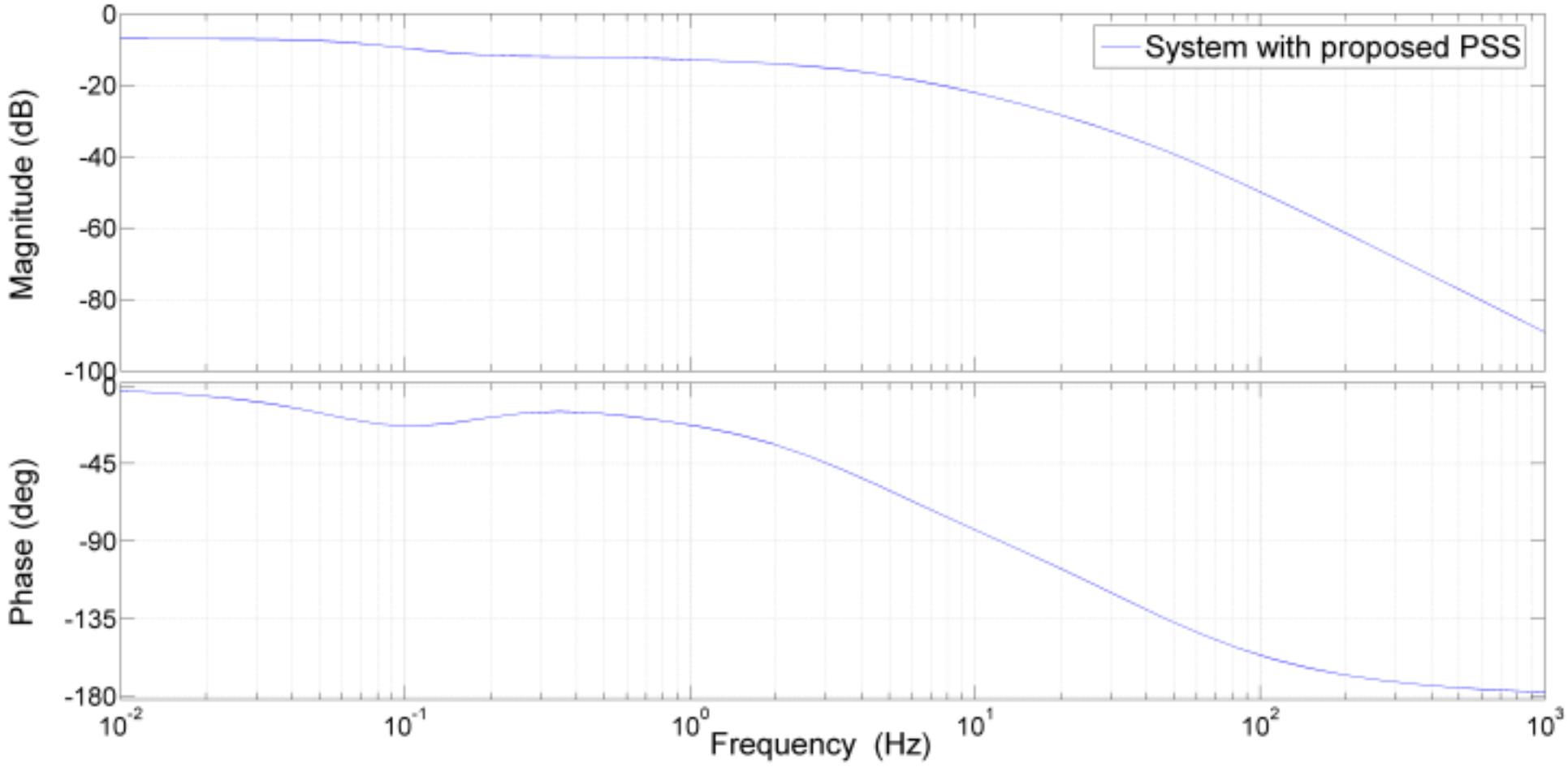
$$fc = \frac{1}{2\pi}\frac{1}{\sqrt{T_1 T_2}} \qquad n = \frac{T_1}{T_2}$$



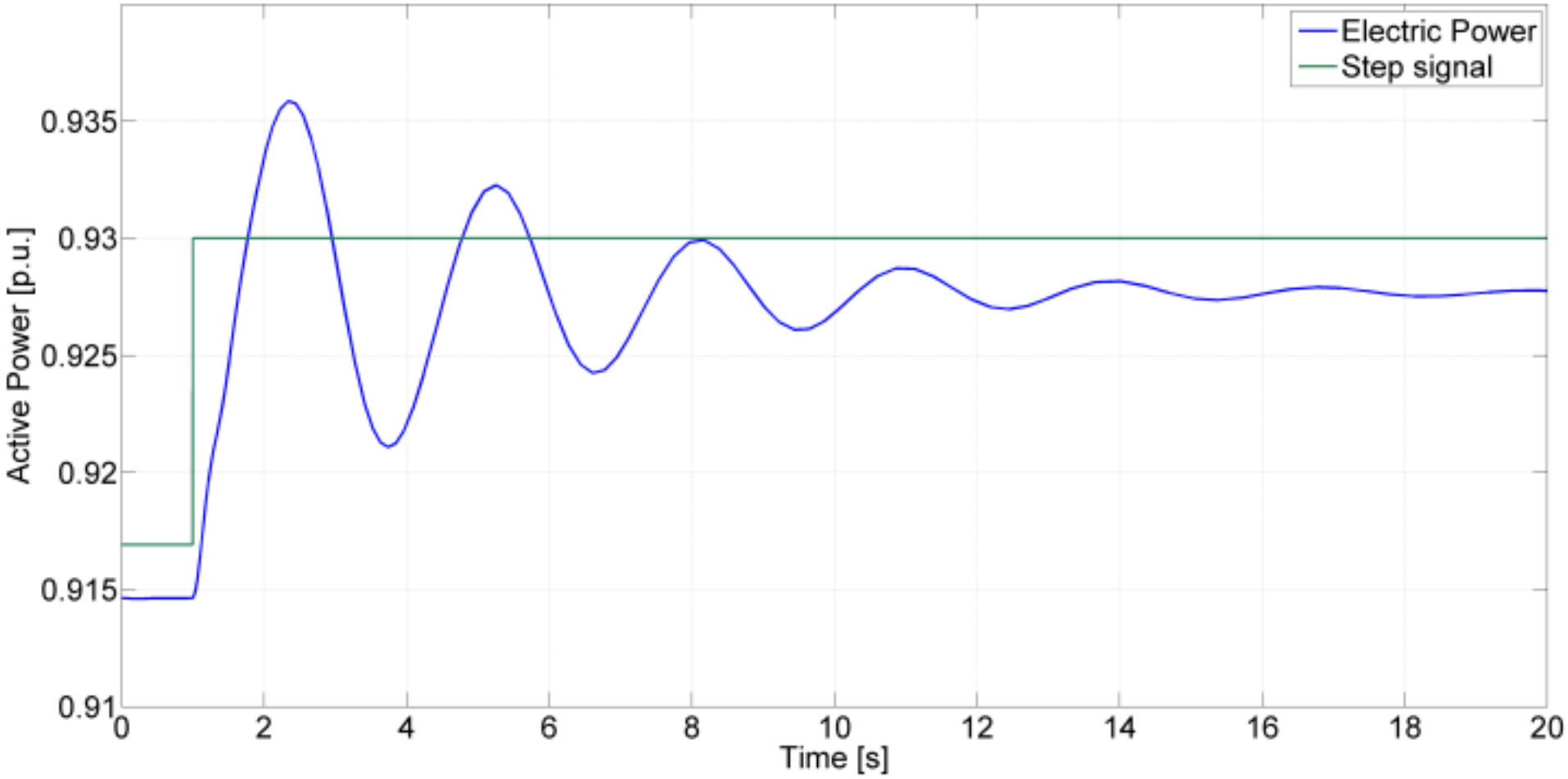
Testbed for PSS Tuning



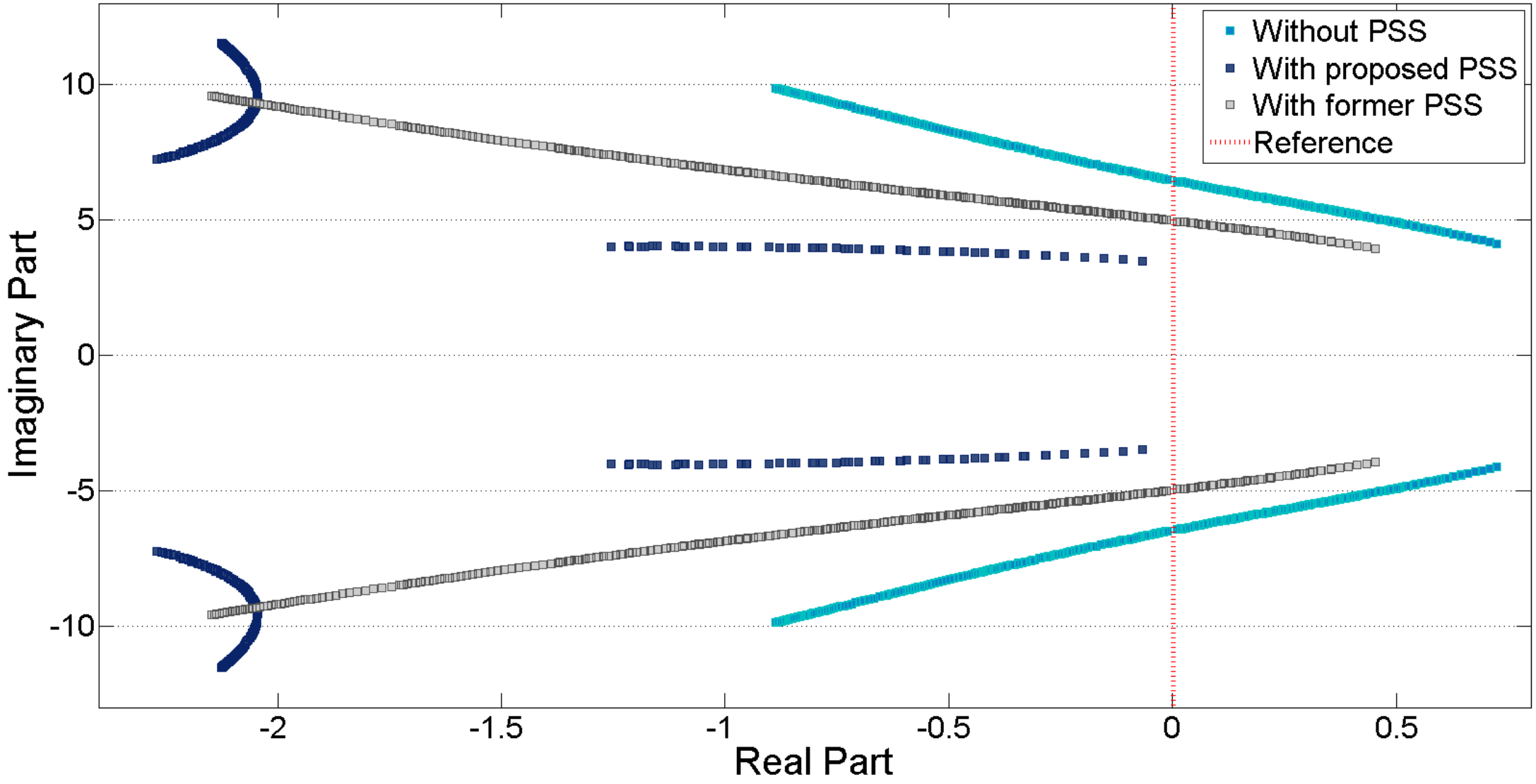
Bode diagram with the proposed PSS parameters



Oscillations detected by eMEGAsim - 1500 MW of generation



Root locus plot: different PSS and different scenarios (Monte Carlo)



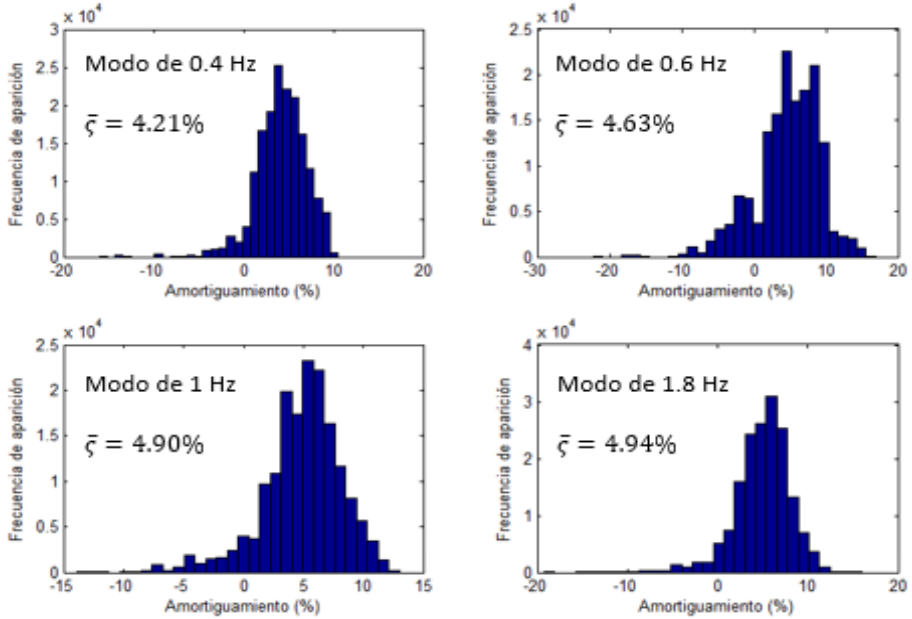
PSS Tuning Field Tests

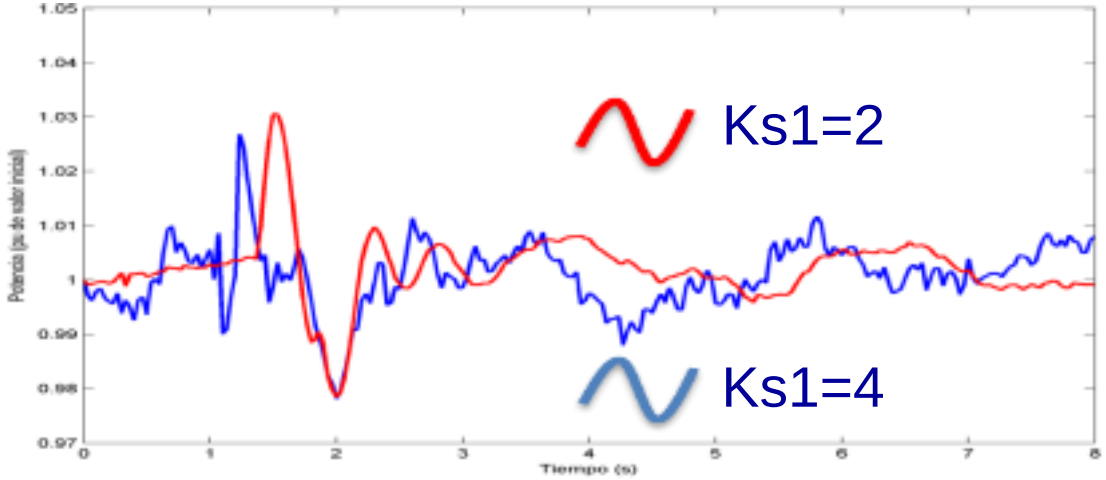
Pulse signal in the voltage reference of AVR

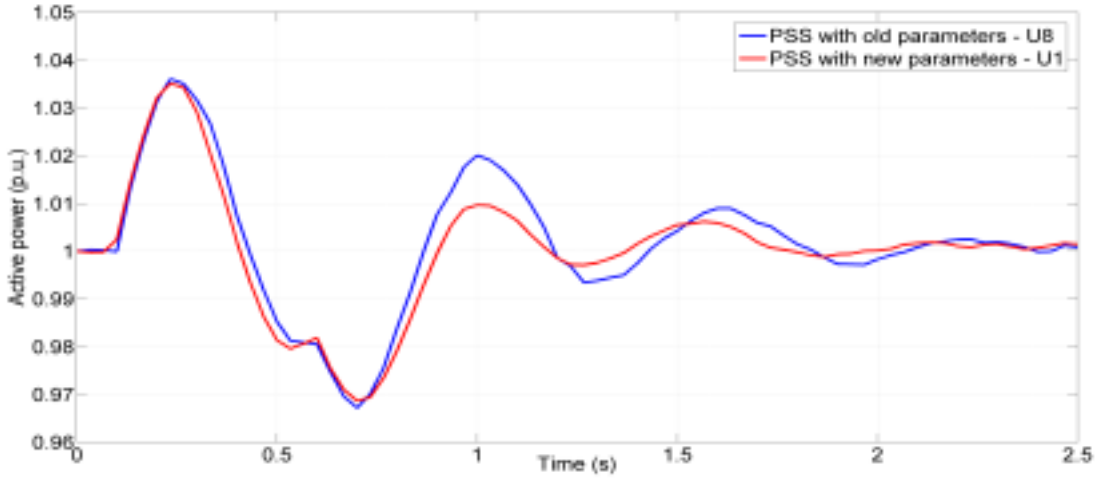
Excitation of oscillatory modes

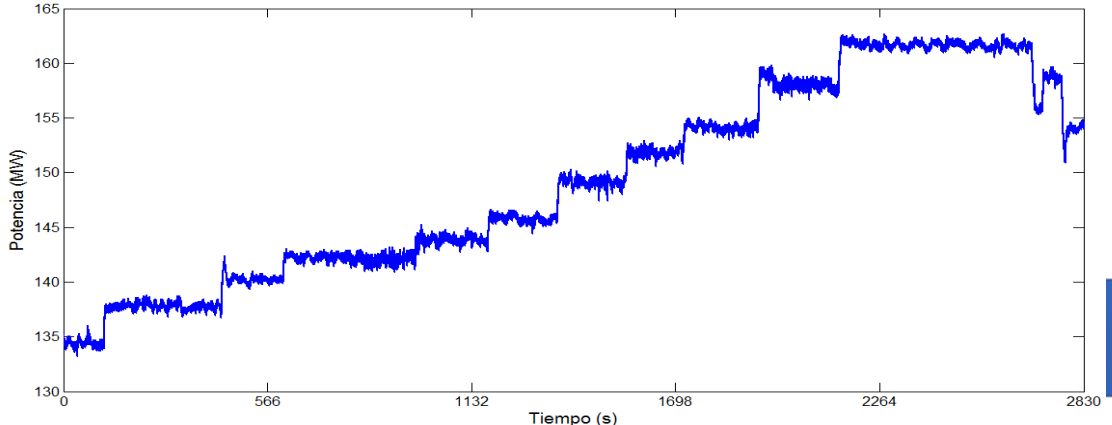
Control Mode excitation – Optimal PSS Gain (1/3 of max gain)

Oscillation damping assessment tests

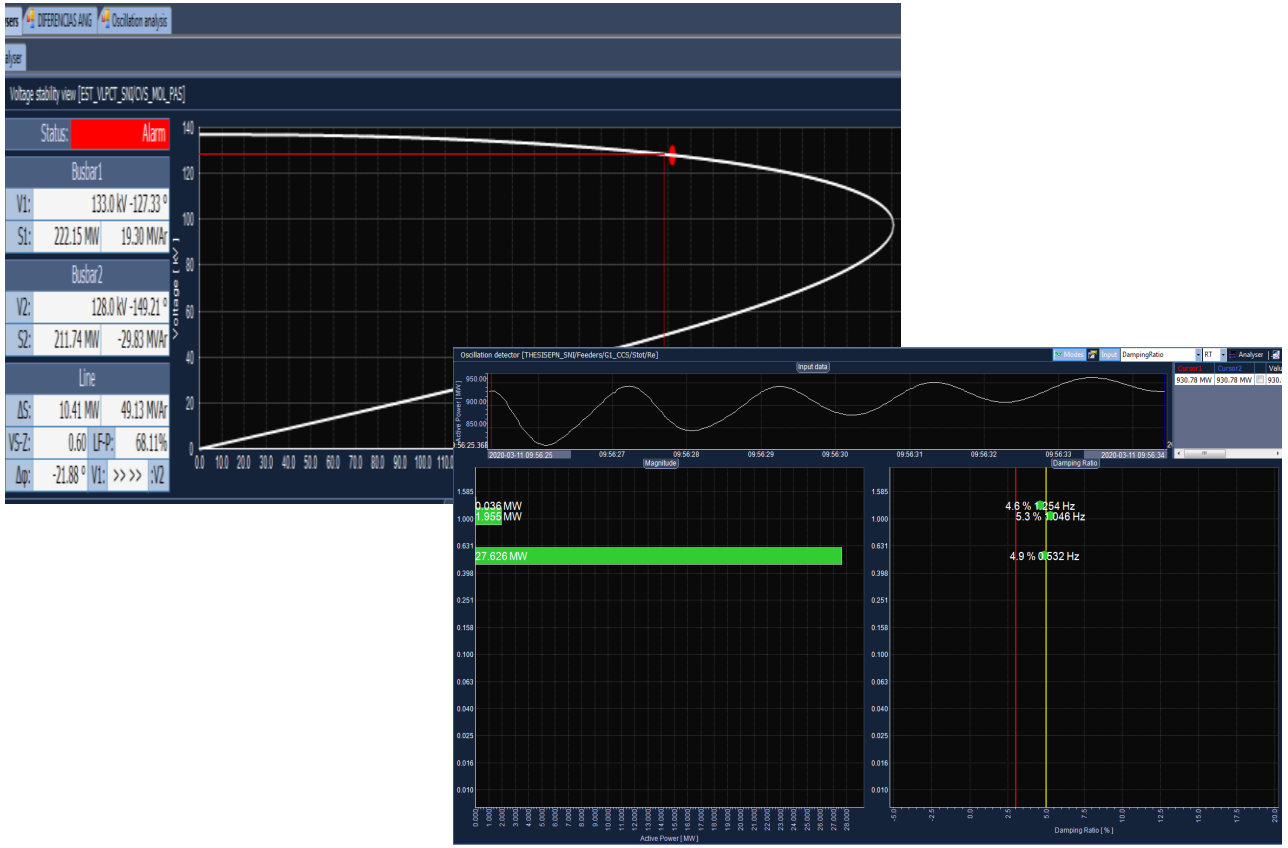








Operators' training Environment using ePHASORsim and WAMS



Implemented methodology

Power System

Dynamic Modelling

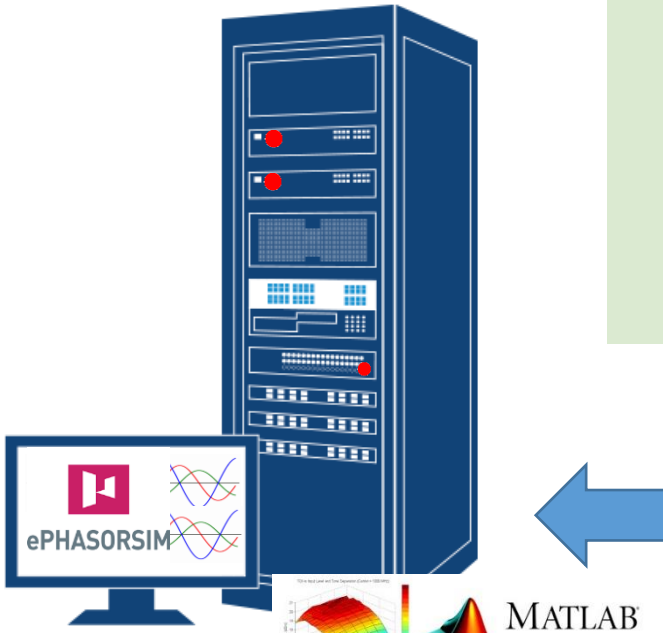
- Generator
- Automatic Voltage Regulator (AVR)
- Power System Stabilizer (PSS)
- Governor (GOV)

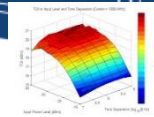
Static Modelling

- Load
- 2W, 3W Transformer
- Transmission lines

FMU

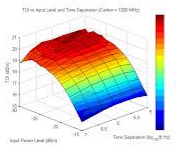
DGS





MATLAB SIMULINK

Implemented methodology

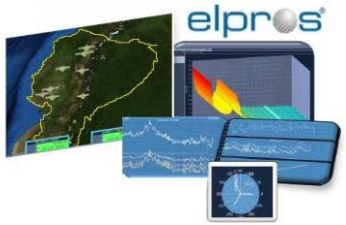


MATLAB SIMULINK

Real-Time Digital Simulator

Virtual PMU

C37.118



Wide Area Measurement Systems

WAMS' APPLICATIONS

- Angular Difference
- Oscillatory Stability
- Voltage Stability of Transmission Corridors
- Frequency Monitoring

- Dynamic Simulation (Operation Commands)
- Load Flow Simulation

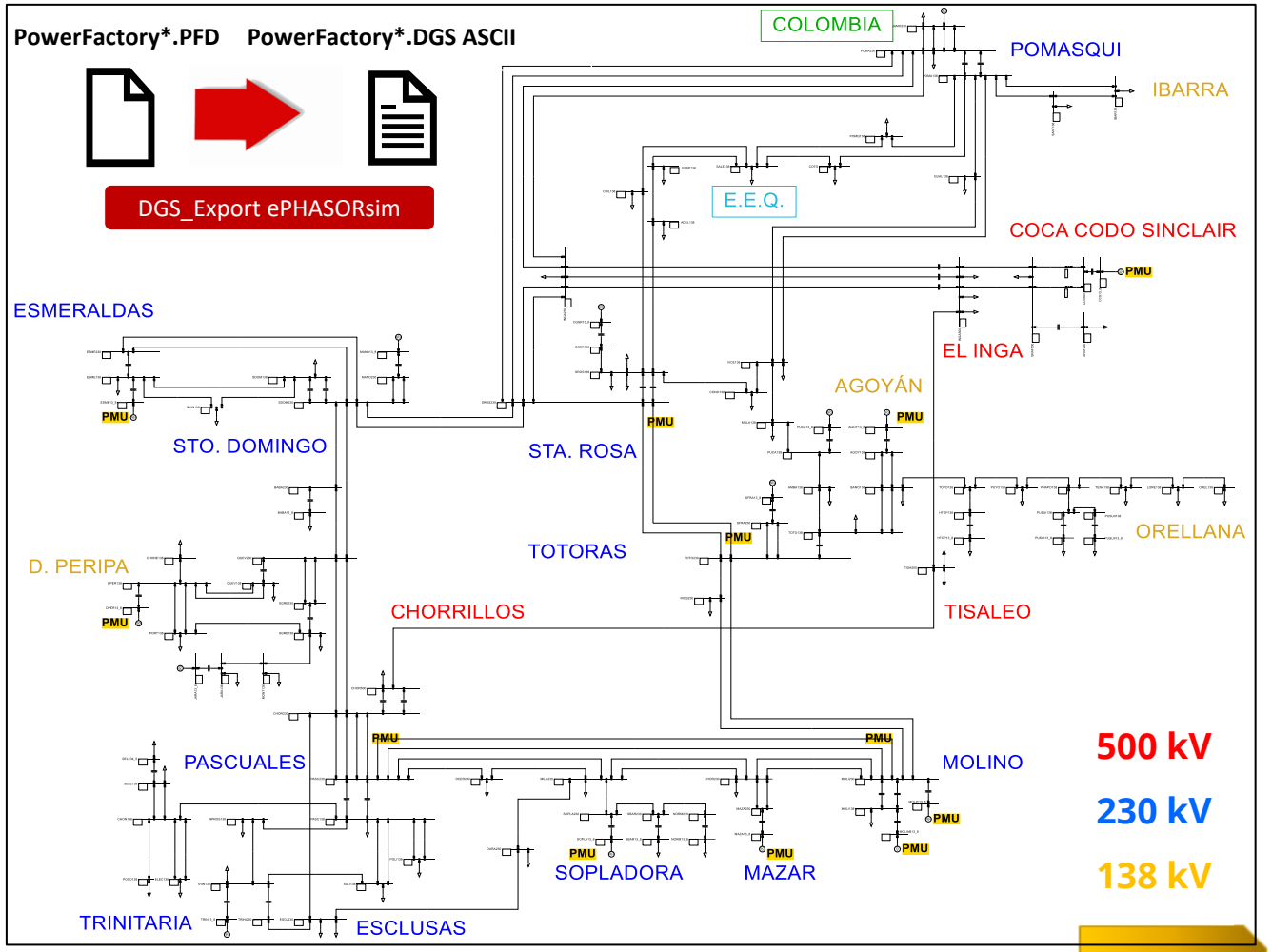
- Study Cases
- Generation and Demand

Training Environment

Modelling of Ecuadorian Power System

STATIC

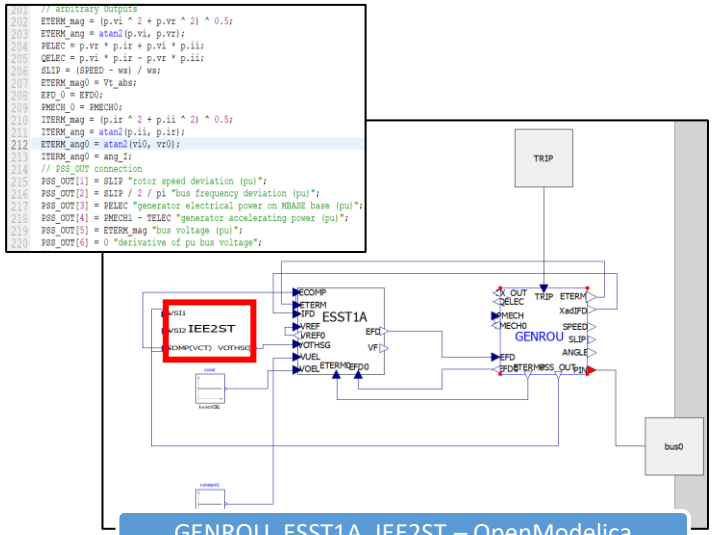
1. DIgSILENT PowerFactory
2. Reduced power system
3. 104 busbar, 42 transformers
4. Transmission-level voltages: 500 kV, 230 kV, 138 kV.
5. Six study cases



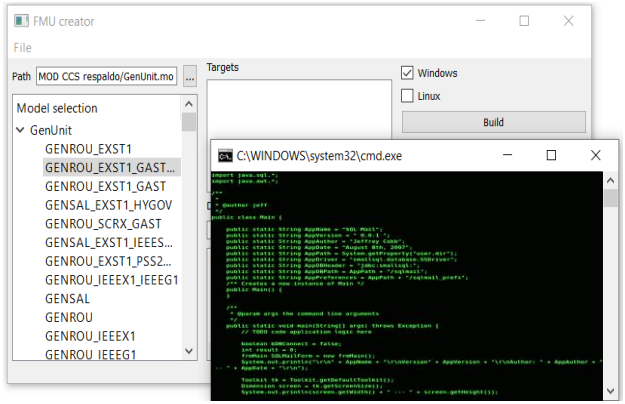
Modelling of Ecuadorian Power System

DYNAMIC

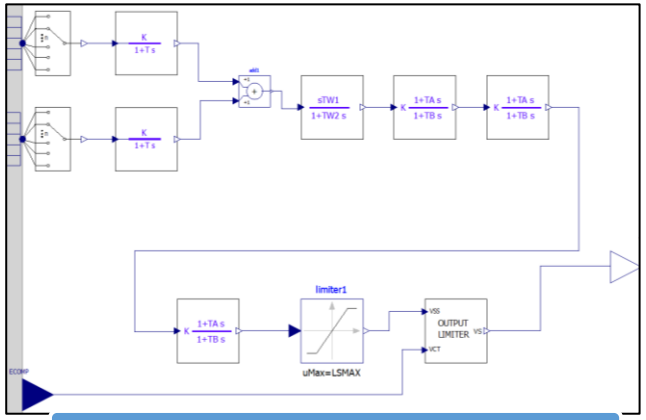
1. OpenModelica-r22929
2. 15 Synchronous Machines
3. Dynamic controller models (AVR, PSS, GOV)
4. Opal-RT and GenUnit Library
5. Block Diagram and DSL



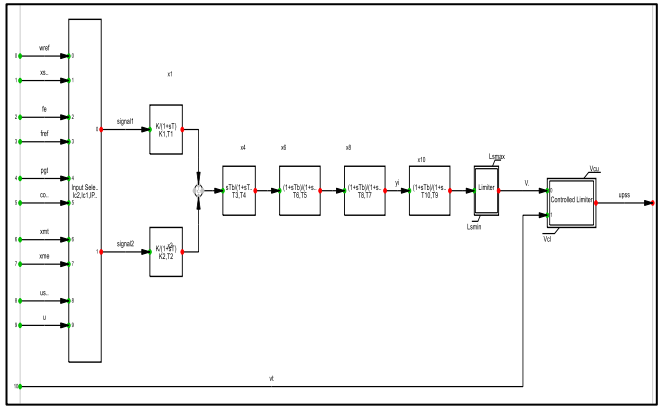
GENROU_ESST1A_IEE2ST – OpenModelica



FMU Creator

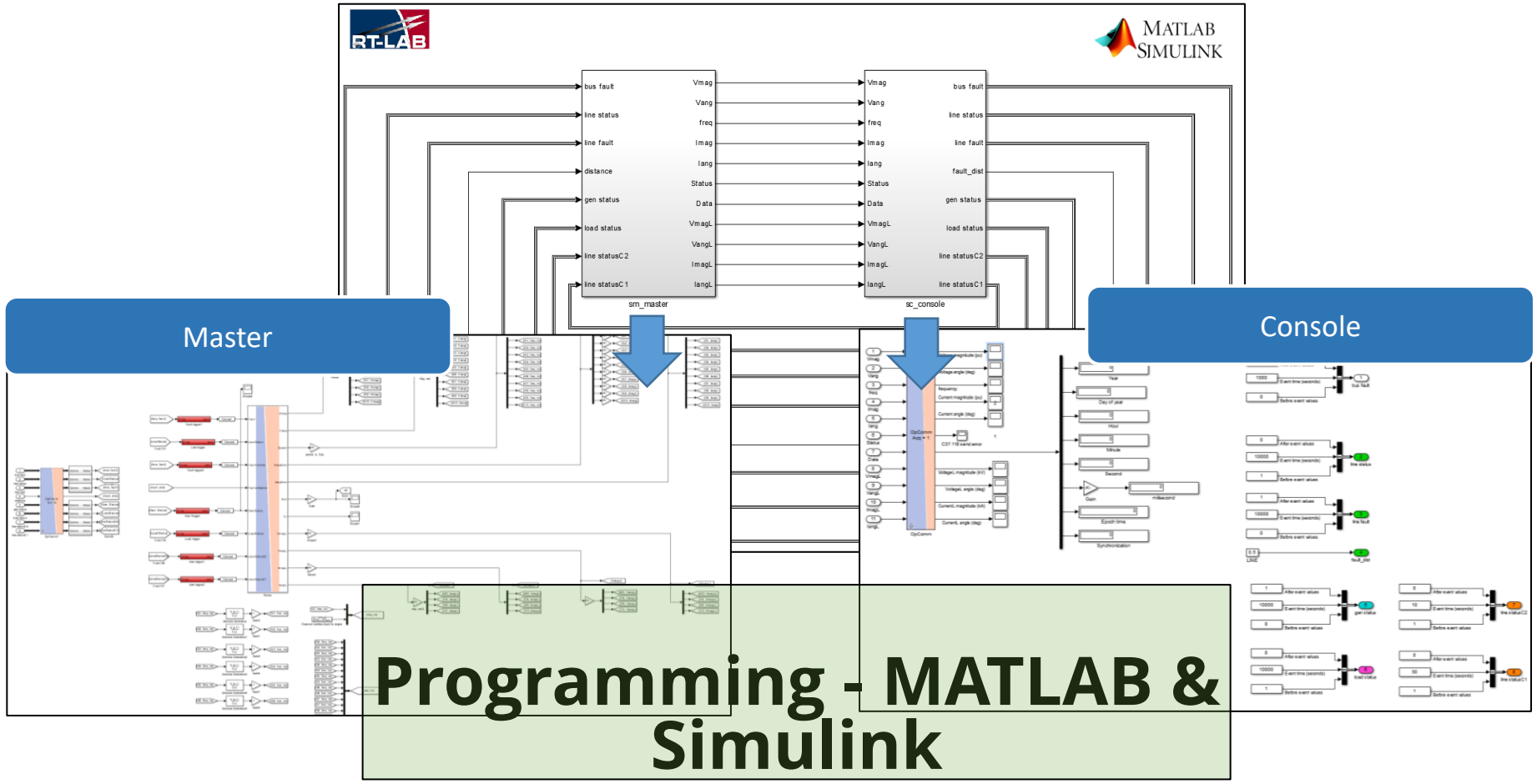


IEE2ST Block Diagram - OpenModelica

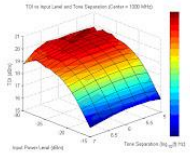


IEE2ST Block Diagram – DIgSILENT Simulation Language

ePHASORsim interface

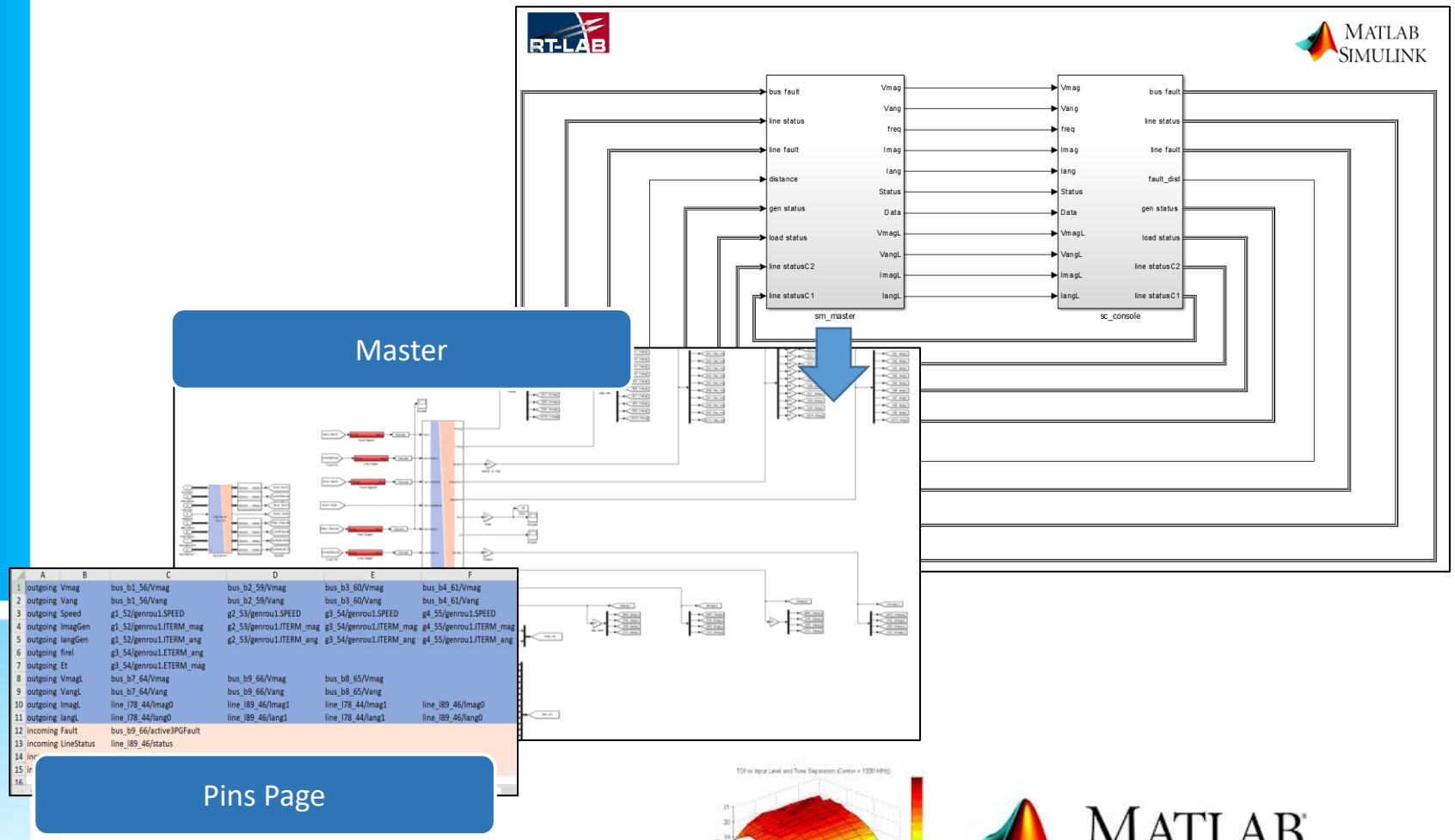


Programming - MATLAB & Simulink



MATLAB SIMULINK

ePHASORsim interface



MASTER:

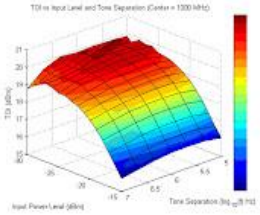
Off-line simulation

ePHASORsim solver

Input and output signals

Time Step

Network data page



MATLAB SIMULINK

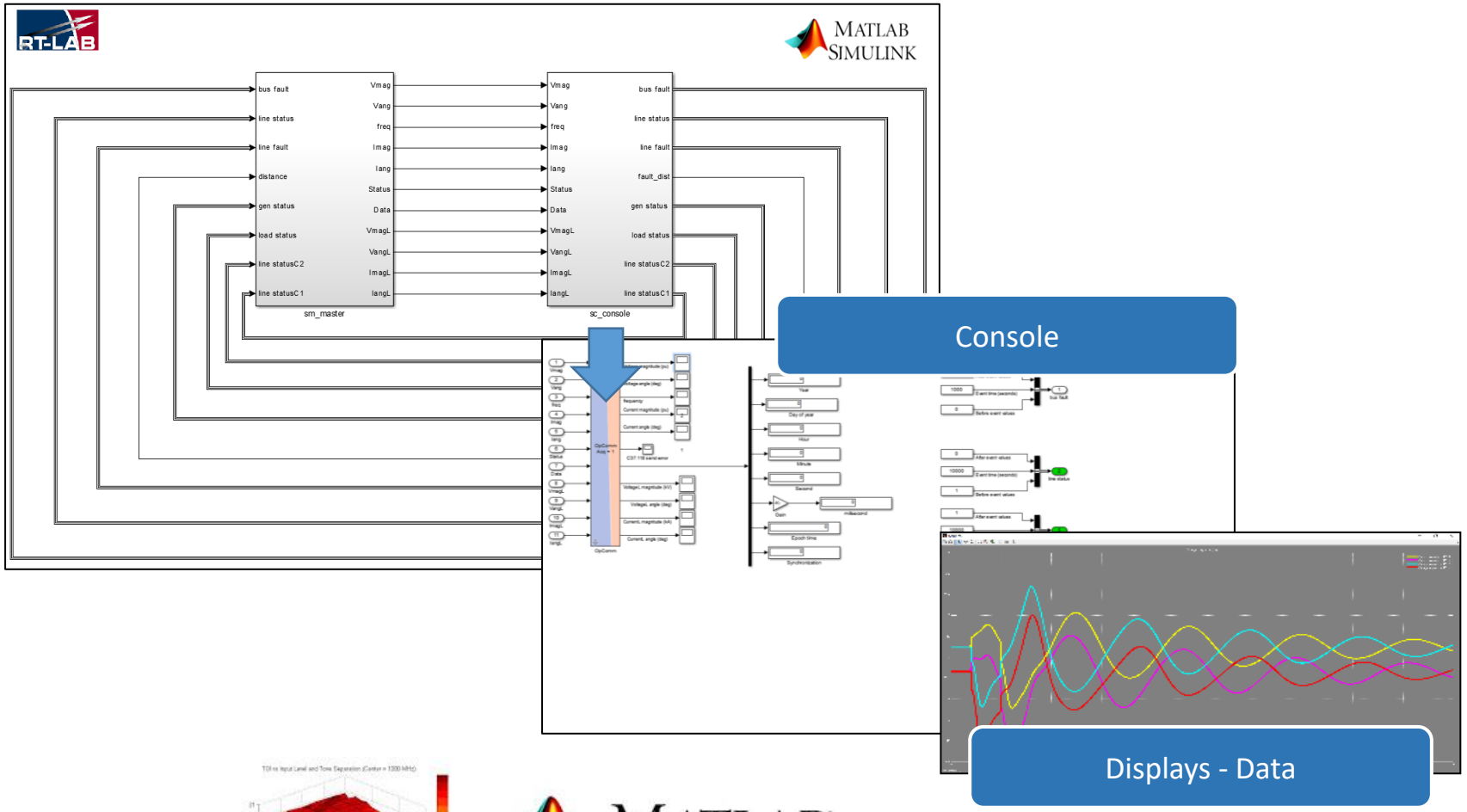
ePHASORsim interface

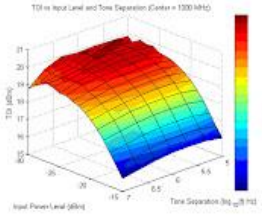
CONSOLE:

Real-time simulation

Operator commands

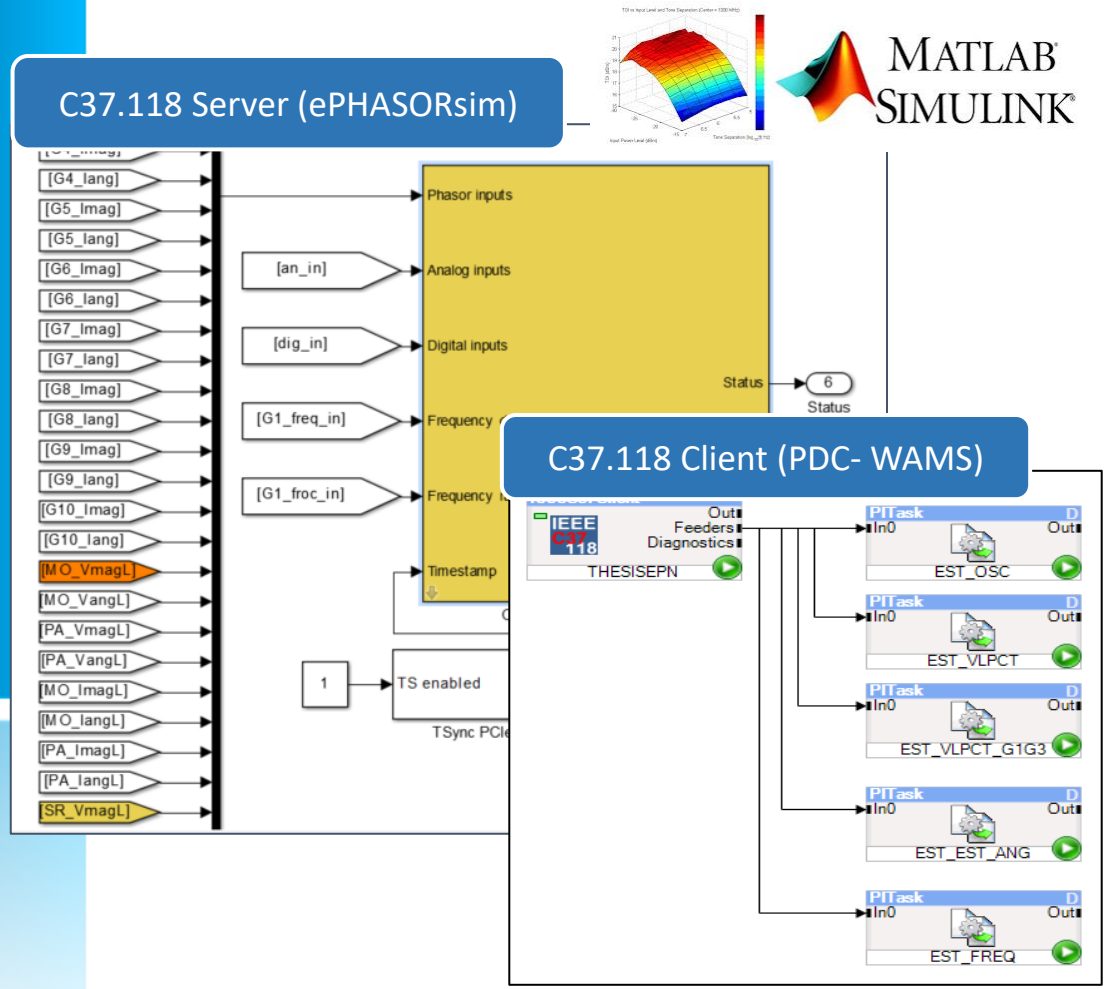
Output variables



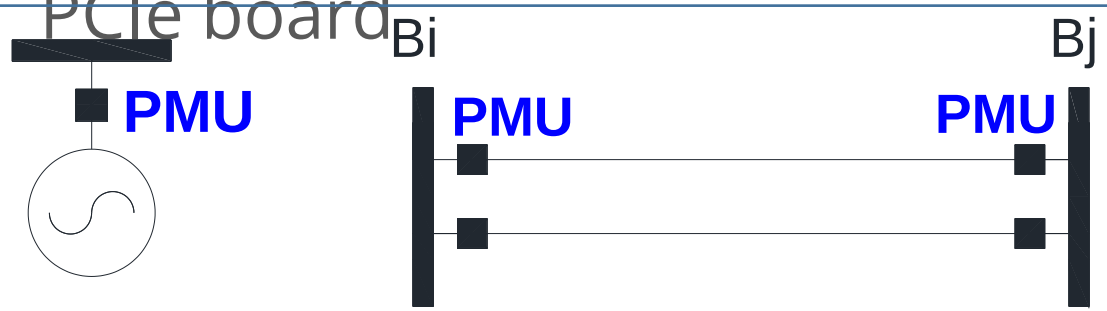


MATLAB SIMULINK

ePHASORsim – WAProtector integration



1. Client-Server Communication
2. IEEE Std C37.118.2-2011
3. TCP IP Protocol
4. GPS synchronized Spectracom TSync PCIe board



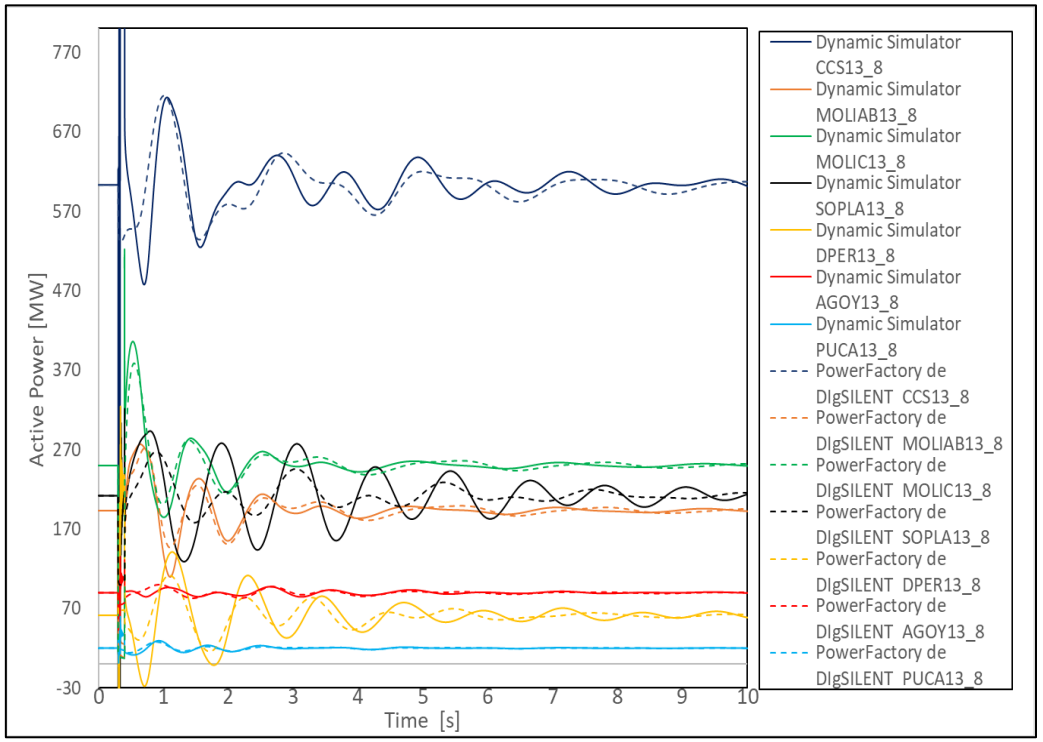
10 Generators and 2 Transmission Corridors are monitored.
Number of PMUs depends on training needs.

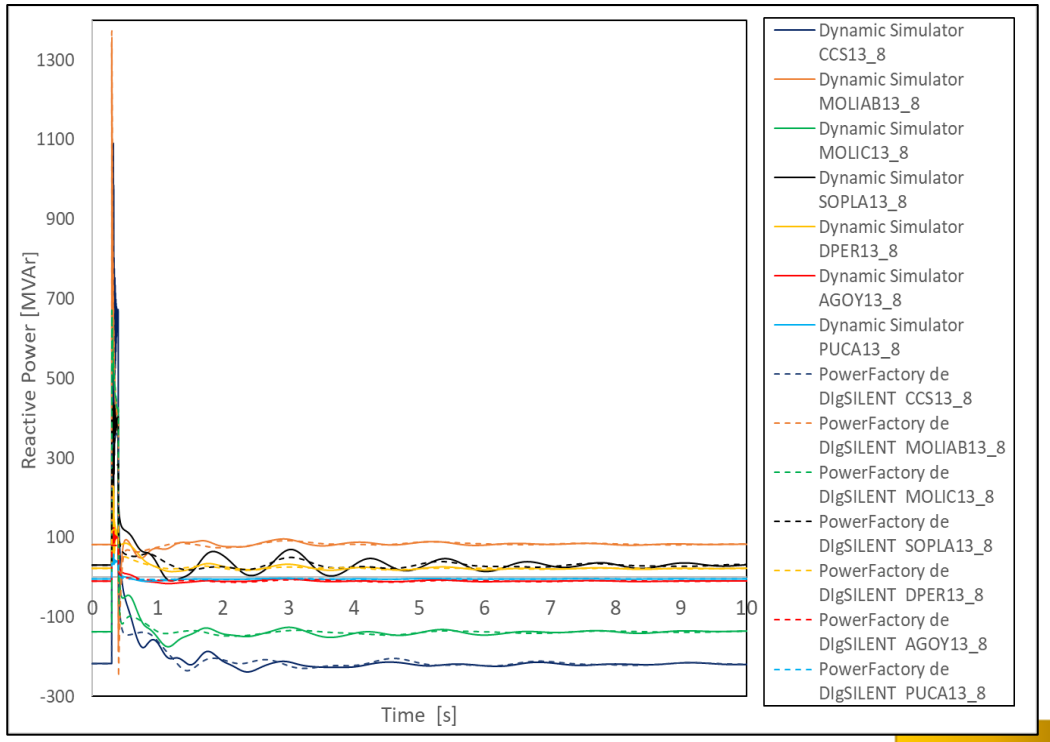
Offline Simulation and Results

Dynamic Simulation - Active and Reactive Power Generation

Low demand – High hydrology Scenario

Three-phase fault on Molino 230 kV Busbar



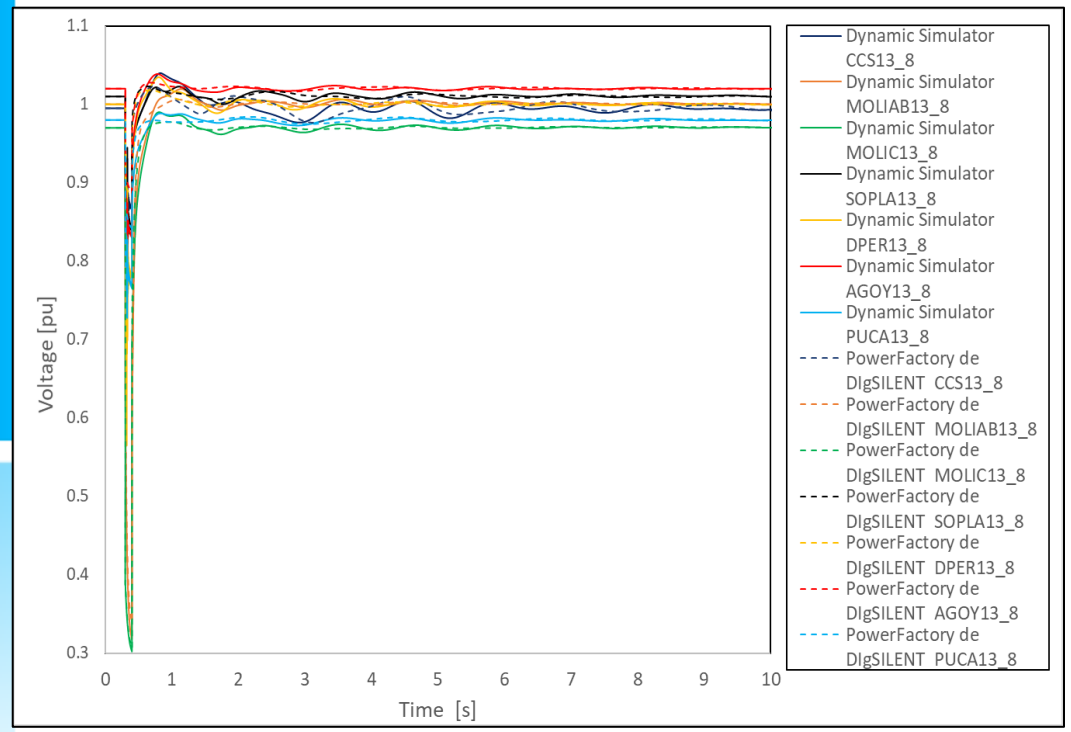


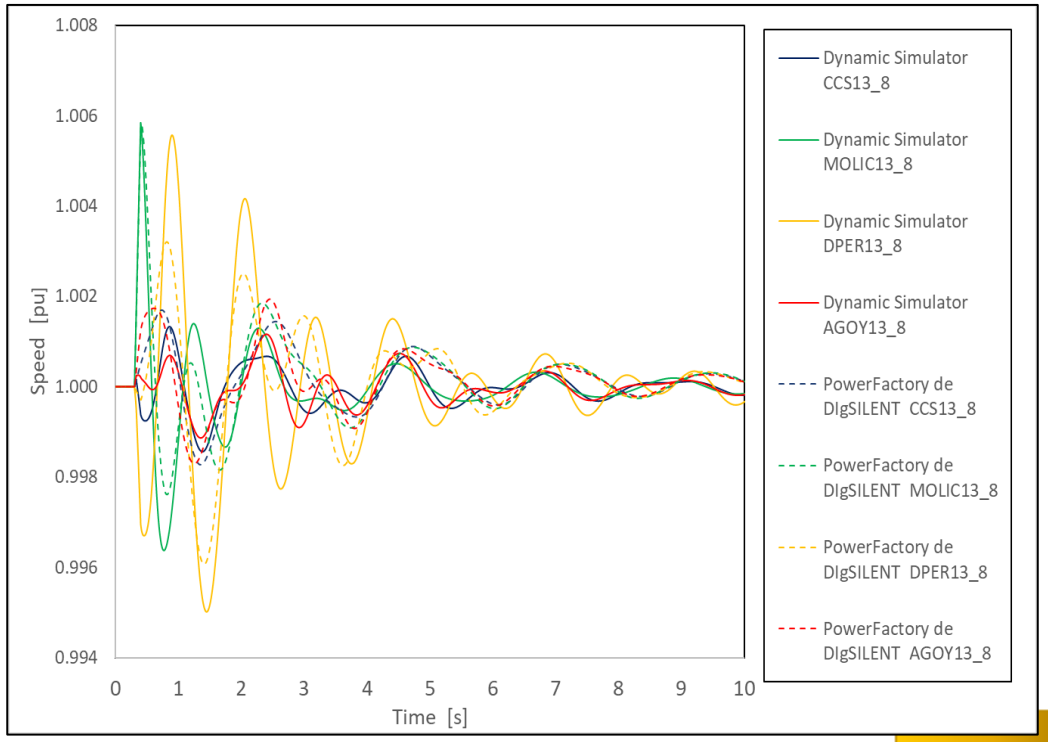
Offline Simulation and Results

Dynamic Simulation - Voltage and Speed Generation

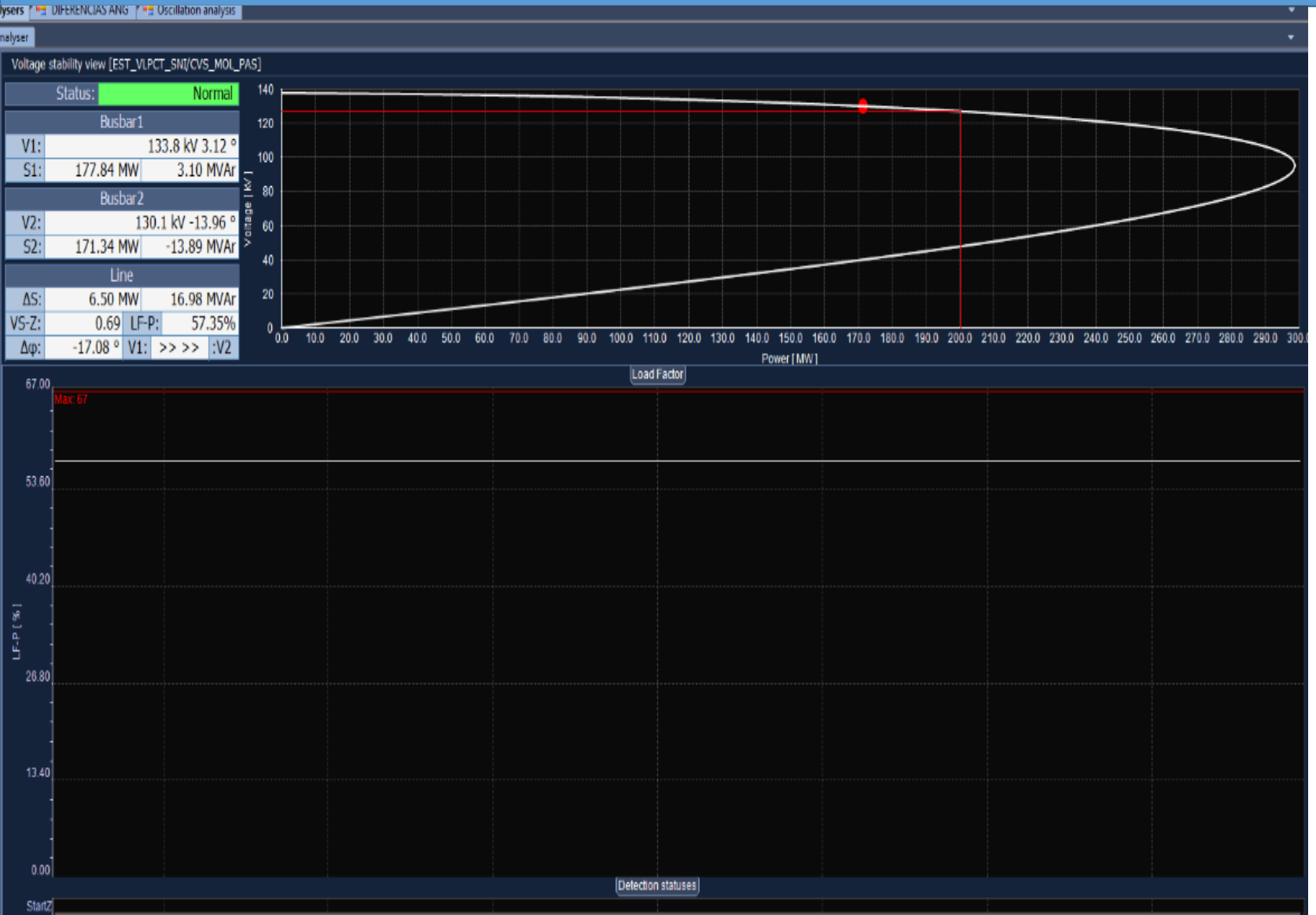
Low demand – High hydrology Scenario

Three-phase fault on Molino 230 kV Busbar



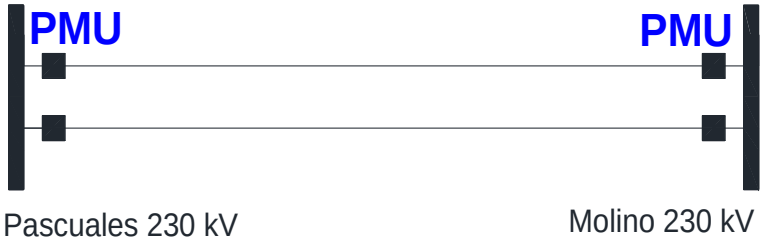


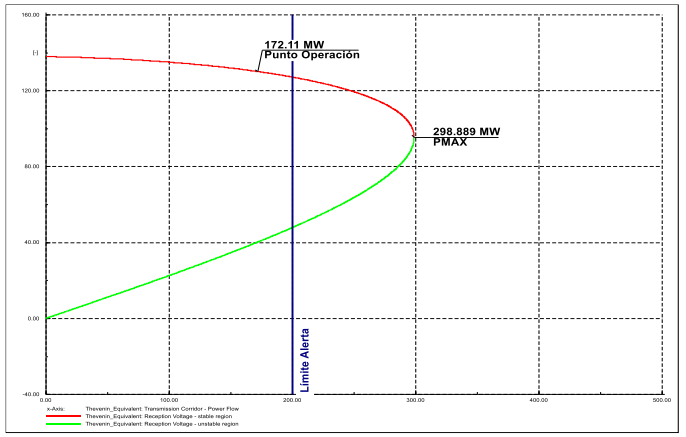
Real-Time Simulation and Results



Voltage Stability of Transmission Corridors (WAMS)

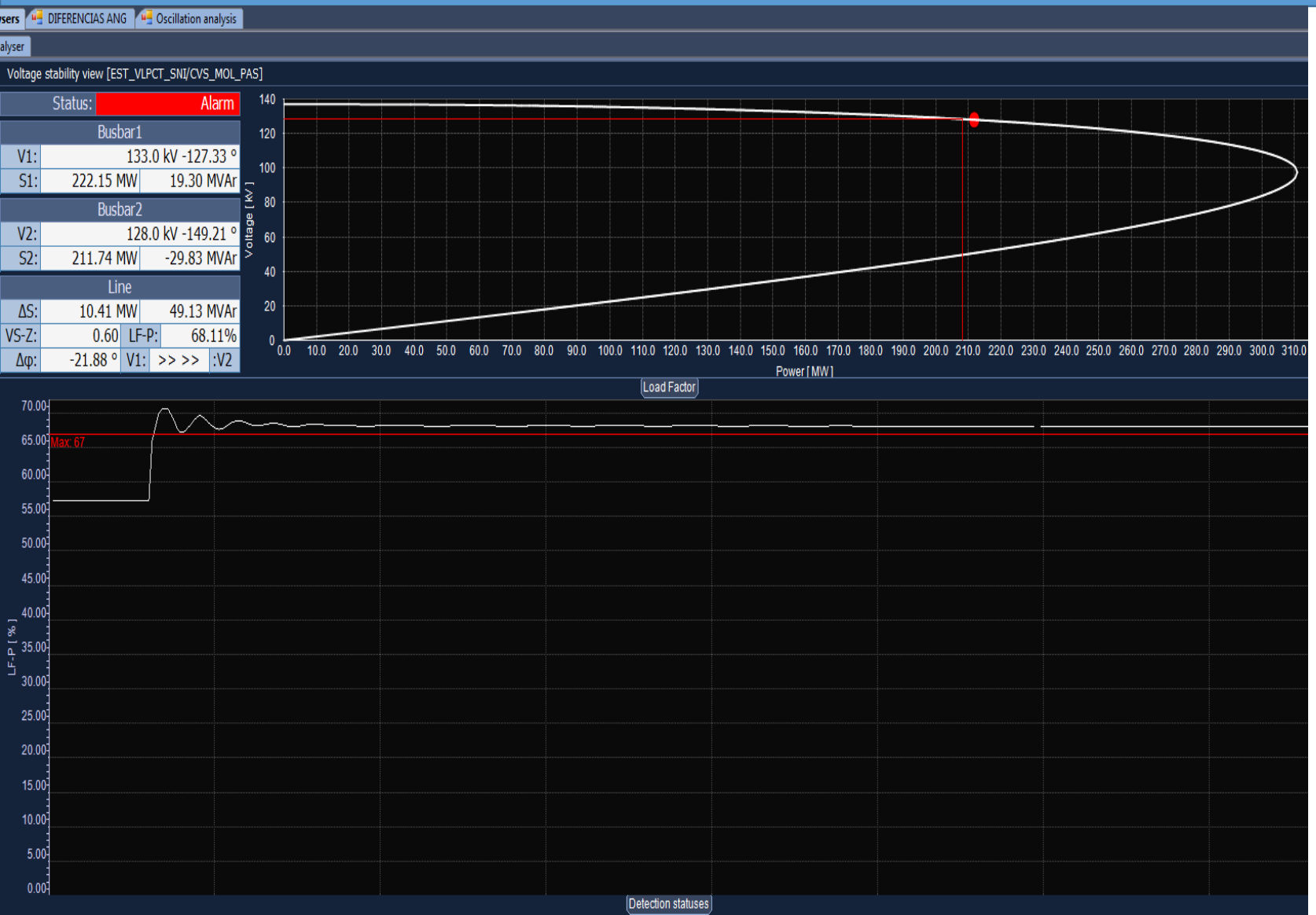
Medium demand – High hydrology Scenario





$$V_2 = \sqrt{\frac{V_{th}^{\ 2}}{2} - (Q_c X_{th} + P_c R_{th}) \pm \sqrt{\frac{V_{th}^{\ 4}}{4} - V_{th}^{\ 2}(Q_c X_{th} + P_c R_{th}) - (P_c X_{th} - Q_c R_{th})^2}}$$

Real-Time Simulation and Results

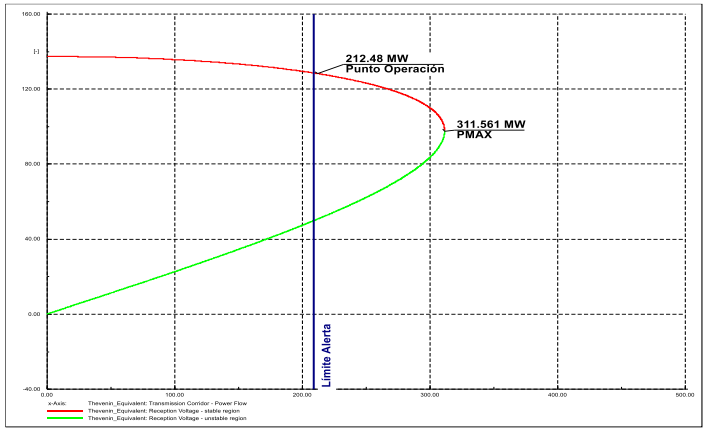


Voltage Stability of Transmission Corridors (WAMS)

Medium demand – High hydrology Scenario

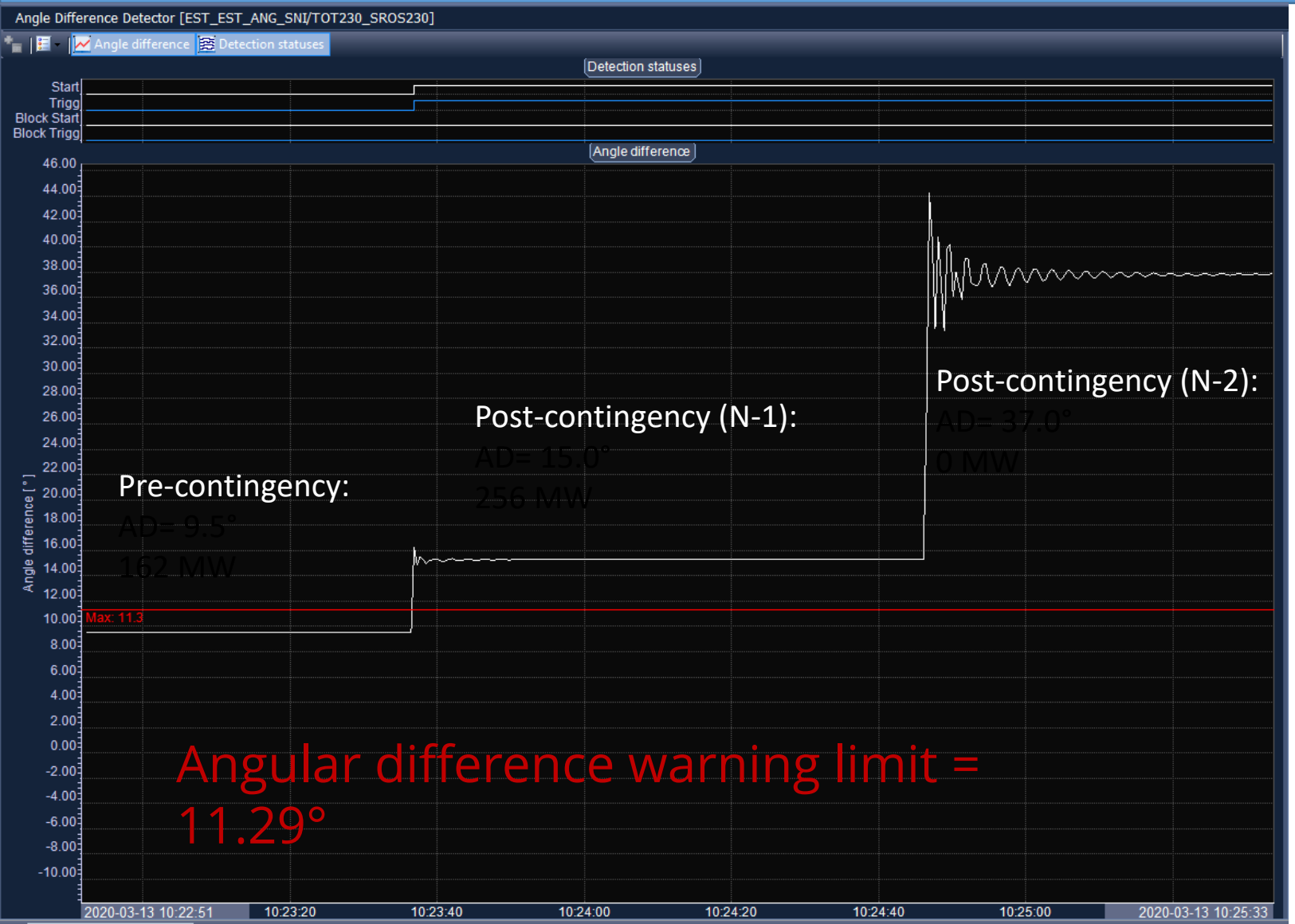
Pascuales 230 kV

Molino 230 kV



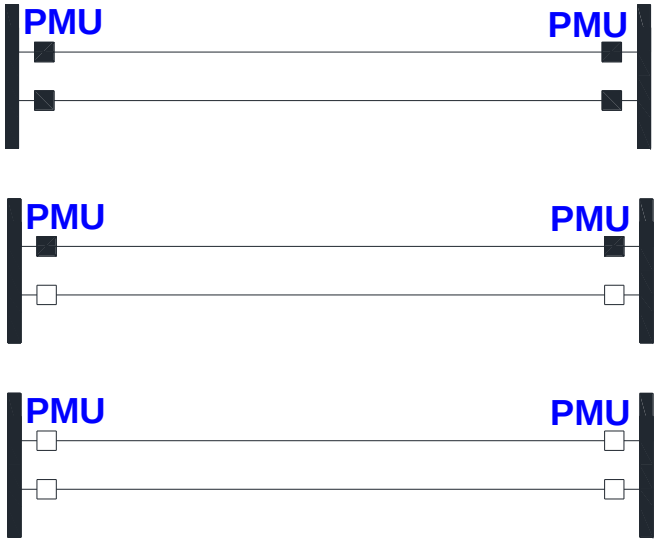
$$V_2 = \sqrt{\frac{V_{th}^{\ 2}}{2} - (Q_c X_{th} + P_c R_{th}) \pm \sqrt{\frac{V_{th}^{\ 4}}{4} - V_{th}^{\ 2}(Q_c X_{th} + P_c R_{th}) - (P_c X_{th} - Q_c R_{th})^2}}$$

Real-Time Simulation and Results



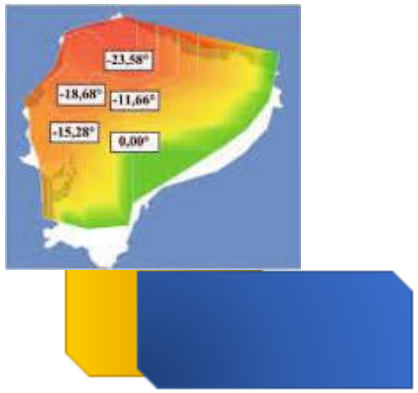
Angular Difference (WAMS)

Medium demand – High hydrology Scenario

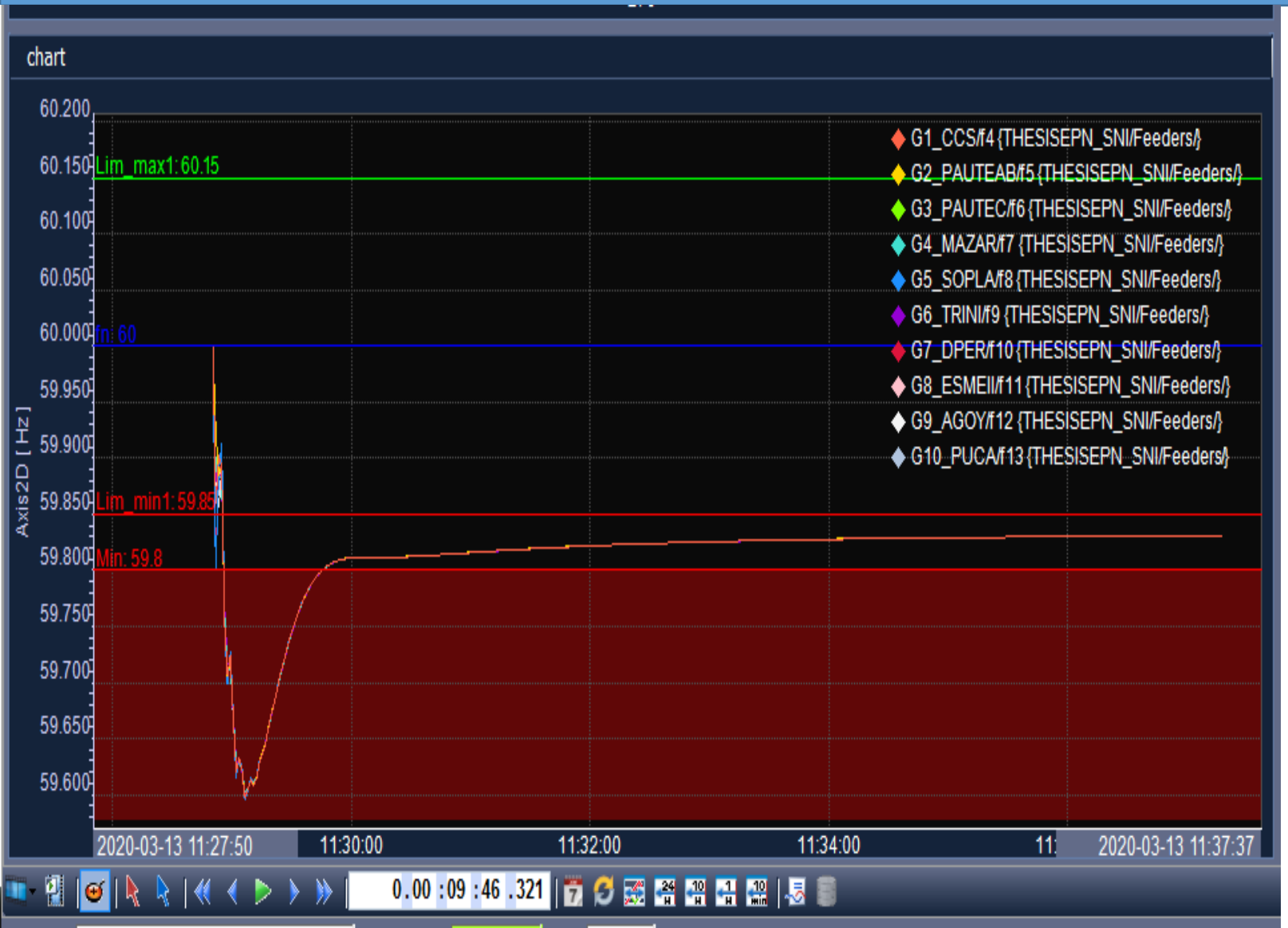


$$P_{AB} = \frac{V_A V_B \sin(\theta_A - \theta_B)}{x} \approx \frac{V_A V_B (\theta_A - \theta_B)}{x}$$

$$P_{AB} \; \alpha \; (\theta_A - \theta_B)$$

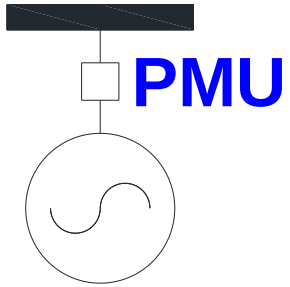


Real-Time Simulation and Results



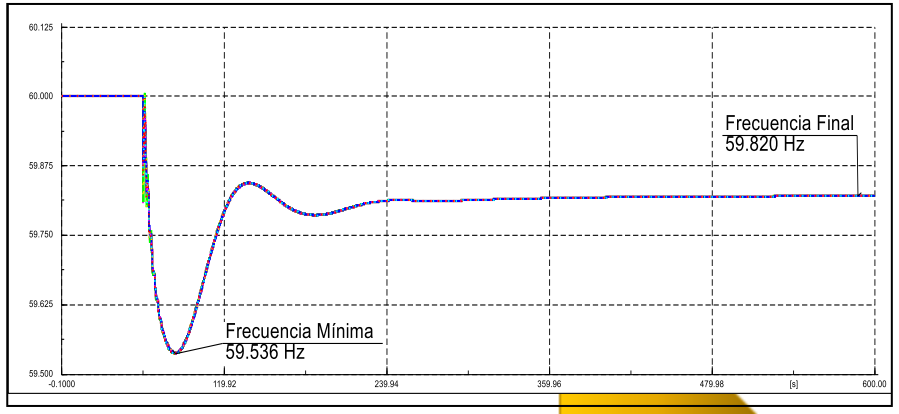
Frequency Monitoring (WAMS)

Medium demand – Low hydrology Scenario

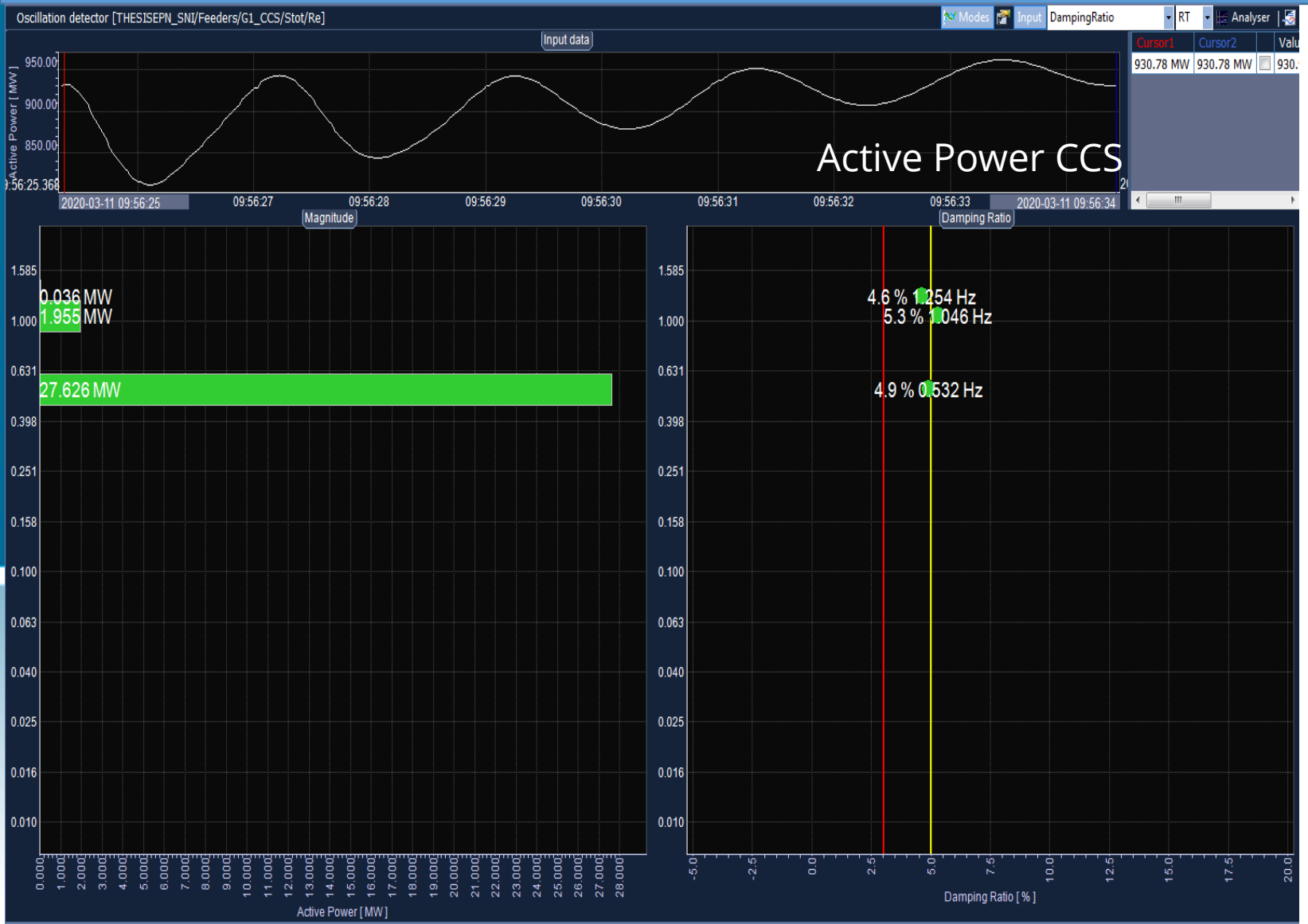


Paute C

Generation Trip (260 MW)

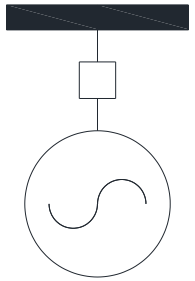


Real-Time Simulation and Results



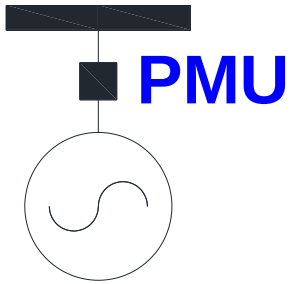
Oscillatory Stability (WAMS)

Medium demand – Low hydrology Scenario



Paute C

Generation Trip (260 MW)



Coca Codo Sinclair

$$\lambda = \sigma \pm j\omega$$

$$\xi = \frac{-\sigma}{\sqrt{\sigma^2 + \omega^2}}$$

$$f = \frac{\omega}{2\pi}$$

THANK YOU

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cenace
OPERADOR NACIONAL DE ELECTRICIDAD