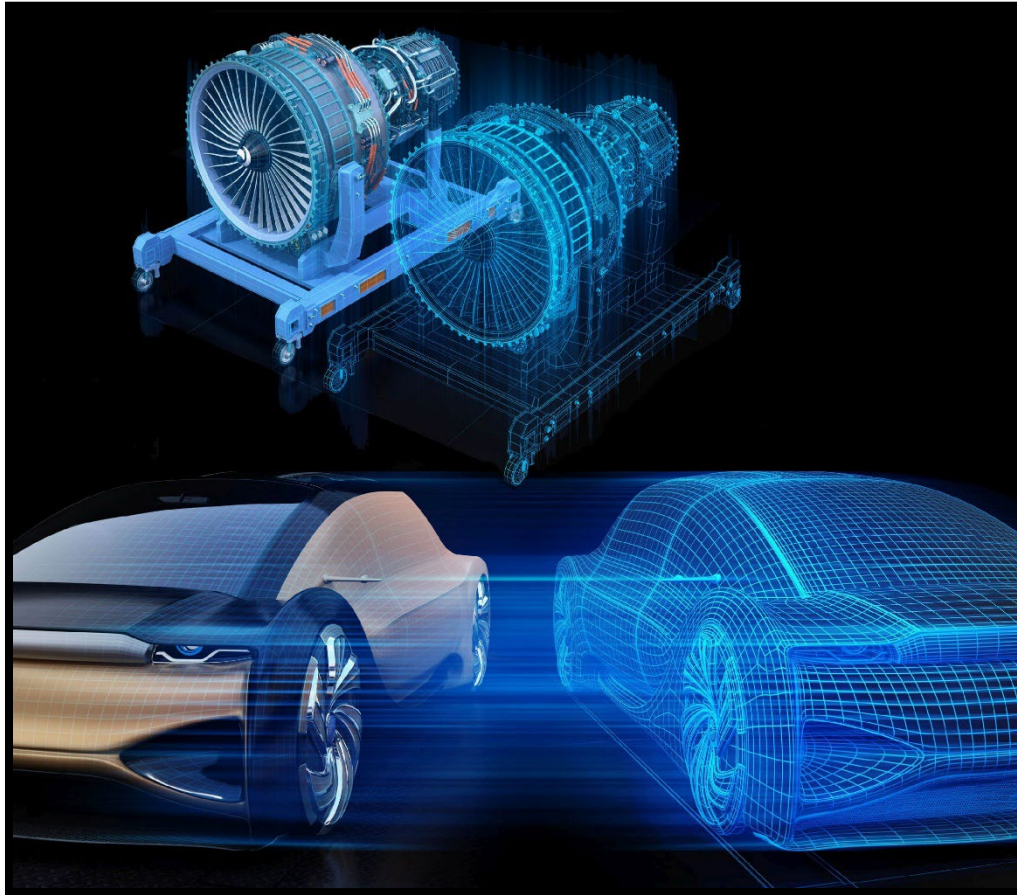


Application of Real-Time Digital Twin Simulation with WAMS for Dynamic Security Improvement of Power Systems

Jaime Cristobal Cepeda, Ph.D.

Escuela Politecnica Nacional, Quito, Ecuador

Digital Twin Concept



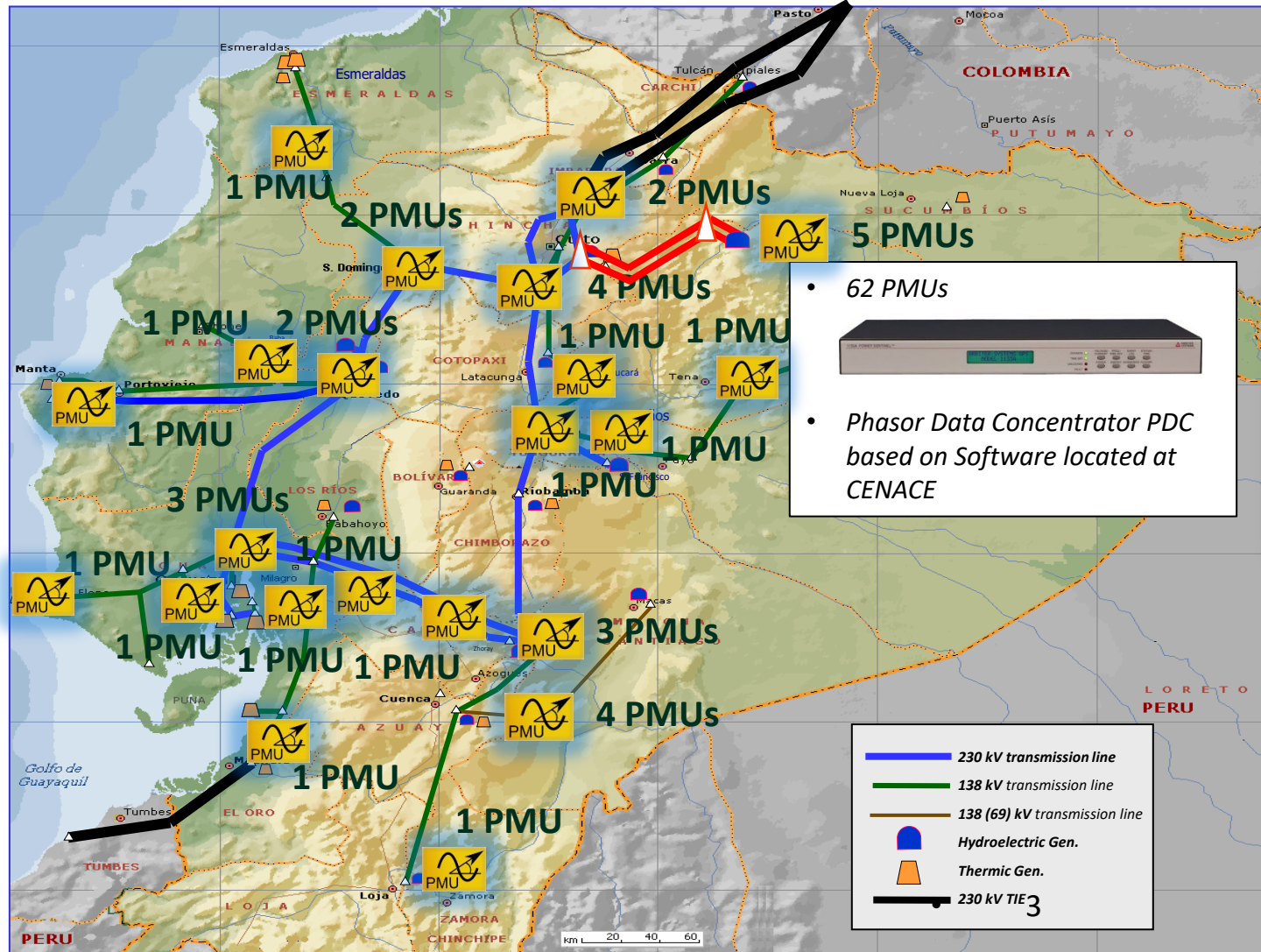
A digital twin is a virtual representation that serves as the real-time digital counterpart of a physical object or process.

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

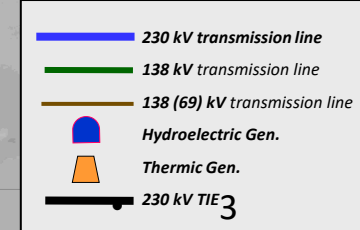
The digital twin concept consists of three distinct parts: the physical product, the digital/virtual product, and connections between the two products.

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.

Ecuadorian WAMS



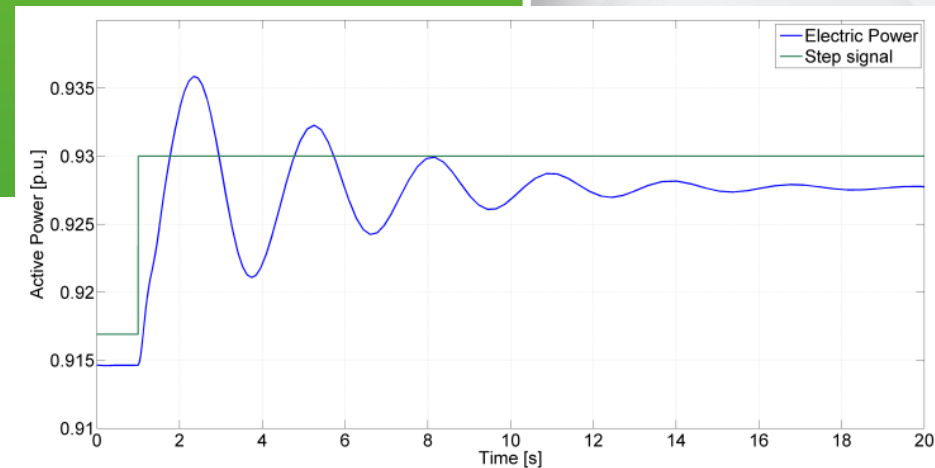
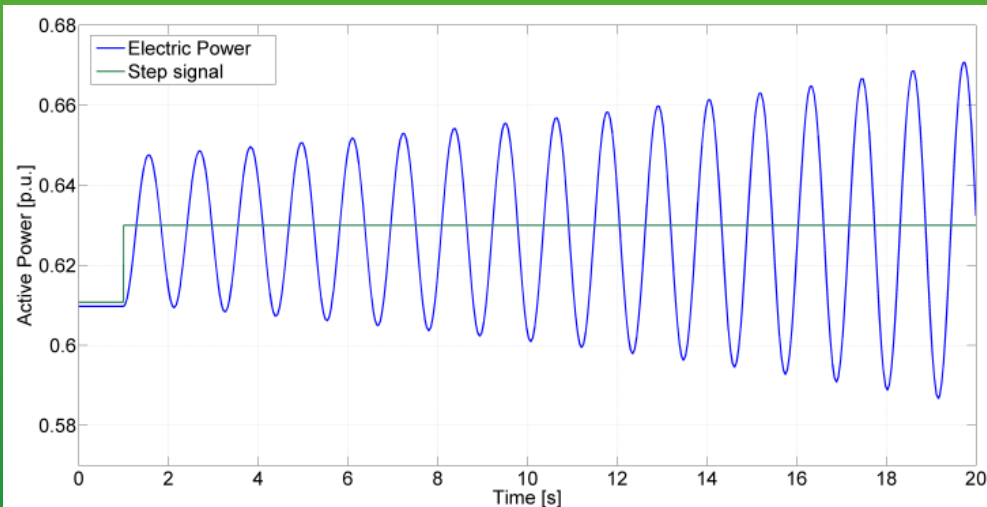
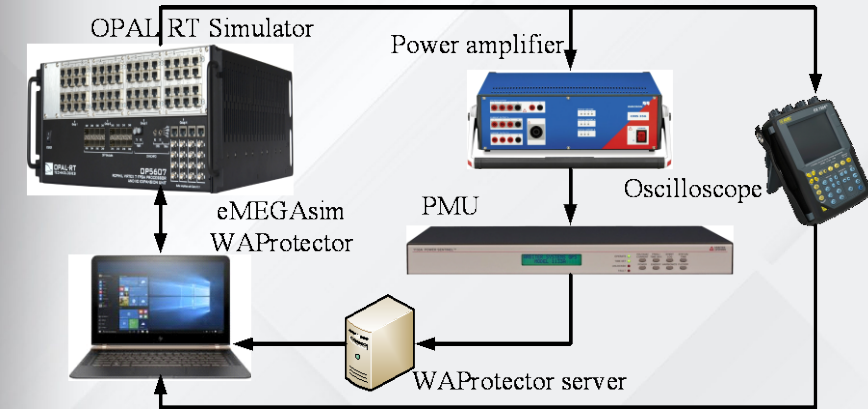
- 62 PMUs
- Phasor Data Concentrator PDC based on Software located at CENACE



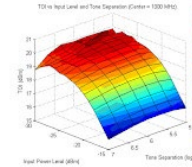
The visualization includes:

- elpros logo:** The software brand name.
- Map:** A small map of Ecuador with data points for various locations like Potosi, Cotacachi, and Loja.
- Server Rack:** A rack of hardware used for data processing.
- Plots:**
 - Line graphs showing "Voltage angle" and other time-series data.
 - A 3D surface plot showing data trends.
 - A circular gauge or polar plot showing voltage levels.

PSS Tuning using eMEGAsim and WAMS



PSS Tuning Methodology



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)

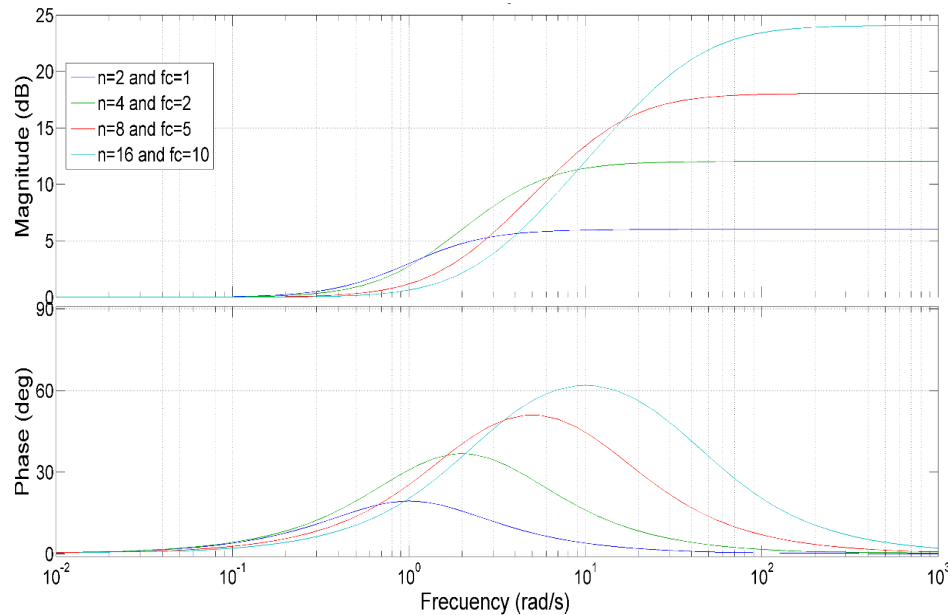
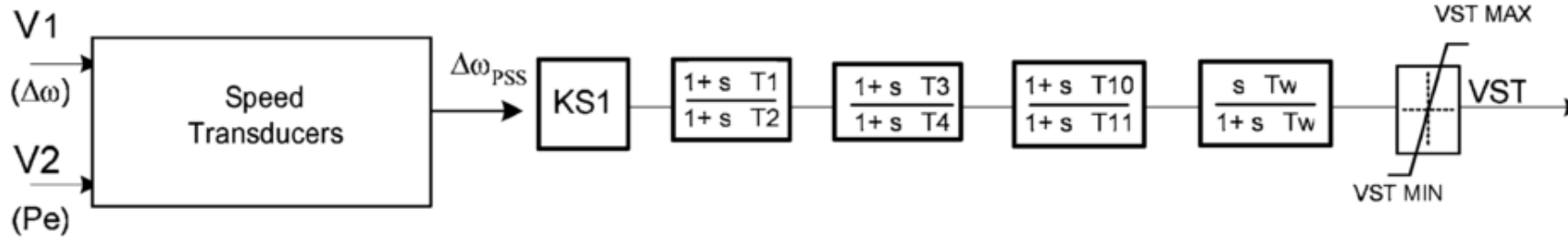
PSS Tuning.- Robust Methodology:

- Multiple scenarios (Monte Carlo)
- Heuristic optimization algorithm
- Frequency response (constraints)

- TestBed for PSS Tuning (Laboratory)

Field PSS tuning
Tuning validation tests
(WAProtector)

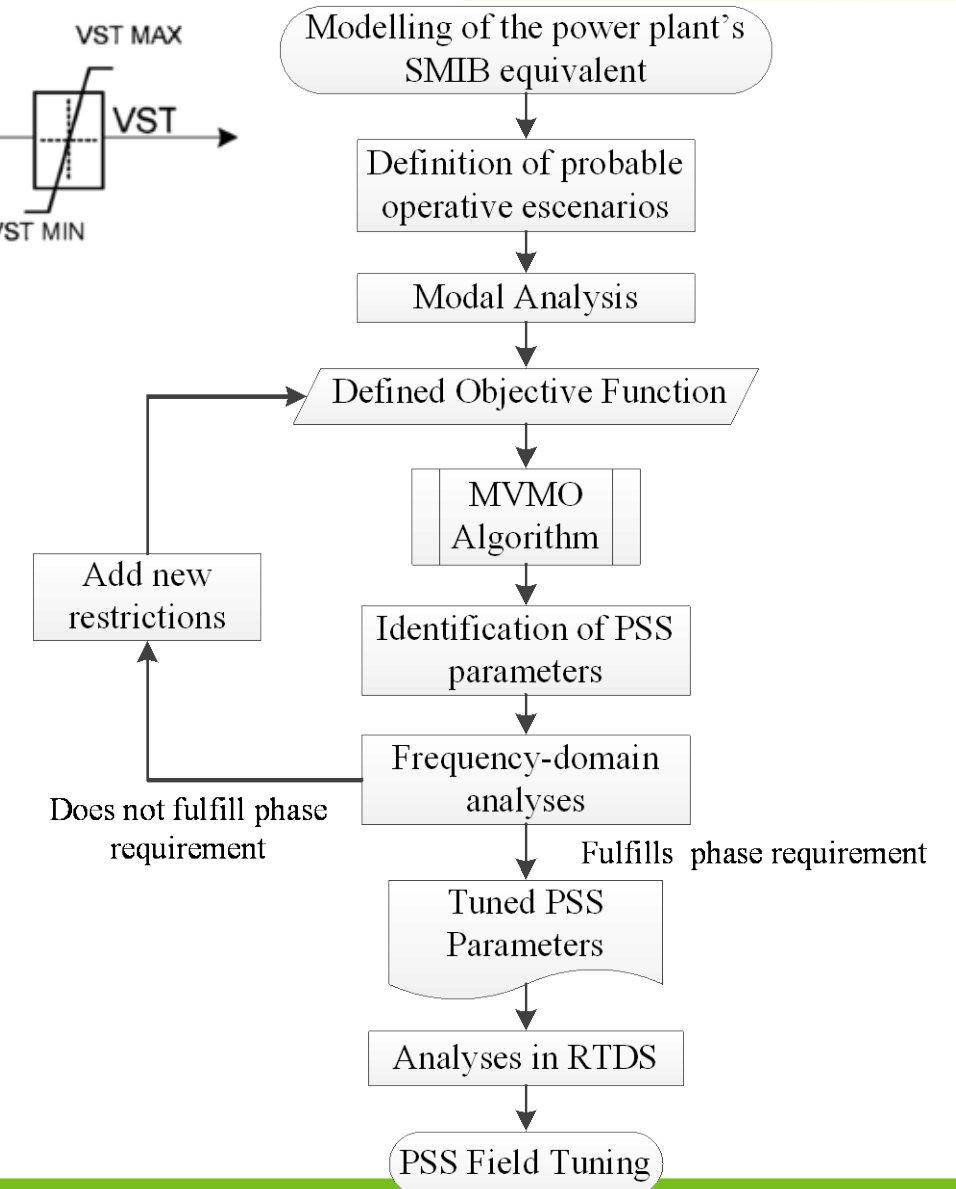
PSS Tuning Methodology



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

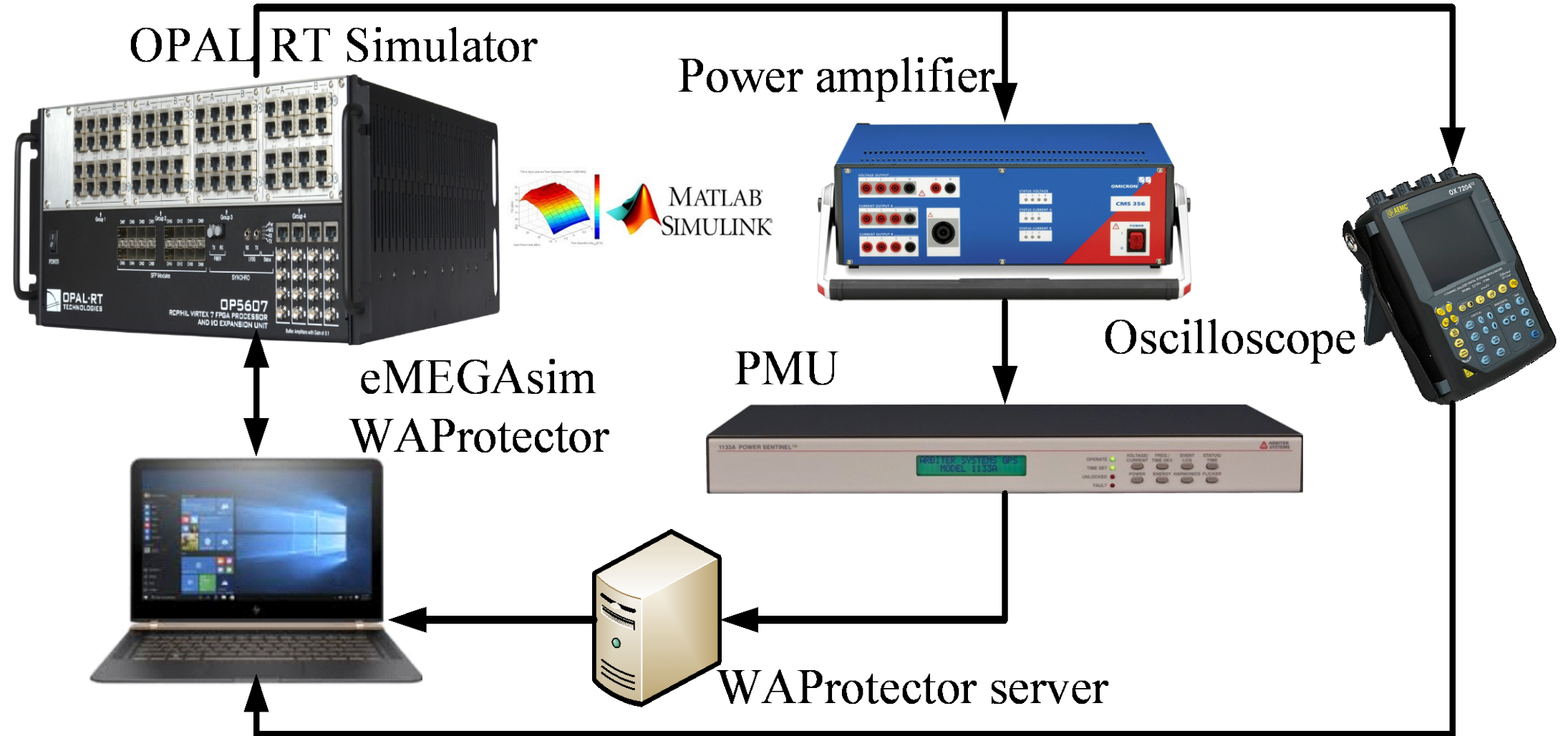
$$\xi_{sys} = \min_{p=1 \dots nm} (\xi_p)$$

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



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

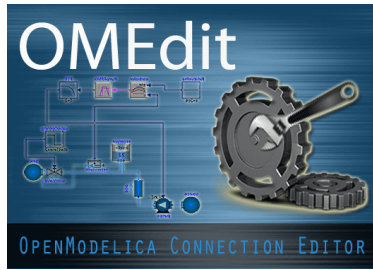
Testbed for PSS Tuning



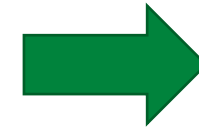
Operators' training Environment using ePHASORSim and WAMS



Implemented Training Environment



Power System



Dynamic Modelling

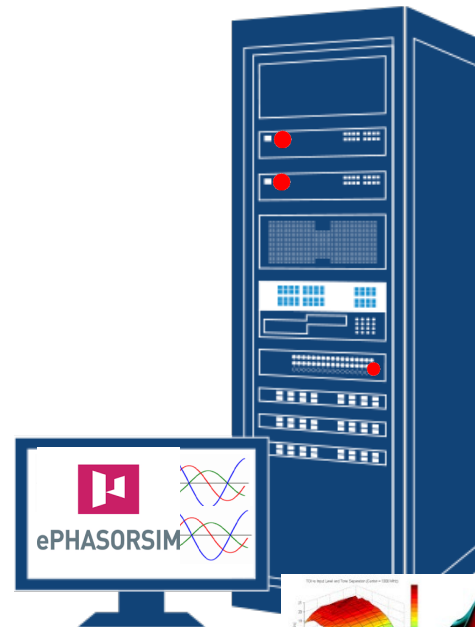
- Generator
- Automatic Voltage Regulator (AVR)
- Power System Stabilizer (PSS)
- Governor (GOV)

Static Modelling

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



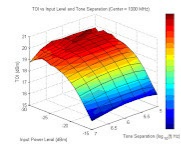
FMU



DGS



Implemented Training Environment



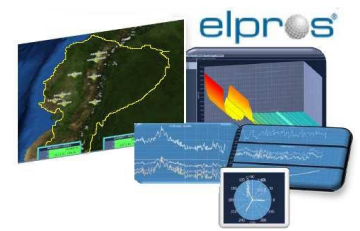
MATLAB
SIMULINK

WAMS' APPLICATIONS

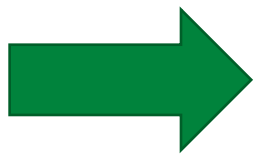
- Angular Difference
- Oscillatory Stability
- Voltage Stability of Transmission Corridors
- Frequency Monitoring

Real-Time Digital Simulator

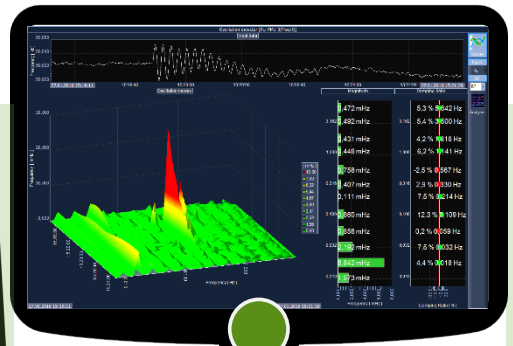
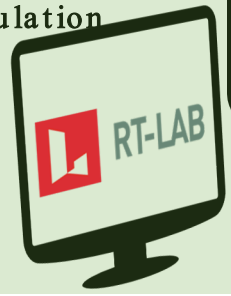
Virtual PMU
C37.118



Wide Area Monitoring System



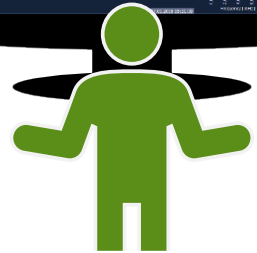
- Dynamic Simulation (Operation Commands)
- Load Flow Simulation



- Study Cases
- Generation and Demand



Training Environment



Implemented Training Environment

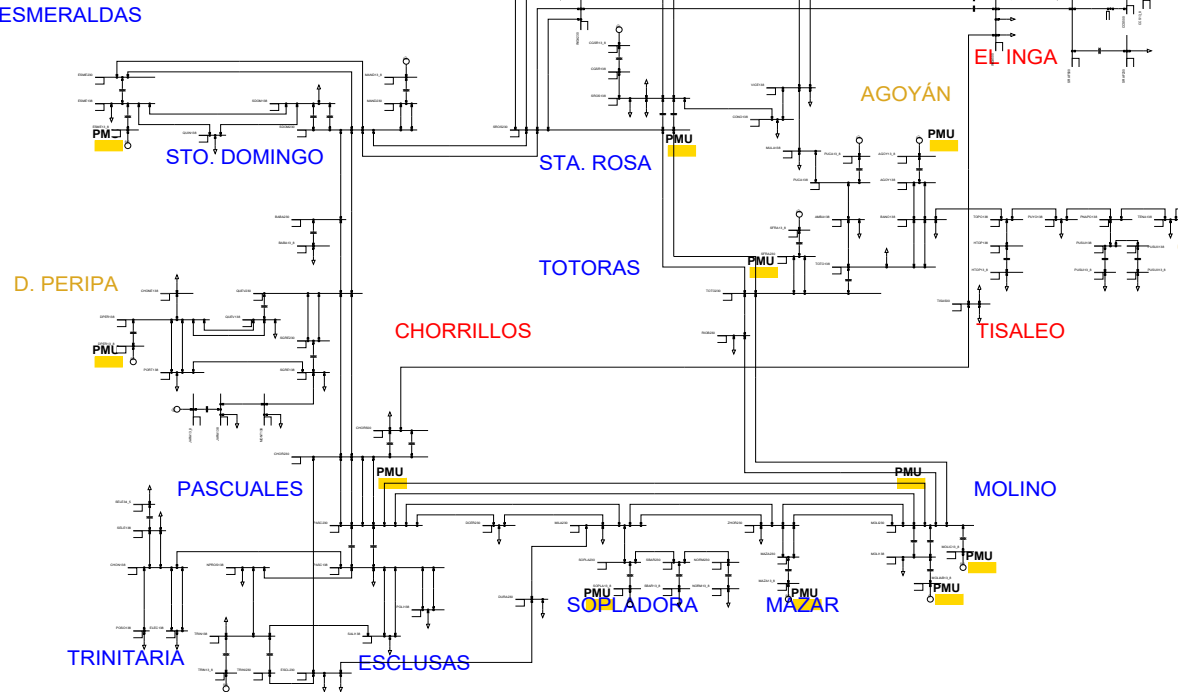
STEADY-STATE MODELS

DYNAMIC MODELS

PowerFactory*.PFD PowerFactory*.DGS ASCII

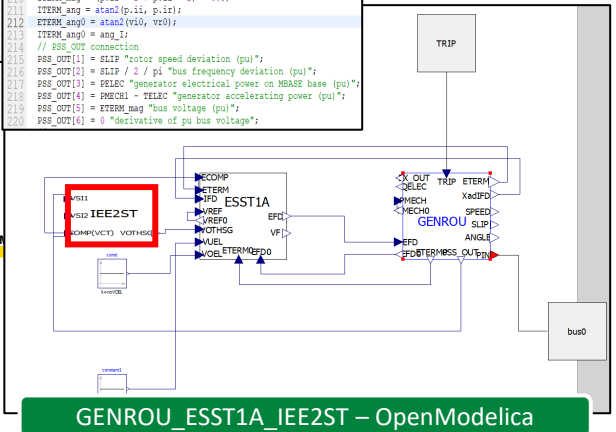


DGS_Export ePHASORsim

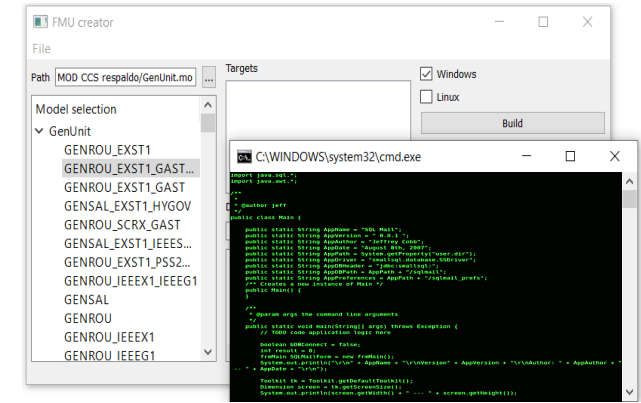


```

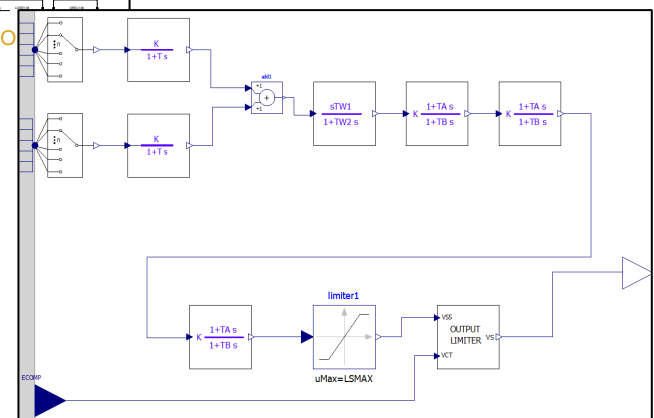
201 // arbitrary outputs
202 ETERM_ang = (p.vi * 2 + p.vt * 2) * 0.5;
203 ETERM_ang = atan(p.vi, p.vt);
204 PELEC = p.vi * p.ir + p.vt * p.ii;
205 CELEC = p.vi * p.ir - p.vt * p.ii;
206 SLIP = (SPEED - ws) / ws;
207 ETERM_mag = Vt_obs;
208 EFD_0 = EFD;
209 PMECH_0 = PMECH;
210 ITERM_mag = (p.ir * 2 + p.ii * 2) * 0.5;
211 ITERM_ang = atan(p.ii, p.ir);
212 ETERM_ang0 = atan(vi0, vt0);
213 ITERM_ang0 = ang_I;
214 // PSS_OUT connection
215 PSS_OUT[1] = SLIP "rotor speed deviation (pu)";
216 PSS_OUT[2] = SLIP / 2 / pi "bus frequency deviation (pu)";
217 PSS_OUT[3] = PELEC "generator electrical power on MBASE base (pu)";
218 PSS_OUT[4] = PMECH - TELEC "generator accelerating power (pu)";
219 PSS_OUT[5] = ETERM_mag "bus voltage (pu)";
220 PSS_OUT[6] = 0 "derivative of bus voltage";
    
```



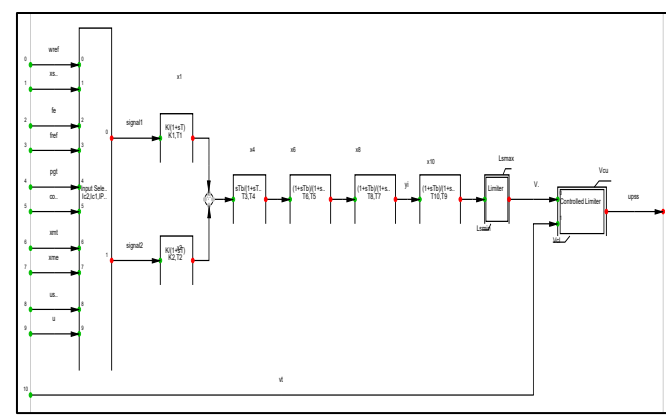
GENROU_ESST1A_IEE2ST - OpenModelica



FMU Creator

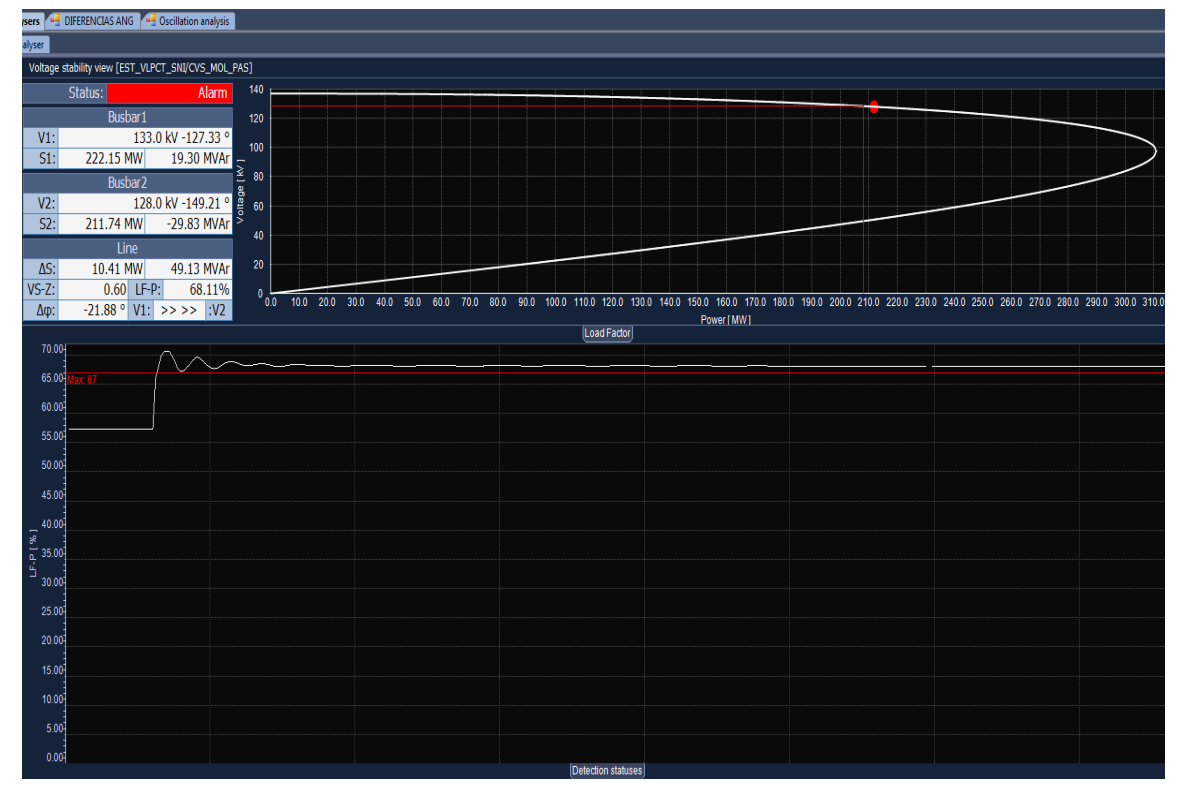
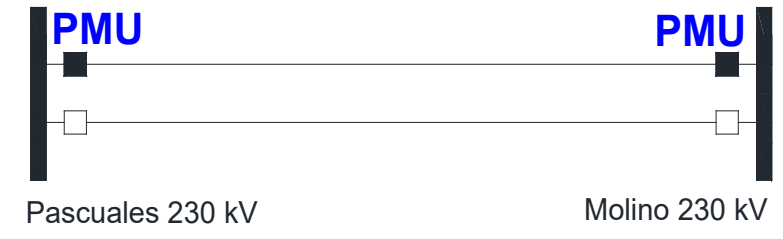
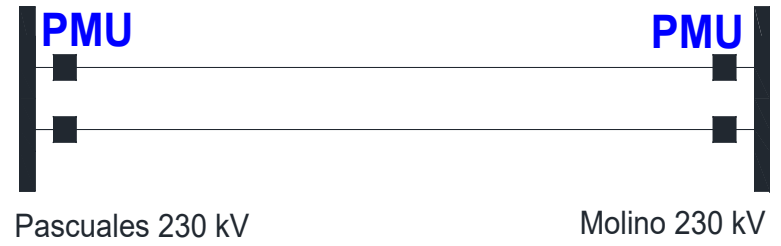


IEE2ST Block Diagram - OpenModelica



IEE2ST Block Diagram - DigSILENT Simulation Language

Real-Time Simulation Results





THANK YOU

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cepedajaime@ieee.org