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

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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

0.7 – 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
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

- 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
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)

Field PSS tuning Tuning validation tests (WAProtector)

- TestBed for PSS Tuning (Laboratory)
Modeling the Electric Power System
Bode diagram without PSS
Oscillations detected by eMEGAsim - 1000 MW generation
\[
f_c = \frac{1}{2\pi} \frac{1}{\sqrt{T_1 T_2}} \quad n = \frac{T_1}{T_2}
\]

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

\[
\xi_{sys} = \min_{p=1\ldots nm} (\xi_p)
\]

\[
x_{j-min} \leq x_j \leq x_{j-max}
\]
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
- Oscillation damping assessment tests
- Control Mode excitation – Optimal PSS Gain (1/3 of max gain)

Graphs showing modal damping ratios for different frequencies:
- Mode of 0.4 Hz: $\zeta = 4.21\%$
- Mode of 0.6 Hz: $\zeta = 4.63\%$
- Mode of 1 Hz: $\zeta = 4.90\%$
- Mode of 1.8 Hz: $\zeta = 4.94\%$
Operators’ training Environment using ePHASORsim and WAMS
Implemented methodology

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

FMU

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

DGS
Implemented methodology

WAMS’ APPLICATIONS
- Angular Difference
- Oscillatory Stability
- Voltage Stability of Transmission Corridors
- Frequency Monitoring

Real-Time Digital Simulator
Virtual PMU C37.118
Wide Area Measurement Systems

- Dynamic Simulation (Operation Commands)
- Load Flow Simulation
- Study Cases
- Generation and Demand

Training Environment
Modelling of Ecuadorian Power System

1. DlgsILENT 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

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

FMU Creator

IEE2ST Block Diagram - OpenModelica

GENROU_ESST1A_IEE2ST – OpenModelica

DYNAMIC
ePHASORsim interface

Programming - MATLAB & Simulink

Master

Console
ePHASORsim interface

MASTER:
Off-line simulation
ePHASORsim solver
Input and output signals
Time Step
Network data page
ePHASORsim interface

CONSOLE:
Real-time simulation
Operator commands
Output variables
ePHASORsim – WAProtector integration

Client-Server Communication

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

C37.118 Server (ePHASORsim)

C37.118 Client (PDC- WAMS)

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

\[ V_2 = \sqrt{\frac{V_{th}^2}{2} - (Q_cX_{th} + P_cR_{th}) \pm \frac{V_{th}^4}{4} - V_{th}^2(Q_cX_{th} + P_cR_{th}) - (P_cX_{th} - Q_cR_{th})^2} \]

Pascuales 230 kV

Molino 230 kV
Real-Time Simulation and Results

Voltage Stability of Transmission Corridors (WAMS)
Medium demand – High hydrology Scenario

\[ V_2 = \sqrt{\frac{V_{th}^2}{2} - (Q_cX_{th} + P_cR_{th})} \pm \sqrt{\frac{V_{th}^4}{4} - V_{th}^2(Q_cX_{th} + P_cR_{th}) - (P_cX_{th} - Q_cR_{th})^2} \]
Real-Time Simulation and Results

Angular Difference (WAMS)

Medium demand – High hydrology Scenario

Pre-contingency:
- AD = 9.5°
- 162 MW

Post-contingency (N-1):
- AD = 15.0°
- 256 MW

Post-contingency (N-2):
- AD = 37.0°
- 250 MW

Angular difference warning limit = 11.29°
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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