EPRI R&D on PMU Applications: Industry Case Studies & Vendor Engagement

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1. Synchrophasor-Based Wide Area Oscillations Damping Controller

- Improved Damping of Target Inter-area/Intra-area Oscillations Mode
- Application of Synchrophasor Technology in Closed Loop Wide Area Control

In collaboration with University Tennessee Knoxville (UTK)
1. Modal Analysis
2. Selection of optimal observation signals
   • PMUs at selected locations for oscillation mode observability
3. Selection of optimal actuation signal
   • Actuators: Generator stabilizer/FACTS/HVDC
4. Model Identification and Validation
5. Control Design
6. Simulation-Based Testing
7. Hardware-In-the-Loop Testing

Real-time Stage

• Adaptive Controller
  • Model: Measurement-derived transfer function
• Controller Design
NYPA Case Study

- **Mode #1**
- **STATCOM**
- **Mode #2**

- 2019 NYISO planning models (light load, summer and winter)
- Modal analysis: Identified coherent groups and dominant modes
- Selection of optimal observation signals & actuator - Marcy STATCOM
- Demonstrating adaptive performance of WADC
  - Online model identification with ringdown data
  - Online model identification with probing data
- WADC design with backup signals and actuators
- Next: Hardware-in-the-Loop Implementation & Demo

<table>
<thead>
<tr>
<th>Candidate actuator &amp; observation</th>
<th>Case</th>
<th>Damping Improvement (Mode 1)</th>
<th>Damping Improvement (Mode 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generator (Area A - Niagara) Frequency---A-E</td>
<td>Winter</td>
<td>+2.57%</td>
<td>+0.2%</td>
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<tr>
<td></td>
<td>Summer</td>
<td>+10.04%</td>
<td>-0.54%</td>
</tr>
<tr>
<td></td>
<td>Spring</td>
<td>+7.35%</td>
<td>-2.24%</td>
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<tr>
<td></td>
<td>Avg.</td>
<td>+6.65%</td>
<td>-0.86%</td>
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<tr>
<td>STATCOM (Marcy) Frequency---E</td>
<td>Winter</td>
<td>+7.85%</td>
<td>+4.47%</td>
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<tr>
<td></td>
<td>Summer</td>
<td>+5.38%</td>
<td>+6.82%</td>
</tr>
<tr>
<td></td>
<td>Spring</td>
<td>+5.65%</td>
<td>+1.63%</td>
</tr>
<tr>
<td></td>
<td>Avg.</td>
<td>+7.21%</td>
<td>+5.73%</td>
</tr>
</tbody>
</table>
NYPA Advanced Grid Innovation Laboratory for Energy (AGILe)

- AGILe: electric power research laboratory with real-time simulation & modeling tools.
- Target: conduct collaborative research with utilities and grid tech companies focused on facilitating stakeholders in solving grid related challenges
- Lab established at NYPA’s White Plains, NY office
- RTDS & OPAL-RT simulators installed
- NY state grid models under development

- 4 NovaCore chassis - 40-core processing power
- Simulation capability: ~600 3-phase buses
- RSCAD simulation software

- 1 8048B-TR4F Super Server - 40-core processing power
- Simulation capability: ~600 3-phase buses (transient simulation), ~10,000 single-phase buses (stability simulation)
- HYPERSIM and ePhasorSim simulation software
TERNA Case Study

• Modal analysis: North-South Mode in TERNA model
• Observation signal selection: PMU1 South Italy – PMU2 North Italy (France area is optimal)
• Actuators: Two synchronous condensers in South Italy
WADC Design for an Actual 2017 Event

- PMU measurements provided by Terna
- Two generator trips
- Event simulated and WADC designed
- Oscillations were damped by WADC
- Next: Hardware-in-the-Loop Implementation & Demo
Saudi Electricity Company (SEC) Case Study

- **Qassim – Medina**: Double line, series compensated, separating West with Central/North/East SEC system
- 3 incidents since 2015 that resulted in tripping of the line
- **Actuators**:
  - STATCOMs in West
  - Additional STATCOM to be installed in Central area
- Study interaction of WADC with transmission line power swing protection
WADC HIL - OpalRT

- OPAL-RT real-time simulator: Emulates grid
- PMUs: Collect real-time measurements
- National Instruments CompactRIO: WADC
WADC HIL - Hybrid TSAT-RTDS Real-Time Simulation

RTDS

GT AO

GT AI

PB 5 processor card

Optical Fiber

Amplifier

Wide-area Damping Controller

IEEE C37.118

FPGA

PCI e 3 X8

PMU

GPS

IEEE C37.118

DSATools/TSAT

RSCAD

Desktop

WADC HIL - Hybrid TSAT-RTDS Real-Time Simulation

RTDS

GT AO

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IEEE C37.118

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DSATools/TSAT

RSCAD

Desktop
2. Data Quality Monitoring and Mitigation of Streaming Synchrophasor Measurements

- Target: Improve synchrophasor data quality by estimating missing data and replacing bad data in synchrophasor streams
- Model free technique, no need for topology information or system model/parameters
- Computationally efficient for real-time implementation
- Performs well for simultaneous & consecutive missing & bad data conditions

**Approach**

- Process *spatial-temporal blocks* of synchrophasor data collected from PMUs in electrically close regions
- Key feature: *low-rankness* of synchrophasor data blocks and their Hankel matrix.
- **Differentiation between event data and bad data**

*In collaboration with RPI*
Numerical Experiments with Missing & Bad Data

Bad Data

SSDQ tested with various datasets provided by EPRI members
- Bad measurements are identified and corrected effectively
- Missing entries are filled in with high accuracy
- Event data are not misidentified as bad data
SSDQ - Entergy Case Study

- Entergy provided 1 hour of recorded synchrophasor data during a 2017 oscillations event
- Event data were not misinterpreted as bad data
SSDQ - Matlab Based Software for Offline Testing

- Streaming Synchrophasor Data Quality Tool (SSDQ) – Offline version
- Detecting missing and invalid bad data, and replacing it with accurate estimated data
- Value: improve results of off-line synchrophasor applications
SSDQ – OpenPDC Implementation

- Streaming Synchrophasor Data Quality Tool (SSDQ) – Online version
- Algorithm implementation on Open PDC
3. PMU Emulator

- Phasor values obtained from dynamic simulation tools may differ from synchrophasors measured by PMUs in the field.

- How a PMU works:
  - Analog signal sampling - A/D Conversion
  - Digital filtering → magnitude attenuation & phase offset
  - Phasor estimation
    - algorithm e.g. DFT
    - window length - P & M class PMUs

- PMU Emulator: interfaced with power system dynamics simulators, and produces “simulated synchrophasors” taking into account PMUs internal signal processing.

- Hardware-In-the-Loop benchmarking (RTDS & hardware PMUs)
- Use cases: Model validation, synchrophasor applications offline testing (especially control applications), operator training, etc
Vendor Engagement & Case Studies

• Vendor Engagement: Collaboration with vendors for implementation of PMU Emulator in commercial platforms

• Coordinating with Powertech Labs and Opal-RT for implementation of PMU Emulator in ePMU and ePHASORsim respectively
4. Synchrophasor Applications Database

- Entries based on publicly available documents
- For each entry, summary description of application and related references

Value: Inform utility/ISO engineers and executive management about uses cases and derived value of synchrophasor technology
### Synchrophasor Applications Database – Entries Table

<table>
<thead>
<tr>
<th>Agency Name</th>
<th>Application Type</th>
<th>Vendor Name</th>
<th>Tool Name</th>
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<tbody>
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<td>ERCOT</td>
<td>Situational Awareness</td>
<td>EPRI</td>
<td>RTDMS</td>
</tr>
<tr>
<td>ERCOT</td>
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<td>RTDMS</td>
</tr>
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<td>GE</td>
<td>PhasePoint</td>
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<td>In-house</td>
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<td>RTDMS</td>
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<td>ABB</td>
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<td>RTDMS</td>
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<td>Event Analysis</td>
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<td>PhaseView</td>
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<td>OG&amp;E</td>
<td>Oscillation Detection</td>
<td>In-house</td>
<td>PhaseView</td>
</tr>
</tbody>
</table>
Synchrophasor Applications Database – Detailed Entry Description

Model Validation at NYPA

Description:
NYPA has used EPRI’s “Static Var System Model Validation” tool to validate the models of a STATCOM (Marcy substation) and an SVC. The generic dynamic Static Var Systems models (also developed by EPRI) were used to parameterize [1], [2]. Figure 1 [2] shows representative results of the model validation.

References:
Together…Shaping the Future of Electricity
Synchrophasor Applications Database – Vendor List
Synchrophasor Applications Database – PMU Installations

SDG&E PMU Placement

References: