Cyber Infrastructure for the Smart Grid

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Smart Grid Measurements and PMU
Sense: Phasor Measurement Unit

Monitoring / EMS > 1 sec

National Operation

High-speed Decisions
100 ms - 1S time frame

Local Operation

PDC

Very High-speed Decisions
10-100 ms time frame

PDC

PMU

PMU

PMU

PMU

PMU
Sense: Phasor Measurement Example

V-I-F Measurement - substations

PMU → Phasor Data Concentrator (PDC)
- Correlates data, feeds selected applications, monitors system

Data input & management - control center

PMU → Phasor Data Concentrator (PDC)

Operations monitors – display & alarms
- SCADA - Voltage, angle & frequency
- Other displays - Power World, etc.

StreamReader Display & recording

System controls
- Real-time controls: Voltage & reactive stability; interarea angle limits

Direct exchange with other utilities

Data storage
The number of PMUs deployed will depend on several factors:

- Whether the tools and data are recognized to provide value
- Learning how to do effective physical and cyber-security at reasonable cost
- Ease of implementation and integration into the communications and data systems; they should be plug & play and remotely configurable, under detailed interoperability specifications and protocols
- Deployment cost should be a minor issue for new facilities
- To assure that PMUs once deployed will receive consistent support with O&M, communications links, and consistent data quality,
- The technology has to be integrated with utility processes.
Phasors will be deployed at the following locations by 2014:

- Major transmission interconnections and interfaces
- All 500kV and above substations and most 200 kV and above substations
- Key generating plants (all > 500 MW) in generator switchyards, even on some individual generators
- Major load centers
- Large wind generators, solar and storage locations
- Other locations to assure observability in areas with sparse PMU coverage

By 2019, remaining 200kV and above substations, in locations needed for local control actions, and even on the distribution network.
Synchrophasor Technology Applications

Source: Novosel, 2008
Sense: PMU Applications (2009)

- Angle/Frequency Monitoring
- Post-mortem Analysis (Including Compliance Monitoring)
- Voltage Stability Monitoring
- Thermal Overload Monitoring
- Improved State Estimation
- Steady-state Model Benchmarking
- DG/IPP Applications
- Power System Restoration

1 to 3 Years

- Congestion Management
- Dynamic Model Benchmarking
- Planned Power System Separation
- State Estimation (Boundary Conditions)
- Deployment Challenge

3 to 5 Years

- Linear State Measurement
- Real Time Control
- Adaptive Protection
- WA-PSS Stabilization

> 5 Years

Credit to NASPI Research Initiatives Task Team
PMU Measurements

- High resolution data
- Synchronized data (angle measurements)
- Estimation may help with data accuracy (unless better quality CT and PT)
- System monitoring is more critical during disturbance and transients. Faster synchronized data is needed to capture the dynamics.
Wind ramp in BPA area
11/18/2013 from 9:15 PM to 11:15 PM

SCADA Data

PMU Data

Source: BPA
Dominion system operators didn’t see this un-damped oscillation (green = PMU) on SCADA (red) until they were notified by the power station operators.
Example of Tools for Synchrophasor Applications

- RTDMS and PGDA (EPG)
- SynchroWave, Voltage stability and oscillation modeling (SEL)
- PhasorPoint (ALSTOM)
- ROSE (V&R)
- VIP (Quanta)
- Space Time Insight
- ABB
- Siemens
Other PMU Applications

- Disturbance and equipment mis-operation (OG&E)
- Fault location using VAR flows (OG&E)
- Failing equipment mis-operation (Duke and OG&E)
- Calibrate Instrument transformers
- PMU data to verify load response to DR calls (ERCOT)
- Model validation for generator, line, SVC, STATCOM, wind plant, HVDC unit, load model, system model (BPA, WECC, CAISO, ERCOT, NYPA)
- Renewable integration
- Phasor data based GIC detection
- Automated control
### PMU Applications

<table>
<thead>
<tr>
<th>Class</th>
<th>Basic Description</th>
<th>Sampling/Data Rate</th>
<th>Required Latency</th>
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<tbody>
<tr>
<td>A</td>
<td>Feedback Control</td>
<td>Fast</td>
<td>Fast</td>
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<tr>
<td>B</td>
<td>Open Loop Control</td>
<td>Medium</td>
<td>Medium</td>
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<tr>
<td>C</td>
<td>Visualization</td>
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<td>D</td>
<td>Event Analysis</td>
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<tr>
<td>E</td>
<td>Research/Experimental</td>
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