Session 4.2

Use of Synchrophasor Technology for Analysis of Cascading Outages

Vahid Madani - Pacific Gas & Electric Co.
Damir Novosel - Quanta Technology

Tutorial on

Understanding Cascading Phenomenon
PMUs APPLICATION LEVELS

SYSTEM
- F, V, and Angle

AREA
- F, V, Angle, P&Q
- F, V, Angle, P-V Curve,
  Imp. Loci R-X,
  AGCC

INTER AREA LINKS
- F, V, Angle,
  P-V Curve,
  Imp. Loci R-X,
  AGCC
  P-V, R-X,
  P-F

- SUBSTATION
- POWER PLANT
# PMU Value Mapping

## Initiative Description
- Overview of PMU capabilities and breakdown into PMU functions

## PMU Capabilities
- Analysis / Assessment
- Situational Awareness
- Monitoring / alarming
- Protection & Control

## PMU Functions

### PMU Capabilities vs. PMU Functions

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<td>Fast Disturbance Replay</td>
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<td>Visualization abnormal Angle/ frequency/volt</td>
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## Value Proposition
- Mitigate prevent Black Out/large incidents
- Detect developing Instabilities
- Run Grid closer to Physical limits
- Assist PSS tuning
- Support during islanding conditions
- Improve state estimator solution
- Improve Look-ahead Analysis
New mantra: “Model, Measure, Monitor, Mitigate!”

Control Room Operations
Wide-Area situational awareness and coordination across seams.
Create and manage robust real-time variable stability limits.
Add Operational Response Guidance to Situational Awareness for Critical Conditions

Engineering Analysis
Big Data Analytics
Risk assessment, data mining, baselining for grid vulnerability.
Analysis tools for condition monitoring, model validation, control tuning, post-event analysis, compliance monitoring.

Wide Area Control
Co-ordinated control hierarchy, centralized (via EMS/DMS), or decentralized as appropriate.
Operational Use Example - NYISO

- Voltage angle differences across 4 regions (NYISO, PJM, MISO, IMO)
- The traffic lights representing the key metric elements
  - Left is internal NYISO control area,
  - Right is external control areas – Angle difference under the Health column should be equaled to zero and lights up if the sum of the four angles exceeds a certain threshold
- Violation message indicator also appears on the EMS SCADA system

Source: NYISO
Pacific Gas & Electric Applications

• Situational Awareness, Visualization and Alarming (angles and voltages; overloads and oscillations)
• Voltage Stability Management
• Enhanced Energy Management Systems
  o Adding synchrophasor measurements to existing SE
  o Tracking dynamic changes and contingency analysis
• System Restoration
• Post-Disturbance Event Analysis, including Fault Location
• Operator and Engineering Training, Dispatch Training Simulator
• Provide interfaces with EMS and with third parties
PMU Operational Applications 1 (2)

- Situational Awareness, Visualization, and Alarming for Operators
  - Abnormal angles and voltages
  - Line overloads & oscillations monitoring
  - System restoration

- Enhanced EMS
  - Adding synchronized measurements to existing SE
  - Track dynamic state changes of a system during disturbances
  - EMS interfaces and with third parties
PMU Operational Applications 2 (2)

• Real-time Voltage Instability Indicator (RVII) and Contingency Analysis based on PMU availability
• Linear and Distributed State Estimation
• Post-Disturbance Event Analysis for Planners and Engineers
• Operator and Engineering Training, Dispatch Training Simulator
• Cognitive task and Performance Analysis
Phase Angle Monitoring and Alarming

- Relative Angles with respect to common reference
  - The difference between the measured voltage angle by and the voltage angle measured at a “reference” bus

- Angle Differences between a pair of nodes
  - Computed as difference in the voltage angle between two locations: typically between the “source” and “sink” areas of the system, or across a known corridor or interface

- Angle Rate-of-Change to detect sudden disturbances in the system
  - Computed as change in voltage angle over a user-defined time period (e.g. 1 s)
  - Represents relatively fast changing angles in time (e.g. pre- and post-event angle change during a disturbance)
**Voltage Stability Assessment**

**Real-Time Voltage Instability Indicator (RVII)**

- **PMUs**
- **PMU measurements**
- **Estimate equivalent parameters in real-time**

**EMS & Online-DSA Applications**

- **CA**
- **VSAT**
- **RAS**

**Model-Based**

- Predict **HOW to respond / Advance Arming (accurate model).**
  - **Predict** $Q_{\text{margin}}$ **changes under “worst case” contingency.**
  - **Provide recommendations on corrective actions.**

**Real-time Alerts**

- **Equiv. Imped. ($Z_{eq}$)**
- **Reactive Margin ($Q_{\text{margin}}$)**
Offline Analysis Use Cases

- **Post Event Analysis**
  - Quicker post-mortem analysis.
  - Sequence of events & root cause analysis.

- **Dynamic Model Validation**
  - Dynamic model verification.
  - Generator model calibration.
  - Load characterization.

- **Baselining**
  - Assess dynamic performance of the grid.
  - Steady-state angular separation.
  - System disturbance impact measures.

- **Compliance Monitoring**
  - Primary frequency (governing) response.
  - Power System Stabilizer (PSS) tuning

**Synchrophasor benefits for Post-Event Analysis**

Phasor data are also valuable for investigation of grid disturbances, improving both the speed and quality of analysis.

In the case of the 2007 Florida blackout, NERC investigators used phasor data to create the sequence of events and determine the cause of the blackout in only two days; in contrast, lacking high-speed, time-synchronized disturbance data it took many engineer years of labor to compile a correct sequence of events for the 2003 blackout in the Northeast U.S. and Ontario.

*NERC RAPIR Report, 2010.*
Post Mortem Forensics to Identify Sequence of Events (Time Domain)

Example: May 30th, 2013 Event

- Frequency drop
- DC Intertie block/restored
- 2000MW Gen drop
- Frequency recovered
- Series Capacitors bypassed
- Shunt Capacitors removed
- Series and Shunt Capacitors inserted
Example: Ring-down Analysis

- Using HTLS algorithm.
- Processed @ 5 samples/second.
- Sorted by proprietary index (RI).
- First voltage swing not considered.
Inter-area mode at 0.49Hz (Colombia-Ecuador). Opposing phase in South

Governor common-mode: whole system oscillates in coherent phase
Key Deployment Success Factors

• Present synchrophasor deployment is only “tip of the iceberg” for on-going reliability improvements and benefit realization

• Assure Life-cycle Quality of Measurements – Requires TOs to take Ownership and Realize own Benefits

• Baselining to Provide Norms: Historical Data/Simulations

• Updates of Application and Design Roadmaps
  o System expandability as measurements & applications grow
  o System integration with other enterprise systems

• Engineering and Operator Guidelines and Training

• Data and Information Exchange Across Interconnections

Finding a killer application!?
Compliance and Risk Management

- **Ensure Performance**
  - What are gaps, and how to close them?
  - Is compliance integrated?

- **Verify Controls**
  - Do we have the right metrics?

- **Understand the Risk**
  - What’s the risk?
  - What’s the potential impact on safety, finances, Company reputation, DOE, customers, shareholders?

- **Know Compliance Requirements**
  - Do we know what they are?
  - How do we demonstrate compliance?
  - How do we manage changes to requirements?

- **Systematic Processes**

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PG&E POC along with other established test facilities have provided the platform for gathering the knowledge to provide the industry with direction and a fast track process for maturing the standards and Production Level Technology.

Source: DECLARATION OF DR. VAHID MADANI IN SUPPORT OF PETITION FOR DECLARATORY ORDER OF PACIFIC GAS AND ELECTRIC COMPANY SEEKING RATE RECOVERY FOR SMART GRID PROJECT
Thank you

Questions?