Protecting the California Grid:
Using Synchrophasors for Smarter Protection Systems and Increased Grid Reliability

Presented to the PIER Symposium:
Paving the Way for Renewables
October 25, 2010
Sacramento, California

by
Lloyd Cibulka
Research Coordinator
California Institute for Energy & Environment
What Are “Protection” Systems in the Grid?

Electric grid **Protection Systems** are automatic and/or operator-controlled systems that detect sudden and unexpected abnormal events that threaten the integrity or operation of the grid, and initiate control actions to protect the grid and the public from the impacts of those events.

Called “**faults**” (or “**disturbances**”), such events include:

- short circuits: lines touching each other or grounded objects such as towers, trees, buildings, etc.
- equipment failure: transmission lines, transformers, generators, etc., suddenly going out of service
- lightning strikes, high winds, and other acts of nature
- loss of 60Hz synchronization (“out-of-step” condition)
- sudden load connection/disconnection (especially large ones)

**Protection systems must operate when needed (reliability/dependability), but should not operate when not needed (security).**
Example of a Fault: Short Circuit

High loading causes a line to get hot and sag too low, touching a tree. Fault current can be many times greater than normal current, cause equipment and property damage, and is a safety hazard.
Components of Protection Systems

Relays: Electromechanical or electronic (digital) devices that monitor voltage, current and other key electric parameters. Relays are calibrated to detect abnormal conditions (faults) and produce the necessary system-wide data.

Communications: Radio, fiber optic, telephone, hard wired circuits; for transmitting monitored data to operators, signals to the control equipment, etc.

Computation & Processing: Data archives, software.

Instrumentation: Meters, gauges, operator displays.

Control Equipment: Circuit breakers, fuses, switches, reclosers, reactors.
Protection Equipment

Oil Circuit Breakers
[Photo courtesy of Prof. Alexandra von Meier, Sonoma State University]

Digital Overcurrent Relay
[Photo courtesy of Schweitzer Engineering Laboratories, Inc.]
Protection Schemes

[Graphics courtesy of Prof. Alexandra von Meier, Sonoma State University]
Research Rationale

• **Problem:** Analysis of recent cascading blackouts has indicated that undesirable relay operations (“false trips”) are often an important contributing factor in the sequence of events leading to a cascading outage.

• **Cause:** Protection systems are calibrated for normal system conditions, and can’t automatically compensate for outages and other events that weaken or stress the transmission system, or for normal changes such as the addition of new lines and generators (especially renewables).

• **Result:** False trips during normal system conditions are not a significant detriment to reliability, but false trips during abnormal conditions can exacerbate system vulnerabilities (i.e., contribute to blackouts) and should be avoided.

• **Goal:** Find ways to make protective relaying technologies more “adaptive” to changing system conditions, i.e., make them “smarter,” and reduce the chance of blackouts.
Cascading Outages (aka “Blackouts”)

The diagram illustrates a record of power system events, specifically the 10 August 1996 blackout. The data was gathered by the Wide Area Measurement System (WAMS) at the Dittmer Control Center in Vancouver, WA. Key events include:

- **15:42:03** Keeler-Alston Line Trips
- **15:48:51** Out-of-Step Separation
- **15:47:36** Ross-Lexington Line Trips/McNary Generation Drops Off

The chart shows changes in frequency over time, with reference to a reference time of 15:35:30 PDT. Significant frequency changes include:

- **0.276 Hz**
- **0.264 Hz, 3.46% Damping**
- **0.252 Hz**

Figure 2. WAMS data gathered during the 10 August 1996 blackout. (Courtesy of Hauer and Dagle, 1999; Data courtesy of Bonneville Power Administration.)
Research Rationale (cont’d.)

• Fact: Numerous factors are working together to make this an urgent problem, including:
  ➢ increased loading of transmission lines, due in part to new renewable generation
  ➢ increased complexity of system operations, also due in large part to new renewable generation
  ➢ reduced electric system inertia, due to inverter-based generation such as many renewables, causing new stability issues
  ➢ dynamics, variability and intermittency of renewable resources

• Hypothesis: Synchrophasor data can be used to develop advanced protection systems that can detect changed system conditions in real time, “supervise” the operation of protective equipment to improve system security (“Adaptive Relaying”), and provide improved visualization of relay system information.

• Objective: Develop these advanced protection systems, demonstrate them in an actual utility environment, and establish the benefits of:
  ➢ increased security: fewer false trips during contingencies
  ➢ increased awareness of reduced reliability margins
  ➢ enhanced situational awareness by operators, engineers and planners
Foundational Research Project: The “Phasor Business Case”

The PIER program funded a groundbreaking synchrophasor research project: The Phasor Measurement Application Study, Principal Investigator Damir Novosel, Kema, Inc. This study identified the following high-value applications in the electric system that could be substantially improved via synchrophasor technology:

- Real-Time Monitoring & Control
- State Estimation
- Real-Time Congestion Management
- Post-Disturbance Analysis
- Benchmarking & System Model Validation
- Power System Restoration
- **Adaptive Protection**

*The Phasor Business Case laid the foundation for two subsequent PIER research projects, and for the current demonstration project.*
Advanced Protection Systems Using Wide Area Measurements

This PIER project developed and tested advanced protection methodologies for three high-priority applications identified in the Phasor Business Case study, using synchrophasor technology:

1. **Adaptive Security/Dependability**: On-line adjustment of relay operations under stressed grid conditions to avoid false trips that can contribute to cascading outages.

2. **Impedance Relay Zone Encroachment**: Real-time alarms and displays to alert operators and planners when evolving system conditions increase the possibility of undesirable relay trips.

3. **Adaptive Out-of-Step Protection**: On-line adjustment of out-of-step relays to keep generators synchronized with the system in the face of changing conditions.

*Principal Investigator: James Thorp, Virginia Polytechnic Institute*
Adaptive Relaying Technology Development & Measurements

This PIER project developed and tested advanced protection methodologies for four additional high-priority applications identified in the Phasor Business Case study, using synchrophasor technology:

1. **Relay Back-up Zone Supervision**: Avoid undesirable or unnecessary Zone 3 back-up relay operations (“false trips”).

2. **Intelligent Load Shedding**: Supervision of load dropping schemes in emergencies, to avoid the formation of “islands” in the grid and to keep system frequency stable at 60 Hz.

3. **Adaptive Loss-of-Field Relaying**: On-line adjustment of generator loss-of-field relays to ensure proper relay operations as system conditions change over time.

4. **Oscillation Damping Controller**: Robust damping of system oscillations using a wide array of system controls, including generator excitation systems and FACTS devices.

**Principal Investigator:** James Thorp, Virginia Polytechnic Institute
Adaptive Relaying Field Demonstration Project

Title: Application of Advanced Wide Area Early Warning Systems with Adaptive Protection

Sponsors: US DOE, CEC

Research Team: CIEE, PG&E, SCE, Virginia Tech, Mississippi State U., Quanta Technologies

Tasks:
2. Relay Impedance Zone “Encroachment” Detection
3. Protection Information Tool (for visualization of synchrophasor and protection system information).

These research tasks will be implemented and demonstrated in the actual utility environment of the PG&E/SCE Midway-Vincent 500kV line protection system.
Task #1: Adaptive Relaying for Security/Dependability Balance
Midway-Vincent Adaptive Protection Scheme
PMU Placement

<table>
<thead>
<tr>
<th>Line Current</th>
<th>PMU</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEVERS</td>
<td>DEVERS</td>
</tr>
<tr>
<td>DEVERS</td>
<td>TESLA</td>
</tr>
<tr>
<td>DIABLO</td>
<td>DIABLO</td>
</tr>
<tr>
<td>TESLA</td>
<td>VACADIXON</td>
</tr>
</tbody>
</table>

References

- Summer: VACADIXON
- Winter: TESLA

Slide courtesy of Virginia Polytechnic Institute
Task #2: Impedance Relay
Encroachment Alarm

Picture courtesy of Virginia Polytechnic Institute
Task #3: Visualization of Synchrophasor Data

- Power system operators work under vigilance conditions, and performance decrements are common where sustained human attention is required.
- Data visualization may need to be modified to improve operators’ situational awareness and decision making, and avoid operator fatigue.
  - Increased understanding of what the data means.
  - How should synchrophasor data integrate with existing and other informational sources?
  - How will synchrophasor data impact decisions?
- **Objective:** Develop and demonstrate a Protection Information Tool (PIT) to assist operators in the interpretation and use of synchrophasor data in system protection applications.

*Principal Investigator: Roger King, Mississippi State U.*
Visualization of Synchrophasor Data (cont’d.)

• Cognitive Task Analysis: Semi-structured interviews with operators, planners and engineers ("end-users") to:
  - Understand current visualization usage and meaning
  - Develop the role of synchrophasor data in power systems monitoring
  - Identify critical decision points in tasks
  - Perform needs analysis for end-users

• Prototype PIT Development and Mock-up
  - Preliminary testing using non-experts
  - Formal testing using experts (power systems monitors)
  - Visualization refinement based on assessment outcomes

• Proof of Concept testing using archived utility data
Bus Angle Visualization:
8/14/03 16:05 EDT (Reconstructed)
Visualization Example

Oscillation Damping and Alarm

![Diagram showing mode estimates, oscillatory frequency, damping ratio, alert threshold, and alarm threshold.]

- Poorly Damped Mode
- Oscillatory Frequency (Hz)
- Damping Ratio (%)
- Alert Threshold <5% damping
- Alarm Threshold <3% damping

Photo courtesy CERTS
Conclusion

• Synchrophasors are rapidly moving from the R&D environment into the world of real-time applications.
• With this demonstration project, California is leading in the commercial adoption of Adaptive Relaying technologies.
• The same utility engineers who will use the technology are the same ones conducting the field trial, facilitating eventual tech transfer.
• The utility “protection laboratories” set up by PG&E and SCE represent a real-world test bed for future AR technology trials.
Questions?

Lloyd Cibulka
Research Coordinator
California Institute for Energy & Environment
Electric Grid Research
Phone: 510-290-3875
Email: Lloyd.Cibulka@uc-ciee.org