Application of Advanced Wide Area Early Warning Systems with Adaptive Protection

DOE Smart Grid Project DE-OE0000120

presented to:
NASPI Working Group
Atlanta, GA

October 18, 2012
Project Objectives

• Field demonstrations of advanced protection systems using synchrophasor data:
  1. Adaptive Security/Dependability Balance
  2. Impedance Relay Zone “Encroachment” Detection & Alarm

• Develop Protection Information Tool:
  1. User-validated visualizations of protection information based on synchrophasor data
  2. Sensor web specifications enabling a uniform and standardized methodology for information exchange via extensions to OpenPDC
Research, Development & Demonstration Team

- Lloyd Cibulka – CIEE: Project management and coordination
- Jim Thorp, Virgilio Centeno – Virginia Tech: Relay algorithms development, testing and evaluation
- Roger King, Kari Babski-Reeves – Mississippi State: Protection information tool development, testing and evaluation
- Vahid Madani – PG&E: Host utility, field testing and evaluation
- Frank Ashrafi – SCE: Host utility, field testing and evaluation
- Tariq Rahman – SDG&E: Historical relay data, technical advisor
- Damir Novosel – Quanta: Technical advisor
Adaptive Security/Dependability Balance

• The primary protection system consists of three redundant sets of relays, any one of which can trip the line if it detects a fault. This biases the protection system in favor of reliability for normal conditions.

• Objective of Adaptive S/D Balance is to minimize the possibility that any one set of relays will false-trip during stressed system conditions, which might contribute to a cascading outage.

• Technical Approach: Utilize an “Adaptive Voting Scheme.” If stressed system conditions are detected using synchrophasor measurements, a relay supervisory signal based on a 2-out-of-3 voting scheme is generated.

Dependability (Reliability): High probability that relays will operate for an actual fault. Security: Low probability that relays will operate when there isn’t an actual fault.
Security/Dependability Adaptive Protection
Conceptual Design
Adaptive Voting Scheme: PMU Placement

### Line Current

<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>LOS BANOS</td>
</tr>
</tbody>
</table>

### References

<table>
<thead>
<tr>
<th>Season</th>
<th>PMU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>VACA-DIXON</td>
</tr>
<tr>
<td>Winter</td>
<td>TESLA</td>
</tr>
</tbody>
</table>
Adaptive Relay System Architecture in SCE Design
Application of Advanced Wide-Area Early Warning System with Adaptive Protection - SCE Design

EXISTING RELAYS ON THE MIDAWY NO. 1 500kV Line @ VINCENT 500kV SUB

REL 350-1
D60/TCF-10B
REL 350-2

To PG&E

PMU
EXISTING PDC @ GCC
PMU

Stream Reader
DECISION TREE (DT)
COMPUTING PLATFORM (SEL-3354)

LOGIC PROCESSING (VOTING LOGIC)
AUTOMATION CONTROLLER (SEL-3530)

Trip CB’s (EXISTING)

Heavy Winter
Heavy Summer

TRIP OUTPUT

© Copyright 2009, Southern California Edison
Alarms for Encroachment of Relay Trip Characteristics

• Looked at Following Relays:
  – Distance
  – Loss of Excitation
  – Out-of-Step

• Concentrated on Path 15 and Path 26

• Alarm system
  – Provides information and warning to engineers
  – Essentially a time-saving tool
The supervisory boundary is a concentric circle 50% larger than the largest zone of the relay.
Distance relays most susceptible to encroachment due to power swings or increasing power flow:

<table>
<thead>
<tr>
<th>Line Name</th>
<th>Dist. From Z2/ Radius of Z2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midway-Vincent ck 3 500kV</td>
<td>1.07</td>
</tr>
<tr>
<td>Midway-Vincent ck 2 500kV</td>
<td>1.12</td>
</tr>
<tr>
<td>Midway-Vincent ck 1 500kV</td>
<td>1.12</td>
</tr>
<tr>
<td>Los Banos-Midway ck2 500kV</td>
<td>3.59</td>
</tr>
<tr>
<td>Diablo-Midway ck 3 500kV</td>
<td>4.05</td>
</tr>
<tr>
<td>Diablo-Midway ck 2 500kV</td>
<td>4.36</td>
</tr>
<tr>
<td>Diablo-Gates 500kV</td>
<td>4.93</td>
</tr>
<tr>
<td>Vaca Dixon-Cottonwood 230kV</td>
<td>4.94</td>
</tr>
</tbody>
</table>

Phasor measurement units at:
Midway 500kV, Los Banos 500kV, Diablo 500kV, and Vaca-Dixon 230kV were initially proposed to monitor these lines.
Real-Time Alarm for Relay Characteristic Encroachments – Wide-Area Measurements to Determine / Predict Trends for Relaying Parameters

• Define a help system for operators and/or system engineers
  – Alarms as system conditions approach relay characteristics

• Identify possible countermeasures
  – Warning System
    • Legacy Systems – Provide information and advance warning
    • Computer Relays – Supervisory Control Action - Alter Settings
Visualization: Overview Screens

• Types:
  • Speedometer to represent phase angle
    • Full speedometer
    • Hollowed speedometer
  • Arrow to represent phase angle
  • Geographic cluster map
  • Circle Display

• Current Functionality:
  • Allows users to assess the state of the whole system quickly
  • Easy identification of trouble areas
  • Ability to view angles between non adjacent angles

• Functions to be Implemented:
  • Ability to choose which overlay is being displayed
Full Speedometer
Hollowed Speedometer
Arrow
Substation View

• Substation View:
  • Based on single-line diagram
  • All overlays are linked to the same substation visualization

• Functionality:
  • Ability to select which PMU data should be displayed
  • Compare angular values for ends of the lines
  • Assess substation problems
  • Zoom in on data
Substation Views – Speedometers
Cluster Overview

- Uses geographic map instead of single-line diagram
- Uses same substation views as single-line diagram visualizations
- Same functionality as the single-line overviews
  - Added functionality of being able to zoom in at the cluster level
Circular Display

- Based on current display at SCE
- Shows a few selected PMUs
- Uses a single reference point
- Can change the number of PMUs displayed
3D Nose Curve

- Changes of active power, reactive power and voltage can be seen on one single surface.
- Shape and/or color can be changed in real time to indicate system status.
- Can include a sphere that moves along the surface of the curves as time progresses as an indication of system state.
2D Nose Curve
Project Status

• Adaptive Relaying Schemes:
  – Phase I (R&D): Development and adaptation of research algorithms to real-time utility environment. (Completed)
  – Phase II (Pilot Testing): Testing and validation (POC) of relaying schemes in University and in PG&E and SCE Protection System Laboratories. (Completed)
  – Phase III (Field Demonstration): In progress. Original project end date was September 2012, now December 2013 (pending DOE approval).
    • Field installations to be completed by ~ January 2013
    • Data collection to be completed by September 2013
    • Data evaluations, Final Report by December 2013

• Visualization Tool:
  – Phase I (R&D): OpenPDC and Sensor Web specifications; initial PIT visualizations developed (Completed)
  – Phase II (Pilot Testing): Interviews and workshops with utility engineers to refine visualizations (Completed)
  – Phase III (Field Demonstration): Second round of evaluations in users’ offices (In progress).
Questions?

Lloyd Cibulka
Research Coordinator
California Institute for Energy & Environment
Electric Grid Research
Phone: 510-290-3875
Email: Lloyd.Cibulka@uc-ciee.org
PMU at DEVERS & Diablo
PMU at - Ii735 (imaginary part of the current through transmission line between Devers – Valley SC) and IR19 (real part of the current through transmission line between Palo Verde – Devers) **DEVERS**
PMU at - Ii1033 (imaginary part of the current through transmission line between Diablo – Midway) **DIABLO**
And
**VACA DIXON**
Decision Tree – Heavy Winter
Reference PMU – Tesla (PG&E)

PMU at TESLA
PMU at – IR1106 (real part of the current through transmission line between TESLA – LOS BANOS) TESLA

Total PMUs req. in this Project (Heavy Summer & Heavy Winter) at:

VACADIXON
TESLA
DEVERS
DIABLO
PDC Phasor Processor

Stream Reader
- Reads C37.118 PDC stream
- Connection via TCP
- User selects phasor from stream for the decision tree

Decision Tree
- Preprocesses data prior to tree assignment
- User selects tree type from controller

Modbus TCP
- Retrieves tree type from controller
- Sends vote value to controller from decision tree
- Tree type and vote status are both displayed in the GUI
Highlighted components being implemented uses openPDC data streams:
- Enables to incorporate standardized models.
- Loose coupling in a Services Oriented Architecture (SOA)-publish/subscribe mechanism.
- Cross-domain integration capabilities
- Development in JAVA for cross platform compatibility
Sensor Web Architecture

Architecture of the Power Sensor Web