EPRI Protection Settings Evaluation Tool (PSET)

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Grid Operations & Planning
EPRI
Protection Settings Evaluation Tool (PSET)

Software

Intended use:

- Automatically assess the protection performance and identify misoperations, uncleared faults, and near-misses
- Use Web Browser/Excel/Access interface to report, track and trend over time

Requires network model with at least some protection relays in CAPE or ASPEN

Project Task Timeline

2015: Initial version of CAPE macro
2016: ASPEN macro, add near-miss to CAPE macro, basic database, case studies
2017: Optimize macros for speed, add new study scenarios, develop advanced trending database, case studies
2018: Further simulations, case studies
The Problem – Protection Misoperations

NERC Stats

- Misoperations occur in roughly 1 in 10 faults
- Approximately 29% of protection misoperations are due to settings, logic or design errors.
- NERC Events Analysis determined that incorrect ground instantaneous overcurrent settings on 115 kV and 230kV systems are a leading cause of relay misoperations.

Trends

- Misoperations tend to be more commonly associated with numerical relays. Number of numerical relays increasing.
- Significant changes to the system (generation retirements, etc.) are occurring quickly and can impact the performance of protection systems.
- Industry is losing P&C expertise at a rapid pace.
Grid Scenarios for Relay Settings

One relay on one bay
One of many devices!

For this small grid:
- 84 transmission line relays
- 11 transmission busbar protection
- 54 transformer relays
- More on distribution grid, generators etc

Relays commissioned at different times
Settings based on different grid scenarios
Settings often not kept in a centralised DB
Protection Settings Evaluation Tool (PSET)

- Evaluate coordination of protection near a busbar, in a grid area or across whole grid
  - Applies multiple fault types across all lines in study area
- Flags relay misoperations, fast/slow trips, uncleared faults
- View results in web browser & store in database for simple reporting, trending over time
- Use database to track performance. Flag when grid changes cause relays to become miscoordinated.

Proactively identify & avert potential misoperations!
What does PSET Analyze?

Examines local protection relays after short circuit simulated and again after each circuit breaker trips open.

Was the fault isolated?

- Did each relay trip correctly and quickly?
- Did any relay over-reach?
- Were any relays miscoordinated?
- Was any relay close to misoperation (near miss)?

Has Protection Performance Changed Since the Last Time the Tool was Run?
Define Fault Study and Protection Criteria - CAPE

- Study all of a grid voltage level, area/zone, or all lines within X buses of the selected busbar.

- Study various fault scenario combinations:
  - Grid scenarios
  - Fault Types
  - Fault Locations

- Selecting all the options means 10,000s of fault simulations!

- Define protection performance requirements

- Identify Near-Misses
Simulations never 100% accurate

Fault current in practice is greater or less than simulation

- Trip setting=1000A, but what if fault current is 999A or 1001A?
- “Near-miss” feature identifies settings with small margin
CAPE/ASPEN Macros – Results – Web Browser

- Output file in XML file format
- Can open in a Web Browser, Excel, Access etc
- High-level results per fault; hover mouse over a fault and a box pops up with specific relay op details
- Just click CTRL-O from Internet Explorer, FireFox, or Excel and select the XML file

<table>
<thead>
<tr>
<th>Fault Number</th>
<th>From Station</th>
<th>To Station</th>
<th>Voltage (kV)</th>
<th>Circuit ID</th>
<th>Distance To Fault</th>
<th>Fault Type</th>
<th>Contingency</th>
<th>Outage(s)</th>
<th>Fault Clearance Time (Seconds)</th>
<th>Test Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2 CLAYTOR</td>
<td>1 GLEN LYN</td>
<td>132</td>
<td>1</td>
<td>5</td>
<td>SINGLE_LINE_GROUND, R=0 (ohm)</td>
<td>Normal state with intact network</td>
<td></td>
<td>9999.000</td>
<td>Inst Overreach Misoperation, Fault Not Cleared</td>
</tr>
<tr>
<td>2</td>
<td>1 GLEN LYN</td>
<td>2 CLAYTOR</td>
<td>132</td>
<td>1</td>
<td>5</td>
<td>SINGLE_LINE_GROUND, R=0 (ohm)</td>
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<td></td>
<td>9999.000</td>
<td>MISOPERATION, Fault Not Cleared</td>
</tr>
</tbody>
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<thead>
<tr>
<th>Station</th>
<th>Circuit Breaker</th>
<th>Voltage (kV)</th>
<th>Circuit ID</th>
<th>Tripping Relay</th>
<th>Tripping Element</th>
<th>Trip time (Seconds)</th>
<th>Test Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 NEVADA</td>
<td>2 CLAYTOR</td>
<td>132</td>
<td>132</td>
<td>NV-G2 (B)</td>
<td>Ground Overcurrent</td>
<td>0.064</td>
<td>MISOPERATION</td>
</tr>
<tr>
<td>8 REUSENS</td>
<td>6 NEVADA</td>
<td>132</td>
<td>132</td>
<td>RE-G1 (B)</td>
<td>Ground Overcurrent</td>
<td>1.319</td>
<td>MISOPERATION</td>
</tr>
<tr>
<td>7 OHIO</td>
<td>6 NEVADA</td>
<td>132</td>
<td>132</td>
<td>OH-P1 (B)</td>
<td>Phase Overcurrent</td>
<td>0.756</td>
<td>MISOPERATION</td>
</tr>
<tr>
<td>6 NEVADA</td>
<td>10 NEW HAMPSHR</td>
<td>33</td>
<td>132</td>
<td>OH-G1 (B)</td>
<td>Ground Overcurrent</td>
<td>1.008</td>
<td>MISOPERATION</td>
</tr>
</tbody>
</table>

132.0kV 132.0kV

<table>
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<th>Station</th>
<th>Voltage (kV)</th>
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<th>Tripping Element</th>
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</tr>
<tr>
<td>3</td>
<td>2 CLAYTOR</td>
<td>132</td>
<td>132</td>
<td>SINGLE_LINE_GROUND, R=0 (ohm)</td>
<td>Normal state with intact network</td>
<td>9999.000</td>
</tr>
</tbody>
</table>
CAPE/ASPEN Macros – Results – New Excel Interface

2017 - New Excel Sheet Interface

• Presents high level overview of latest or historical simulation run
• Compare sets of results; e.g. this week vs last month/last year
• Easy to filter results by station, fault clearance issue etc. Report instantly updates
• Identify changes since last run – flag new misoperations, miscoordinations, uncleared faults that weren’t an issue the last time you ran the tool
• Track/trend fault clearance times
• Present high level statistics and graphs on fault clearance times and issue type
User can view results from one or more past studies.

Pie chart showing main protection issues.

Easily filter results to look at particular stations or examine particular issues.

Present spread of trip times for all faults.
CAPE/ASPEN Macros – Results – New Excel Interface

<table>
<thead>
<tr>
<th>ID</th>
<th>Faulted Circuit</th>
<th>Clearance Time</th>
<th>Protection Performance Assessment</th>
<th>Tripped Element</th>
<th>Tripping Element</th>
<th>Trip Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>04/13/2017 #0001</td>
<td>GLEN LYN 112.0 kV 2 CLAY TOP 112.0 kV</td>
<td>0.05</td>
<td>Overreach Misoperation</td>
<td>1 GLEN LYN 112.0 kV 2 CLAY TOP 112.0 kV</td>
<td>0.017</td>
<td>Automatically and instantaneously updates</td>
</tr>
<tr>
<td>OK</td>
<td>1 GLEN LYN 112.0 kV 2 CLAY TOP 112.0 kV</td>
<td>0.05</td>
<td>Phase Deenergize</td>
<td>0.017</td>
<td>Ground Overcurr 0.017</td>
<td></td>
</tr>
<tr>
<td>INST TRIP OVER REACH</td>
<td>1 GLEN LYN 112.0 kV 2 CLAY TOP 112.0 kV</td>
<td>0.05</td>
<td>Phase Deenergize</td>
<td>0.017</td>
<td>Ground Overcurr 0.017</td>
<td></td>
</tr>
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<td>OK</td>
<td>1 GLEN LYN 112.0 kV 2 CLAY TOP 112.0 kV</td>
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<td>Ground Overcurr 0.017</td>
<td></td>
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<td>Ground Overcurr 0.017</td>
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<td>0.05</td>
<td>Phase Deenergize</td>
<td>0.017</td>
<td>Ground Overcurr 0.017</td>
<td></td>
</tr>
<tr>
<td>MISOPERATION, Fault Not Cleared</td>
<td>6 NEVADA 112.0 kV 2 CLAY TOP 112.0 kV</td>
<td>0.05</td>
<td>Ground Overcurr 0.017</td>
<td>0.182</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td>OK</td>
<td>6 NEVADA 112.0 kV 2 CLAY TOP 112.0 kV</td>
<td>0.05</td>
<td>Ground Overcurr 0.017</td>
<td>0.182</td>
<td>0.55</td>
<td></td>
</tr>
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<td>0.182</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td>MISOPERATION, Fault Not Cleared</td>
<td>7 OHIO 112.0 kV 6 NEVADA 112.0 kV</td>
<td>0.05</td>
<td>Phase Deenergize 0.720</td>
<td>0.55</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td>OK</td>
<td>7 OHIO 112.0 kV 6 NEVADA 112.0 kV</td>
<td>0.05</td>
<td>Phase Deenergize 0.720</td>
<td>0.55</td>
<td>0.55</td>
<td></td>
</tr>
</tbody>
</table>

Results shown here are just faults on lines connected to Glen Lyn 132 kV.
CAPE/ASPEN Macros – Results – Access Database

- Output file in XML file format; Can also import into an Access Database
- Store protection assessment results
- Easily create custom reports for trending over time, audit reports etc
- Basic version complete in 2016, advanced version with tracking/trending/auditing in 2017

Protection Setting Evaluation Tool

View Station Report From Most Recent Results
View All Results For Grid Voltage
View Zone 1 and Inst Overcurrent Over-reaches
Trend Historical Protection Performance at Substation
View issues by Type

1 GLEN LYN 132.0KV
132

Help: Select from any of the drop-down boxes above to view a report on the selected topic.
CAPE/ASPEN Macros – Results – Access Database

Quickly Generate Reports such as:

- View all Zone 1/Overcurrent over-reaches
- View protection performance near a line or a station
- Trend over time, find where protection performance across the grid has improved or new issues have arisen e.g.
  - New issues flagged this month that weren’t there last month or 2017 vs 2016
- Study future grids and see if new issues arise in coming year with the commissioning of new lines, commissioning/de-commissioning of generators

**Faults By Station** 1 GLEN LYN 132.0kV

<table>
<thead>
<tr>
<th>Fault Type</th>
<th>Fault Clearance Time</th>
<th>Protection Performance Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>SINGLE_LINE_GROUND</td>
<td>0.03</td>
<td>Misoperation</td>
</tr>
<tr>
<td>THREE-PHASE, R=0</td>
<td>0.03</td>
<td>Misoperation</td>
</tr>
<tr>
<td>SINGLE_LINE_GROUND, R=0</td>
<td>0.05</td>
<td>Misoperation</td>
</tr>
<tr>
<td>THREE-PHASE, R=0</td>
<td>0.05</td>
<td>Misoperation</td>
</tr>
</tbody>
</table>

**Faults with Issue: Misoperation**

<table>
<thead>
<tr>
<th>Distance To Fault</th>
<th>Fault Type</th>
<th>Fault Clearance Time</th>
<th>Relay_TripStation</th>
<th>Voltage</th>
<th>Reliability</th>
<th>Trip Time</th>
<th>Relay Performance Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>SINGLE_LINE_GROUND</td>
<td>0.05</td>
<td>LYN 132.0kV</td>
<td>Ground</td>
<td>0.017</td>
<td>Misoperation</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>SINGLE_LINE_GROUND</td>
<td>0.05</td>
<td>LYN 132.0kV</td>
<td>Ground</td>
<td>0.017</td>
<td>Misoperation</td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>SINGLE_LINE_GROUND</td>
<td>0.05</td>
<td>LYN 132.0kV</td>
<td>Ground</td>
<td>0.017</td>
<td>Misoperation</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>THREE-PHASE, R=0</td>
<td>0.05</td>
<td>LYN 132.0kV</td>
<td>Ground</td>
<td>0.017</td>
<td>Misoperation</td>
<td></td>
</tr>
</tbody>
</table>

Thursday, September 19, 2014
# Summary of Protection Settings Evaluation Tool (PSET)

## Problem

- Protection becoming more numerous and complex: 10s to 100+s of settings
- Grid state (outages and generators) can have a massive impact on protection performance and coordination
- Relay settings calculated for credible grid states (N-1 etc) at that time
- Settings checked/revised at maintenance intervals like 3-7+ years
- 10% of faults in US have at least one relay misoperation; 29% of misoperations due to relay configuration/settings issues

## Solution

- Automatically simulate multiple fault types at multiple locations along each transmission line across the grid and for each fault assess each relay tripping
- For each fault, look at trip times of each relay and identify if all protection relays near the fault meet set criteria. Did any relays over-reach or misoperate, was the fault cleared quickly?
- Engineers can’t be expected to manually examine 1000s of results, so produce short, simple, easy to read report identifying issues - results file can be viewed in a webpage, Excel, or brought into an Access DB
- Automatically compare latest results with last week/month/year etc. **Flag new protection issues which didn’t exist the last time you ran the tool**
Together…Shaping the Future of Electricity
System Simulator Example: Fault Initiation (5% of Line)

L-G Fault occurs at 5% along line
System Simulator Example: First PCB Opens

Correct CB Operation

0.055 s: Station D: Station A, GR_IOC
System Simulator Example: Second PCB Opens (Misoperation and Near Miss)

- **Relay Near Miss** (fault current close to trip setting)
  - 0.075 s: Station B: Station A, GR_IOC

- **Relay misoperates** (over-reaches)
  - 0.075 s: Station C: Station A, GR_IOC

- **Correct Relay Tripping**
  - 0.055 s: Station D: Station A, GR_IOC
System Simulator Example: Third PCB Opens & Clears Fault

Relay Near Miss
(fault current close to trip setting)

0.075 s: Station B: Station A, GR_IOC

Relay misoperates
(over-reaches)

0.075 s: Station C: Station A, GR_IOC

Correct Relay Tripping

0.055 s: Station D: Station A, GR_IOC

0.418 s: Station A: Station D, Z2_G
System Simulator Example: Miscoordination

Station A

Station B

0.075 s: Station B: Station A, GR_IOC

Relay miscoordination  Station C

0.428 s: Station C: Station A, GR_IOC

Correct Relay Tripping  Station D

0.055 s: Station D: Station A, GR_IOC

Correct Relay Tripping

0.418 s: Station A: Station D, Z2_G
System Simulator Example: Primary Protection

L-G Fault occurs at 5% along line

Only these circuit breakers should trip to isolate the fault
System Simulator Example: Backup Protection

L-G Fault occurs at 5% along line

These circuit breakers should trip if primary circuit breaker fails to open