AUTOMATED APPROACH FOR COMPLIANCE WITH NERC PRC-027-1 REQUIREMENTS FOR PROTECTION SYSTEM COORDINATION OF BES ELEMENTS

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Background

- NERC standards are continually updated to help reduce misoperations and improve power system reliability
- New standards also put additional burden on engineers to study and demonstrate compliance
- Utilities are leaning towards compliance solutions that are comprehensive and provide long term efficiency
- NERC PRC-027-1 is an opportunity for utilities to adopt the industry leading protection analysis practices, and benefit from an automated solution
NERC PRC-027-1 Standard

What is PRC-027-1?

• NERC Reliability Standard with stated purpose: “To maintain the coordination of Protection Systems installed to detect and isolate Faults on the Bulk Electric System (BES) Elements, such that those Protection Systems operate in the intended sequence during Faults.”

• Comes into effect October 2020

PRC-027-1 Requirements – The standard has three main requirements:

• R1. Establish a process for developing new and revised protection system settings for BES elements such that the protection systems operate in the intended sequence during faults

• R2. Perform protection system coordination studies periodically, as per options described in the standard

• R3. Develop new protection system settings by following the process developed in requirement R1
Focus of the Paper

- The main focus of the paper is PRC-027-1 requirement R2

- PRC-027-1 requirements R1 and R3 are related to establishing and following a protection settings development process.

- Automation does have a role to play in R1 and R3 compliance; but it is not the focus of this paper.

- They are discussed as they relate to requirement R2, such as:
  - Primary Network and Protection System review and update
R2 Compliance Options – For each BES element with protection system functions:

- **Option 1.** – Perform a protection System Coordination Study in a time interval not to exceed six-calendar years;

- **Option 2.** – Compare present Fault current values to an established Fault current baseline and perform a Protection System Coordination Study when the comparison identifies a 15 percent or greater deviation in Fault current values (either three phase or phase to ground) at a bus to which the BES Element is connected, all in a time interval not to exceed six-calendar years;

- **Option 3.** – Use a combination of Option 1 and 2

*The standard provides the flexibility to use different options, therefore automation tools must be designed to be flexible as well.*
PRC-027-1 R2 Compliance Process Overview

Year 0

Coordination Studies Conducted for Ongoing Projects

Update Baseline Fault Levels

Update Short Circuit and Protection Model

Fault Current Comparison
Coordination Review
PRC-027 Compliance Check

Fault Current Comparison
Coordination Review
PRC-027 Compliance Check

Final Audit Ready Compliance Reporting
Primary Network and Protection System Modeling

- PRC-027-1 evaluations will require access to accurate and up-to-date primary network and protection system models.
- Utilities are moving towards maintaining system parameters in centralized databases and protection data in asset management applications.
- Protection simulation software platforms are capable of creating system model directly from centralized data sources.
- Centralized databases must be setup to support automation-assisted model creation and verification.
Access to the centralized data is only part of the puzzle...

Interfacing application relies on:
- Standardization of naming across data sources
- Processes to maintain accuracy and the usefulness of the data

Automated modeling tools are limited by the data available, therefore, some manual customizations may still be required

Even if manual customizations may be required, investment in centralized databases and interfacing applications that convert this data into simulation ready models is highly valuable
Utilities must invest in automated modeling tools that directly retrieve relay data (type, setting file, location) from Asset Management database, and prepare simulation ready protection model.
When should the baseline bus fault be updated?

*Protection Systems responsible for clearing faults on equipment connected to the BES buses shall operate in the intended sequence.*

The bus fault current at which the protection systems are verified to operate as expected, should be set as the baseline.
Determining and Tracking Bus Fault Baseline

- Initial baseline fault current levels can be determined based on:
  - Past records of coordination evaluation
  - Performing an initial system wide coordination study

- Continuously update baseline
  - Baseline fault current levels can be updated, as coordination studies are completed for network equipment connected to BES bus
  - The topological relationship between BES buses and connected equipment is determined from the short circuit program
Determining Buses with >15% Current Deviation and Study Due Dates

- Two Main Fault Current Comparison Outputs:
  - Buses with >15% deviation, and coordination study due date

- Key Inputs

Coordination study due date is not only a function of present fault comparison date, but also depends on results of previous fault comparisons, and when baselines were last updated.
For BES buses with >15% deviation:

- Equipment connected up to two levels away from a BES bus will need to be part of the coordination analysis

Example BES bus for Fault Comparison
Determining Equipment Requiring Coordination Studies

- Modern protection simulation software applications allow topological searching to identify equipment requiring coordination studies.
- The list of lines can also be used to start batch coordination studies.

Diagram:
- Buses with >15% Deviation
- Short Circuit Model
- Identify Equipment Requiring Coordination
- For each BES Bus >15% Deviation:
  - Get a list of line requiring coordination studies
Performing Coordination Studies

- Protection coordination studies can be performed in many different ways
- A systematic and comprehensive coordination review process should be adopted

Running Coordination Studies in Simulation Software
Processing Coordination Study Results Data
Documenting Issues, and Mitigation Plans
Performing Coordination Studies

Wide Area Coordination Macros/Scripts

- Wide area coordination study approach is designed for relay coordination across a large area within a transmission network.
- Evaluate protection performance under numerous fault cases and contingencies including relay failure and/or breaker failure.
- Highly automated to relieve the protection engineer from the tedium of running the studies.
- Study generates sequence of events report showing primary and backup protection behavior and highlighting any misoperation or coordination time interval issues.
Performing Coordination Studies

Wide Area Coordination Macros/Scripts

**CLASSIC**
- TPH & LTL close-in fault at local bus for system normal (2)
- TPH close-in fault at local bus with strongest source out (1)
- Minimum LTL close-in fault at local bus (1)
- SLG remote bus fault at system normal (1)
- Minimum & maximum SLG remote bus fault at remote bus (2)
- LTL remote line-end fault for system normal (1)
- SLG line-end Fault (Strongest Source out) (1)
- No. of simulations per terminal = 9

**AUTOMATED**
- Four bolted faults SLG, LTL, DLG and TPH,
- Four resistive faults 1 & 5 ohms SLG & DLG
- Five fault locations
- Assume five local sources including mutual coupling
- Assume five remote sources
- Two protection packages, A and B
- No. of simulations per terminal =
- \[8 \times 5 \times 11 \times 2 = 880\]
Performing Coordination Studies

Be prepared for the high volume of test cases!

Fault Cases for Line Coordination Study

- Package A in Service (Package B out of Service)
  - Pilot In
    - Normal Study
      - Contingency 1 (Ex. Line Outages)
      - Contingency 2 (Ex. XFMR Outages)
      - Contingency 3 (Ex. Mutually Coupled Line Outage)
      - Contingency 4 (Ex. Generator Outage)

- Package B in Service (Package A out of Service)
  - Pilot In
    - Normal Study
      - Contingency 1 (Ex. Line Outages)
      - Contingency 2 (Ex. XFMR Outages)
      - Contingency 3 (Ex. Mutually Coupled Line Outage)
      - Contingency 4 (Ex. Generator Outage)

- Package A and B in service
  - Pilot Out
    - Normal Study
      - Contingency 1 (Ex. Line Outages)
      - Contingency 2 (Ex. XFMR Outages)
      - Contingency 3 (Ex. Mutually Coupled Line Outage)
      - Contingency 4 (Ex. Generator Outage)

- Network Outage Contingency Studies

Locations:
- 0%
- 10%
- 20%
- 50%
- 80%
- 90%
- 100%

Locations:
- TPH
- LTL
- SLG
- DLG - RF

TPH
SLG
DLG
DLG - RF

LTL
0%
10%
20%
50%
80%
90%
100%

SLG
10%
20%
50%
80%
90%
100%

DLG
50%
80%
90%
100%

DLG - RF

...
Performing Coordination Studies

- How can we focus an engineer’s limited time on solving relay settings problems rather than reviewing thousands of pages of raw data?
- How do we keep track of all of the mitigation plans?
- How do we manage the studies being worked upon by a large team?

-Stepped Event Simulations on the study line for a 1LG fault at 10% from bus 0 AA 230 kV.
-Stepped Event Simulations on the study line for a 1LG fault at 50% from bus 0 AA 230 kV.
-Stepped Event Simulations on the study line for a 1LG fault at 90% from bus 0 AA 230 kV.

-0.017 AA 230 kV end of study line DS ground relay AA_23054_21G_B 0.5 DS gnd relay BB_23055_21G_B at 0 BB230kV 230.kV-0 AA 230 230.KV 4L
-0.017 BB230kV 230.KV end of study line DS ground relay BB_23054_21G_B 2.28 OC gnd relay PEN_23051_51G_B at 0 PEN230 230.kV-0 AA 230 230.KV 1L
-0.033 BB230kV 230.KV end of study line DS ground relay BB_23054_21G_B 0.537 OC gnd relay AA_23055_51G_B at 0 AA 230 230.kV-0 BB230kV 230.KV 4L

-Element: 9893 TI
-Element: 9781 AUX "TRIP"; (PILOT_WIZARD); Contact Logic Code: POTT_TRIP_A
-Element: 9745 AUX "67G1"; (SEL 421); Contact Logic Code: 67NI_A
-Element: 9747 AUX "TRIP"; (PILOT_WIZARD); Contact Logic Code: POTT_TRIP_A
-Element: 9745 AUX "TRIP"; (PILOT_WIZARD); Contact Logic Code: POTT_TRIP_A
-Element: 9745 AUX "TRIP"; (PILOT_WIZARD); Contact Logic Code: POTT_TRIP_A

South         LN 97, 345 kV,        LINE  BACKUP   22.00 2.00  24.00  19.56 PREDICTED
North_West    LN 39, 345 kv,
North_East    LN 39, 345kV,         LINE  PRIMARY  0.94  2.00  2.94   N/A   NORMAL OPERATION
South         LN 97, 345 kV,        LINE  BACKUP   22.00 2.00  24.00  19.56 PREDICTED

500 Transmission lines can produce about 4 million lines of raw data
Performing Coordination Studies

Translate Fault Summary to Device Summary

- Example:

<table>
<thead>
<tr>
<th>Substation</th>
<th>Device</th>
<th>Element</th>
<th>Contact Logic Code</th>
<th>LZOP</th>
<th>Risk</th>
<th>System Normal</th>
<th>N-1 Contingency</th>
<th>System Normal</th>
<th>N-1 Contingency</th>
<th>Action</th>
<th>Action Tag</th>
<th>Reason/Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ontario TS</td>
<td>D60</td>
<td>594 TIMER &quot;T2_GND&quot; &quot;1&quot;</td>
<td>21G2T A</td>
<td>Ontario_Line1_1000</td>
<td>1</td>
<td>CTI</td>
<td>CTI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alberta TS</td>
<td>D60</td>
<td>11261 TIMER &quot;T2_PHS&quot; &quot;1&quot;</td>
<td>21P2T B</td>
<td>Alberta_Line2_2000</td>
<td>4</td>
<td>CTI</td>
<td>CTI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quebec TS</td>
<td>SEL-311</td>
<td>6172 AUX &quot;Z2D&quot;</td>
<td>21P2T A</td>
<td>Quebec_Line3_3000</td>
<td>5</td>
<td>MISOP</td>
<td>MISOP</td>
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<td></td>
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<tr>
<td>Quebec TS</td>
<td>SEL-311</td>
<td>6172 AUX &quot;Z2D&quot;</td>
<td>21P2T A</td>
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<td>MISOP</td>
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</tbody>
</table>

Element: 594 TIMER "T2_GND" "1"
Substation: Ontario TS
LZOP: Ontario_Line1_1000
Type: D60
Tested Line: C21J
0% = Bus1 (220kV)
100% = Bus2 (220kV)
Ph-G Fault

Pilot In
- Package A: Line: 7101-7259-1(C242)
- Package B: Line: 7101-7259-1(C242)
- Both in service: Line: 7101-7259-1(C242)

Pilot Out

Mitigation Plan
- Setting Change
- Protection Upgrade
- System Upgrade
- No Change Required

Reducing 1000s pages of results into a list of miscoordinating devices requiring investigation and mitigation plan
Performing Coordination Studies

Risk Assessment

<table>
<thead>
<tr>
<th>Risk</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
</table>

**Function of Probability**
- Fault Probability
- Contingency Probability
- Time Margin

**Function of Consequence**
- Impact to Bulk Electric System
- Load Lost Through Outage Buses

**Misoperation**
- 50 ms
- High Risk
  - Misoperation
  - Higher Probability Fault Type
  - No Network Outage
  - Multiple Fault Locations

**Low Coordination Margin (70 ms)**
- 120 ms
- Low Risk
  - Coordination Margin Low
  - Lower Probability Fault Type
  - Network Outage
  - Single Fault Location
Performing Coordination Studies

Document Mitigation Plan and Update Baseline

- A database can help manage the large number of coordination studies and the mitigation plans
- By having the network topology and coordination studies results, the Baseline Fault Levels can be automatically updated
The database that can store all PRC-027 related fault comparison studies, network topology information, and coordination studies data will allow creation of audit ready documentation showing proof of compliance.
Overall Process - Recap

- Year 0: Coordination Studies Conducted For Ongoing Projects
- Year 6: Update Baseline Fault Levels
- Year 12: Update Short Circuit and Protection Model

- Fault Current Comparison
- Coordination Review
- PRC-027 Compliance Check

- Final Audit Ready Compliance Reporting
## Conclusion

<table>
<thead>
<tr>
<th>PRC-027 compliance has several aspects that require significant effort for preparation and execution</th>
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<tbody>
<tr>
<td>The automated approach leverages advanced modeling and simulation capabilities of modern protection software</td>
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<tr>
<td>Protection engineers’ skills and time utilization is maximized by focusing their attention on investigation and mitigation of issues</td>
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<td>It is in harmony with other industry drivers of power system network and protection data consolidation efforts</td>
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<td>The time and effort for showing PRC-027 compliance is greatly reduced</td>
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<td>Gives confidence to utilities that they are meeting/exceeding PRC-027 Compliance Requirements</td>
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</table>
Thank you!

For more questions, please contact:
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