Protective Relay End-End Testing

Matthew G. Bucek, PE
Overview of End-End Testing

What is it?

• GPS synchronized equipment is used to inject secondary currents and potentials at opposing ends of a transmission or subtransmission line, simulating real-time fault conditions at various locations both inside and outside of the line section in order to test communication-assisted protection schemes.

• Also has ability to verify operation of relay logic and/or DC inputs and outputs
Example

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**SUB 1**
SEL-311L
400 / 1 CTs
1200 / 1 PTs

**SUB 2**
SEL-311L
400 / 1 CTs
1200 / 1 PTs

10.01 mi

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**SUB 1 - SUB 2 #1**

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**SUB 1 - SUB 2 #2**

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**SUB 1 Substation - SEL-311L Test Descriptions - Tested vs SEL-311L Line Differential at SUB 2**

<table>
<thead>
<tr>
<th>TEST</th>
<th>PHASE</th>
<th>LOCATION</th>
<th>EXPECTED RESULTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A-G</td>
<td>SUB 1 - 138 kV Bus</td>
<td>No Trip/No Targets</td>
</tr>
<tr>
<td>2</td>
<td>A-B-C</td>
<td>SUB 1 - 138 kV Bus</td>
<td>No Trip/No Targets</td>
</tr>
<tr>
<td>3</td>
<td>B-C</td>
<td>SUB 1 - 138 kV Bus</td>
<td>No Trip/No Targets</td>
</tr>
<tr>
<td>4</td>
<td>A-G</td>
<td>SUB 2 - 138 kV Bus</td>
<td>51GT (39 cyc)</td>
</tr>
<tr>
<td>5</td>
<td>A-B-C</td>
<td>SUB 2 - 138 kV Bus</td>
<td>Zone 2 Time</td>
</tr>
<tr>
<td>6</td>
<td>B-C</td>
<td>SUB 2 - 138 kV Bus</td>
<td>Zone 2 Time</td>
</tr>
<tr>
<td>7</td>
<td>A-G</td>
<td>SUB 1 - SUB 2</td>
<td>87L, Zone 1 Ground</td>
</tr>
<tr>
<td>8</td>
<td>A-B-C</td>
<td>SUB 1 - SUB 2</td>
<td>87L, Zone 1 Phase</td>
</tr>
<tr>
<td>9</td>
<td>B-C</td>
<td>SUB 1 - SUB 2</td>
<td>87L, Zone 1 Phase</td>
</tr>
<tr>
<td>10</td>
<td>A-G</td>
<td>SUB 1 - SUB 2</td>
<td>87L, Zone 1 Ground</td>
</tr>
</tbody>
</table>
Overview of End-End Testing

Why do it?

End-End testing simultaneously tests and provides documentation of elements of:

- Protective Relays
- Communications Systems (DCB, DCUB, POTT, PUTT, Line Current Differential)
- AC Inputs to relays in Voltage and Current Sensing Device circuits
- Station DC Supply to protective relays, communications systems, and control circuits
- Control Circuits

These are all protection system components addressed by NERC PRC-005
Overview of End-End Testing

Why do it?

**Relay calibration** and **functional testing** does not always address:

- Logic issues (i.e. AND vs. OR discrepancies)
- Communication system timing and functionality
- Backup protection timing
- Directionality concerns

End-End testing is not a substitute for relay calibration

- Note that many relay calibration routines will not address functionally testing or calibrating communications-based protective elements
  - Example: Alpha plane restraint region utilized in SEL-311L line current differential relays.
  - Power Line Carrier timing/carrier “holes” in DCB schemes
Test Results Example

<table>
<thead>
<tr>
<th>Test</th>
<th>Phase</th>
<th>TRIP</th>
<th>MRB</th>
<th>ZIG</th>
<th>MRPT</th>
<th>SIG1</th>
<th>SIG2</th>
<th>SIG3</th>
<th>SIG4</th>
<th>SIG5</th>
<th>SIG6</th>
<th>SIG7</th>
<th>SIG8</th>
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<tbody>
<tr>
<td>1</td>
<td>A-G</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2</td>
<td>A-B-C</td>
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<tr>
<td>3</td>
<td>B-C</td>
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</tr>
<tr>
<td>4</td>
<td>A-G</td>
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<td>X</td>
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<tr>
<td>5</td>
<td>A-B-C</td>
<td>X</td>
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<td>X</td>
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</tr>
<tr>
<td>6</td>
<td>B-C</td>
<td>X</td>
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</tr>
<tr>
<td>7</td>
<td>A-G</td>
<td>X</td>
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<tr>
<td>8</td>
<td>A-B-C</td>
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<tr>
<td>9</td>
<td>B-C</td>
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</table>

<table>
<thead>
<tr>
<th>Test</th>
<th>Time</th>
<th>PASS/Fail</th>
<th>Fault Loc</th>
<th>Op Time</th>
<th>Targets</th>
<th>Comments</th>
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<tbody>
<tr>
<td>1</td>
<td>13:20</td>
<td>PASS</td>
<td></td>
<td></td>
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<td>NONE</td>
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<tr>
<td>2</td>
<td>14:12</td>
<td>PASS</td>
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<tr>
<td>3</td>
<td>14:34</td>
<td>PASS</td>
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<td>NONE</td>
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<tr>
<td>4</td>
<td>14:45</td>
<td>PASS</td>
<td>10.24MI</td>
<td>38.80CY</td>
<td>TRIP, TIME, A, G, 50/61</td>
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<tr>
<td>5</td>
<td>15:13</td>
<td>PASS</td>
<td>7.96MI</td>
<td>31.01CY</td>
<td>TRIP, TIME, A, B, C, ZONE2</td>
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<tr>
<td>6</td>
<td>15:25</td>
<td>PASS</td>
<td>7.92MI</td>
<td>31.7CY</td>
<td>TRIP, TIME, B, C, ZONE2</td>
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<tr>
<td>7</td>
<td>16:39</td>
<td>PASS</td>
<td>0.77MI</td>
<td>0.75CY</td>
<td>TRIP, 87, 50/61, A, G, ZONE1</td>
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<tr>
<td>8</td>
<td>15:50</td>
<td>PASS</td>
<td>0.79MI</td>
<td>1.06CY</td>
<td>TRIP, A, B, C, ZONE1</td>
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<tr>
<td>9</td>
<td>16:00</td>
<td>PASS</td>
<td>0.79MI</td>
<td>1.00CY</td>
<td>TRIP, B, C, ZONE1</td>
<td></td>
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</tbody>
</table>
Oscillographic Results (Test 7)
“On July 13, 2011, NERC’s Event Analysis and Investigations Group submitted a Reliability Standard Suggestions Form to initiate a new standard development project to create a standard to address the testing of Protection System equipment before that equipment is placed into initial service. NERC’s Event Analysis and Investigations Group provided an example of an event where an entity did not perform in-service testing as part of commissioning a new Protection System, resulting in line relays placed in service with the incorrect current transformer ratio. The defect remained undetected until the occurrence of a severe system disturbance when the relaying operated incorrectly, increasing the magnitude and scope of the disturbance.”
Regulatory Stance

Compliance Application Notice — 0043
PRC-005 Protection System Maintenance and Testing Evidence

Posted: December 30, 2011
Revised: February 16, 2012

Primary Interest Groups
Compliance Enforcement Authority (CEA)¹
NERC
Regional Entity (RE)
Transmission Owner (TO)
Generator Owner (GO)
Distribution Provider (DP) that owns a transmission Protection System

Issue: What types of evidence do CEAs assess in regard to Protection System maintenance and testing to demonstrate compliance?
This CAN clarifies what types of evidence a CEA is to assess in the following areas of compliance:
• Commissioning tests;
• Historical evidence;
• The basis of time allowances for maintenance and testing intervals;
• Providing evidence of continuous monitoring devices; and
• The degree of specificity needed for electronic evidence files.

¹ CEAs, when designated by the Commission, are responsible for ensuring compliance with the PRC-005 standard.
Overview of End-End Testing

• When should we do it?
  • New installations or upon significant changes to the composition of the protection system.
  • Confirmation of protection system performance after misoperations
  • Can use modeled faults or play back fault records
  • New or modified interties with other Transmission Owners (NERC PRC-001)

R3.2. Each Transmission Operator shall coordinate all new protective systems and all protective system changes with neighboring Transmission Operators and Balancing Authorities.
Challenges

• Personnel availability & knowledge
  – Technicians
  – Engineers
• Communications methods/information between test sites
• In-service Testing
• Equipment Models
• Firmware Versions
Applicability of Fault Simulations in Other Instances

• Breaker Failure/Failure-to-trip protection
  • Establish correct coordination of primary protection with backup protection
    • Timing Verification
    • Verify appropriate I/O is satisfied - or is not satisfied – during abnormal system conditions
Breaker Failure/Failure to Trip Example
Breaker Failure/Failure to Trip Example