Testing and Commissioning Ultra-High-Speed Line Protection on a 345 kV Transmission Line

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Schweitzer Engineering Laboratories, Inc.
• Serves customers and provides network integration transmission services to other utilities

• Owns approximately 14,338 miles of 46 kV, 69 kV, 115 kV, 230 kV, and 345 kV transmission lines
Provides service for new industrial load

Results in 170% compensation of CZ line; Zone 1 distance protection in select phasor-based relays was disabled

Ultra-high-speed (UHS) relays installed to provide fast, secure protection and accurate fault locating on WW line and CZ line
Traditional PNM Protection for 345 kV Lines

- Three phasor-based relays
- Four zones of 21P and 21G (quadrilateral characteristics)
  - Zones 1, 2, and 4 set forward
  - Zone 3 set reverse
- POTT scheme using overcurrent and distance elements
- One 51G element coordinates with remote terminal relay
- One level of 67P and 67G detects faults in first 10–15% of line
- 87L enabled
PNM Motivated to Apply UHS Line Protection

- UHS relays using incremental quantities and TWs respond to events prior to voltage change across capacitor bank
- PNM was motivated by speed, security, and reliability performance in simulations
- PNM applied UHS relays in conjunction with traditional phasor-based protection
## Testing Using State Simulation

Commonly used to test operation of protection elements and schemes

<table>
<thead>
<tr>
<th>Name</th>
<th>State 1</th>
<th>State 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V A-N</td>
<td>66.40 V 0.00° 60.000 Hz</td>
<td>16.40 V 0.00° 60.000 Hz</td>
</tr>
<tr>
<td>V B-N</td>
<td>66.40 V -120.00° 60.000 Hz</td>
<td>66.40 V -120.00° 60.000 Hz</td>
</tr>
<tr>
<td>V C-N</td>
<td>66.40 V 120.00° 60.000 Hz</td>
<td>66.40 V 120.00° 60.000 Hz</td>
</tr>
<tr>
<td>I A</td>
<td>5.000 A 0.00° 60.000 Hz</td>
<td>20.00 A -86.00° 60.000 Hz</td>
</tr>
<tr>
<td>I B</td>
<td>5.000 A -120.00° 60.000 Hz</td>
<td>5.000 A -120.00° 60.000 Hz</td>
</tr>
<tr>
<td>I C</td>
<td>5.000 A 120.00° 60.000 Hz</td>
<td>5.000 A 120.00° 60.000 Hz</td>
</tr>
<tr>
<td>CMC Rel</td>
<td>0 output(s) active</td>
<td>0 output(s) active</td>
</tr>
<tr>
<td>Trigger</td>
<td>1.000 s</td>
<td>200.0 ms</td>
</tr>
</tbody>
</table>
Signals may exhibit sharp change during transition from pre-fault to fault state

- Causes artificial incremental replica current calculated by UHS relay
- Can cause unexpected operation of elements that use incremental quantities
Removing Sharp Signal Changes Between States

Transitioning from pre-fault to fault state at $t_0$ removes sharp signal change at transition point

\[ t_0 = \frac{1}{\text{NFREQ}} \left( \frac{\text{NC} - \text{angle}(\Delta I)}{360^\circ} \right) \]
Testing Using Realistic Fault Signals

• Generated COMTRADE files from software; played files back to UHS relays during commissioning testing

• Represented internal and external faults, including different types and locations

• Verified wiring, relay health and settings, and operation of elements that use incremental quantities
Combining TWs With Fundamental Frequency Signals

- Used time-synchronized local test equipment
- Satisfied lower-frequency supervisory conditions, allowing verification of TW-based functions
End-to-End Commissioning Testing

• Used time-synchronized local and remote test equipment

• Applied TWs simultaneously with fault condition 1 second after pre-fault signals initiated
Commissioning Testing
Internal Fault

- AG fault simulated on WW line 46% away from San Juan
- TD21, POTT, and TW87 expected to operate at San Juan and Cabezon
Commissioning Testing Results

Internal Fault

TD21, POTT, and TW87 operated as expected

San Juan

Cabezon
TWs captured by San Juan and Cabezon terminals

- Same polarity
- Arrival times separated by less than TW line propagation time
• BG fault simulated on FW line
• TD21, POTT, and TW87 expected to restrain at San Juan and Cabezon terminals
• TD32 expected to assert forward at San Juan and reverse at Cabezon
Relay operated as expected

Commissioning Testing Results
External Fault

San Juan

Cabezon
Commissioning Testing Results
TWs for External Fault

TWs captured by San Juan and Cabezon terminals

- Opposite polarity
- Arrival times separated by TW line propagation time
Summary

- PNM implemented UHS line protection on critical, overcompensated 345 kV line
- UHS relays that operate on incremental quantities and TWs are better-suited to protect series-compensated lines
- Test incremental quantity-based elements using realistic signals and TW-based functions using TW test equipment
- TD21, POTT, and TW87 performance can be verified with time-synchronized end-to-end commissioning testing