Protective Relays and Cascading Failures

Dr. Greg Zweigle
Schweitzer Engineering Laboratories, Inc.
IEEE General Meeting, August 8, 2018
Purpose of Protective Relaying

“The purpose of protective relays and relaying systems is to operate the correct circuit breakers so as to disconnect only the faulty equipment from the system as quickly as possible, thus minimizing the trouble and damage caused by faults when they do occur”

A.R. van C. Warrington, 1962
Purpose of Protective Relaying

“The purpose of protective relays and relaying systems is to operate the correct circuit breakers so as to disconnect only the faulty equipment from the system as quickly as possible, thus minimizing the trouble and damage caused by faults when they do occur.”

A.R. van C. Warrington, 1962
“Relays are compact analog networks that are connected throughout the power system to detect intolerable or unwanted conditions within an assigned area. They are, in effect, a form of active insurance designed to maintain a high degree of service continuity, and limit equipment damage.”

J. Lewis Blackburn, 1982
Purpose of Protective Relaying

“Relays are compact analog networks that are connected throughout the power system to detect intolerable or unwanted conditions within an assigned area. They are, in effect, a form of active insurance designed to maintain a high degree of service continuity, and limit equipment damage.”

J. Lewis Blackburn, 1982
Purpose Summary

• Watch:
  – Observe a subset of the power system
  – Detect bad conditions within that subset

• Act:
  – Disconnect only the faulted equipment
  – Do so as quickly as possible

• So that:
  – Limit equipment damage (and keep people safe)
  – Keep remainder of system in service
Trip Fast!

Faster tripping =>
- stays closer to equilibrium
- fewer contingencies
- less state variation
Purpose Summary

• Watch:
  – Observe a subset of the power system
  – Detect bad conditions within that subset

• Act:
  – Disconnect only the faulted equipment
  – Do so as quickly as possible

• So that:
  – Limit equipment damage (and keep people safe)
  – Keep remainder of system in service
Protection Design Criteria (Blackburn)

• Reliability
  Dependability: Perform correctly when needed
  Security: Do not operate incorrectly

• Speed
  A faster response reduces damage and increases stability

• Selectivity
  Disconnect the minimum amount of equipment

• Economics

• Simplicity
Relays During Major Disturbances*

...low voltage, high power flows, power swings, abnormal frequency changes, rapid topology changes, ...

<table>
<thead>
<tr>
<th>Element</th>
<th>Challenges During Major Disturbance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1 distance</td>
<td>Power swing sensitivity&lt;br&gt;Polarizing voltage memory</td>
</tr>
<tr>
<td>Overreaching distances – zones 2, 3, 4</td>
<td>Load encroachment</td>
</tr>
<tr>
<td>Instantaneous overcurrent</td>
<td>Power swing</td>
</tr>
<tr>
<td>Undervoltage</td>
<td>Transient low voltage conditions</td>
</tr>
<tr>
<td>Generator protection</td>
<td>Protecting the asset</td>
</tr>
<tr>
<td>Differentials &amp; phase comparison</td>
<td>Immune to swings</td>
</tr>
</tbody>
</table>

* D. Tziouvaras, “Relay Performance During Major System Disturbances”, WPRC, 2006 – Available at www.selinc.com
Protection Design Criteria (Blackburn)

• Reliability
  Dependability: Perform correctly when needed
  Security: Do not operate incorrectly

• Speed
  A faster response reduces damage and increases stability

• Selectivity
  Disconnect the minimum amount of equipment

• Economics

• Simplicity
Normal Operation

Power flows from East and North

Loads are in the Western region
500 kV line tripped (human error)

Not normally a problem

But, could not reclose because of large standing angle

And, could not see angle

Heavy loads cause power flow directional change
Transformer overloads and trips

Multiple power flow changes

Lines become highly overloaded

San Diego fed primarily through single line to San Onofre Nuclear and it also is highly overloaded
San Onofre line overload duration leads to line trip

Large frequency swings

Final cascading blackout
# Relay Actions

<table>
<thead>
<tr>
<th>Time</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>15:27:39</td>
<td>Trip H-NG transmission line to clear A-C fault (500kV)</td>
</tr>
<tr>
<td>15:28:16</td>
<td>Trip CV transformer No.2 on inverse time overload (230/92kV)</td>
</tr>
<tr>
<td>15:28:17</td>
<td>Trip CV transformer No.1 on inverse time overload (230/92kV)</td>
</tr>
<tr>
<td>15:32:10</td>
<td>Trip Ramon transformer on inverse time overload (230/92kV)</td>
</tr>
<tr>
<td>15:32:11 –</td>
<td>Trip distribution on undervoltage (92kV)</td>
</tr>
<tr>
<td>15:33:46</td>
<td>Loss of multiple small generation sites</td>
</tr>
<tr>
<td>15:32:13 –</td>
<td>Loss of multiple transmission lines on overload and zone 3 (161kV)</td>
</tr>
<tr>
<td>15:32:15</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>15:38:21</td>
<td>Trip Path 44, current exceeded 8000 amps (230kV)</td>
</tr>
</tbody>
</table>
Relay Manufacturer Responsibilities

Did the relay operate as expected?
Protection element design
Relay SW design
Relay HW design
Relay reliability

Was relaying properly engineered?
Listening / Learning
Teaching
Relay instruction manual
Technical papers (free)
Local product support
Relay settings simplicity
Relay settings software

Did we understand the system?
Relay models
System Integrity Protection Schemes
aka
Remedial Action Schemes
aka
Special Protection Systems
Remedial Action Scheme (FERC)

A scheme designed to detect predetermined System conditions and automatically take corrective actions that may include, but are not limited to, adjusting or tripping generation, tripping load, or reconfiguring the System.

- Meet requirements identified in the NERC Reliability Standards;
- Maintain Bulk Electric System (BES) stability;
- Maintain acceptable BES voltages;
- Maintain acceptable BES power flows;
- Limit the impact of Cascading or extreme events.
Uruguay RAS

Future: Control System Design That:

• Is designed for **nonlinear** systems
• Is **structural**, not signal based
• Stabilizes a **wide range** of contingencies
• Keeps states within **acceptable bounds**
• Minimizes the **cost** of controls
• Is **robust** and **resilient**
Settings!

- System: 13%
- Unknown: 14%
- Settings / Logic / Design / As-left: 37%
- Equipment Failure: 36%

NERC Staff Analysis of System Protection Misoperations, December 2014
## Getting The Settings Right

### Device Comparison

<table>
<thead>
<tr>
<th>Name</th>
<th>Feeder_A</th>
<th>Feeder_B</th>
<th>Feeder_C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Device</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Device Type</td>
<td>SEL-751A</td>
<td>SEL-751A</td>
<td>SEL-751A</td>
</tr>
<tr>
<td>In Service</td>
<td>False</td>
<td>True</td>
<td>False</td>
</tr>
<tr>
<td>Device Name</td>
<td>Feeder_A</td>
<td>Feeder_B</td>
<td>Feeder_C</td>
</tr>
<tr>
<td>Serial Number</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global Device ID</td>
<td>435d84a4cfcb949f2aff1ee0cd2f75207</td>
<td>ac5775316cd846ebbofe75d2073d7cb24</td>
<td>3c4c3b5aa194d5a9d9f2e2462c20</td>
</tr>
<tr>
<td>Firmware Version</td>
<td>R418</td>
<td>R419</td>
<td></td>
</tr>
<tr>
<td>Part Number</td>
<td>751A0180X0X0X81000X</td>
<td>751A0180X0X0X81000X</td>
<td>751A0180X0X0X81000X</td>
</tr>
<tr>
<td>FID String</td>
<td>SEL-751A-Rxxx-V0-Z011003-Dxxxxxxxx</td>
<td>SEL-751A-Rxxx-V0-Z011003-Dxxxxxxxx</td>
<td>SEL-751A-Rxxx-V0-Z011003-Dxxxxx</td>
</tr>
<tr>
<td>Settings Version Number</td>
<td>011</td>
<td>011</td>
<td>011</td>
</tr>
<tr>
<td>WhoAreYou Response</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Generate Password Script</td>
<td>751A_DEFAULT_GENERATE_PASSWORD</td>
<td>751A_DEFAULT_GENERATE_PASSWORD</td>
<td>751A_DEFAULT_GENERATE_PASSWORD</td>
</tr>
<tr>
<td><strong>Device Passwords</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Access Level</td>
<td>ACC</td>
<td>ACC</td>
<td>ACC</td>
</tr>
<tr>
<td>Password</td>
<td>*********</td>
<td>*********</td>
<td>*********</td>
</tr>
<tr>
<td>Set Password Script</td>
<td>751A_ACC_DEFAULT_SET_PASSWORD</td>
<td>751A_ACC_DEFAULT_SET_PASSWORD</td>
<td>751A_ACC_DEFAULT_SET_PASSWORD</td>
</tr>
</tbody>
</table>

### In Service

<table>
<thead>
<tr>
<th>Feeder</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>False</td>
</tr>
<tr>
<td>B</td>
<td>True</td>
</tr>
<tr>
<td>C</td>
<td>False</td>
</tr>
<tr>
<td>D</td>
<td>True</td>
</tr>
</tbody>
</table>
Conclusions

• Relays take quick action to isolate only faulted elements - but during a cascade asset removal can further weaken the system
• Need better modeling of relays in planning and control systems
• Simplifying settings and providing better settings tools
• System level control solutions of the future adapt to large order contingencies
• The “need for speed” – time domain protection