AEP Event of March 20, 2018

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Overview

- N-5(+) System Configuration
- Large Voltage Angle Separation
- 138kV CG Line Fault
- Ten other lines tripped
  - Seven 138kV lines tripped
  - Three 69kV lines tripped
- Outage of entire area ~130MW
Pre-fault Configuration
Load / Generation / Price

Total Load in the Area (MW)

Total Generation in the Area (MW)

Price spike

Area Energy Price ($/MWh)

Outage Occurred
Phase Angle Difference (RP vs. HR) before Event
LO-LF-SA 138kV Line Loading

Emergency loading: 202 MVA

100% Normal loading: 185 MVA

Price Spiked
Power Flow Prior to Line Outage
Source Line Fault
& Successive Trips
Area of Outage
LO-LF-SA 138kV Line Fault (Initiating Event)

- Normal LG fault.
- LLG fault on reclose.
- No problems with protection here.
EM-FR 138kV Line Trip

- Uh-Oh!
- Better call for help!
- Looks like a power swing / voltage collapse trip.
Recap of Sequence of Events (CDT)

- 03/19 13:59: IM – NW 138kV section was open (last one of total 6 138kV lines scheduled out of service in the area)
  - 21 hours 1 minutes
- 03/20 11:00: Energy price in affected area spiked from $20/MWH to $3500/MWH
  - 3 hours 33 minutes
- 03/20 14:33:20.194: LO-LF-SA 138kV line CG fault, cleared in 5 cycles
  - 0.426 seconds
- 03/20 14:33:20.620: Seven 138kV lines and three 69kv lines tripped within 0.1 second
  - 0.339 seconds
- 03/20 14:33:20.959: LO-LF-SA 138kV line reclosed and tripped on multi-phase fault
  - 0.172 seconds
- 03/20 14:33:21.131: Two SVCs and three cap banks tripped, one UFLS operation (12kV), total loss of 136MW load
  - 1 hours 27 minutes
- 03/20 16:00: All lost load was restored
## Power System Element Tripping After Line Fault

<table>
<thead>
<tr>
<th>Line</th>
<th>Time (CDT)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BL-OZ 69kV line</td>
<td><strong>14:33:20.620</strong></td>
<td>BL terminal relay tripped by <strong>Z1</strong></td>
</tr>
<tr>
<td>EM-FR 138kV line</td>
<td>14:33:20.637</td>
<td>Relays tripped at both ends by <strong>Z1</strong></td>
</tr>
<tr>
<td>HR-IL 138kV line</td>
<td>14:33:20.641</td>
<td>Relays tripped at both ends by <strong>Z1</strong></td>
</tr>
<tr>
<td>FR-OZ 69kV line</td>
<td>14:33:20.645</td>
<td>FR terminal relay tripped by <strong>Z1</strong></td>
</tr>
<tr>
<td>FR-SO 138kV line</td>
<td>14:33:20.649</td>
<td>FR terminal relay tripped by <strong>Z1</strong></td>
</tr>
<tr>
<td>FL-FR 138kV line</td>
<td>14:33:20.649</td>
<td>FL terminal relay tripped by <strong>Z1</strong></td>
</tr>
<tr>
<td>MX-SO 138kV line</td>
<td>14:33:20.652</td>
<td>Relays tripped at both ends by <strong>DCB Z2</strong></td>
</tr>
<tr>
<td>FL-MV 138kV line</td>
<td>14:33:20.657</td>
<td>MV terminal relay tripped by <strong>Z1</strong></td>
</tr>
<tr>
<td>LL-WY 138kV line</td>
<td>14:33:20.669</td>
<td>WY terminal relay tripped by <strong>Z1</strong></td>
</tr>
<tr>
<td>FL-IR 69kV line</td>
<td><strong>14:33:20.680</strong></td>
<td>IR terminal relay tripped by <strong>Z1</strong></td>
</tr>
<tr>
<td>RU 138kV Capacitor</td>
<td>14:33:21.131</td>
<td>Tripped by 67P4T during high voltage period; beat the OV trip</td>
</tr>
<tr>
<td>WB 138kV Capacitor</td>
<td>14:33:36.460</td>
<td>Tripped by time delay high voltage control trip</td>
</tr>
<tr>
<td>HR SVCs 138kV</td>
<td>14:36:04.916</td>
<td>Collapse Zone – tripped cooling auxiliaries due to UV</td>
</tr>
<tr>
<td>CSO 69 kV Capacitor</td>
<td>14:37:48</td>
<td>Collapse Zone - Tripped 27 UV control element</td>
</tr>
</tbody>
</table>
Key Bus Voltages Under OOS Condition

- BL (138kV)
- EM (138kV) (swing Center)
- FR (138kV)
- HR (138kV)
BL and HR Voltages Out-of-Step

Out of phase
Relay Voltage Magnitudes in the Affected Area
PSSE Simulation of Voltages

Results = Unrecoverable Without Successful Reclose of Line
PSSE Simulation of Voltages
Stable “IF” Line Successfully Reclosed after 675 msec delay
Protection System Operation Summary

- The LO-LF-SA 138kV line was cleared properly for an “in-zone” fault.
- Three capacitor banks were properly tripped off-line for OC, OV and UV conditions.
- One 12kV UFLS operation was proper (islanded and system coasted down).
- Ten line protection systems tripped for non-fault, swing/collapse conditions.
  - Out of Step Blocking was not in place on any of the line protection systems in the area.
  - AEP practice is NOT to implement Out of Step Blocking due to the risk of NOT clearing for an in-zone fault.
  - Event was unrecoverable.
  - Thus, No Misops.
Other Items

- System Operators failed to close the IM-NW 138kV line section.
  - Large angle separation vs. CB relay setting
  - Line switches, not CBs (no relay)

- PST operation was not optimal for the situation as it limited the power transfer needed to recover.

- System Operators had less than adequate awareness of the RTCA solutions not solving.
Ongoing Actions

- The 10 lines that tripped after the fault were analyzed under PRC-026.
- Corrective Actions were identified, where needed, and are in various stages of implementation.
Questions?