Evaluation of 13kV Dry-Type Shunt Reactor Protection following Near-Miss

Gary L. Kobet, P.E.

Presented to the 71st Annual TAMU Conference for Protective Relay Engineers

March 28, 2018
Overview

- Shunt reactors at TVA
- Event sequence
- Protection questions
- Post-event actions
- Conclusion
Shunt reactors at TVA

- Compensate lightly loaded 500kV lines
- 45MVAR three-phase
- Dry type (air core)
- Connected to tertiary windings of 500/161/13kV transformer banks
- Neutral-switched – reactors remain energized even with circuit breaker open and zero current flowing!
Shunt reactor – neutral-switched

1. Circuit breaker open, reactors energized but zero current
2. Circuit breaker closed, reactors energized, load current flowing

So: With the circuit breaker open: Is this a fault?
Original TVA Standard – Split Winding Shunt Reactor Protection

45MVAR (three-phase) split-winding shunt reactor
Three-line diagram
Event initiation

• A hawk wingspan could easily bridge the outer phases of the neutral breaker bushings
15:44 Bird lands on 3018 bridging phases between reactor and breaker

2000A current flowing in all three phases – uncontrolled arcing
From 15:44 to 15:58:53 Split winding differential relays operate

Trip 96 xfmr bank LOR

Standing open

Trip 3018

Breaker already open!!
By 16:00:50 (16 minutes later) Split winding CTs and buswork destroyed

Trip 96 xfmr bank LOR

A- and C-phase (one each phase) stingers laying on grounded support steel

Standing open

To xfmr bk diff
Operator information

Next step?
18:21:38 Operator attempts to open 3017 beginning with A-phase

Switch flashes over, arc creates 3-phase fault (82kA)

Trip 96 xfmr bank LOR

Bank differential trips bank, deenergizes 13kV yard

Standing open

To xfmr bk diff
Left wing

Right wing

Appears to be head of hawk
Protection questions

1. Why didn’t bank differential operate before the fault occurred?
   - Relay pickup/slope characteristic

2. Why did tertiary bus ground detection alarm not assert?
   - All components tested good
   - Scheme will not detect double-line-to-ground fault (only single)

\[ V_0 = 0.5pu \]
Operational practice – changes

• De-energize 13kV yard by de-energizing 500kV transformer prior to:
  – Any switching in 13kV yard, routine or emergency
  – Inspecting yard after tertiary bus ground fault alarm
<table>
<thead>
<tr>
<th>IEEE Std C37.109:</th>
<th>TVA (original design):</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Turn-to-turn faults:</td>
<td>• Turn-to-turn faults:</td>
</tr>
<tr>
<td>• Voltage unbalance (single winding)</td>
<td>• Same as C37.109</td>
</tr>
<tr>
<td>• Split winding differential</td>
<td>• Phase-phase faults, unbalance current, open circuits on neutral side:</td>
</tr>
<tr>
<td>• Phase-phase faults, unbalance current, open circuits on neutral side:</td>
<td>• Negative sequence relays – <strong>ALARM</strong></td>
</tr>
<tr>
<td>• Negative sequence relays</td>
<td>• Tertiary bus ground detection – alarm (?)</td>
</tr>
<tr>
<td>– <strong>TRIP</strong></td>
<td></td>
</tr>
</tbody>
</table>
Revised TVA Standard – **Split** Winding Reactor Protection

<table>
<thead>
<tr>
<th>Element</th>
<th>Original Design</th>
<th>Revised Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>46 negative sequence</td>
<td>Alarm only</td>
<td>Trip reactor breaker &amp; arm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>reactor breaker failure</td>
</tr>
<tr>
<td>51 phase overcurrent</td>
<td>Trip transformer bank</td>
<td>Trip reactor breaker &amp; transformer bank</td>
</tr>
<tr>
<td>87 split-winding differential</td>
<td>Trip reactor breaker</td>
<td>Trip reactor breaker &amp; arm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>reactor breaker failure</td>
</tr>
<tr>
<td>50BF reactor breaker failure</td>
<td>Not installed</td>
<td>Trip transformer bank</td>
</tr>
</tbody>
</table>

![Diagram of protection system](image)
Revised TVA Standard – Split Winding

Shunt Reactor Protection

Trip/lockout 500kV & 161kV PCBs

Trip 3018 & BFI

Any relay trip to 3018 BFI

45MVAR (three-phase) split-winding shunt reactor
Tertiary bus ground detection

• Previous action:Alarm only
  – With no guidance given to operators on what to do
  – Next ground fault results in fault currents between 60kA to >200kA

• Revised action: Trip transformer bank after 15 cycles
  – Field to inspect tertiary buswork, transformer tertiary bushings, etc
Conclusion

- Protection application to neutral-switched equipment unique
- Event illustrated danger to personnel & catastrophic equipment damage
- Protection MUST ensure equipment is deenergized on faults & abnormal conditions

Equipment must NOT remain energized with current flowing after a protective relay operation!!!
Questions?