Modern Design Principles for Numerical Busbar Differential Protection
Coauthors

- Hamdy Faramawy, ABB GA Products, Sweden
- Li He, ABB GA Products, Sweden
- Klas Koppari, ABB GA Products, Sweden
- Lee Max, ABB GA Products, Sweden
Presentation Content

- Basic Principles of BBP
- Zone Selection
- Testing of Busbar Protection
- Conclusion
Busbar Protection

- Based on differential current measurement:
  - Out-of-zone fault, currents balance (i.e. $\Sigma i = 0$)
  - in-zone fault, currents no longer balance (i.e. $\Sigma i >> 0$)

- Practical problem is that the differential relay measures secondary currents of magnetic core CTs
  - CT saturation
  - Remanence
  - Secondary DC transients
Representation of the bus differential protection zone
How to handle Complex Busbar Arrangements?
Complex Busbar Arrangements

Double busbar arrangements with two sections

Double busbar with transfer bus
Complex Busbar Arrangements
Analogue Solution (CT switching)
Presentation Content

- Basic Principles of BBP
- Zone Selection
- Testing of Busbar Protection
- Conclusion
Zone Selection Naming

- CT switching
- Zone selection
- Disconnector replica
- Dynamic bus replica
- Bus image
- Bus mimic
- Disconnector replica

To provide proper zone selection the position information from all relevant primary apparatuses (that is, disconnectors and/or circuit breakers and/or earthing switches) must be given to the BBP. This is typically done by connecting two auxiliary contacts (that is, normally open and normally closed aux contacts) from each primary switch to the BBP binary inputs (that is, optocouplers)
Zone Selection Tasks

- Dynamic linking of measured CT currents to the appropriate differential protection zones as required by substation topology.
- Efficient merging of two or more differential zones when required by substation topology (that is, zone interconnection or load-transfer).
- Easy zone merging initiated externally by closing of bus-sectionalizing disconnectors.
- Selective operation of busbar differential protection to ensure tripping only of circuit breakers connected to the faulty zone.
- Correct marshaling of backup-trip commands from internally integrated or external circuit breaker failure protections to all surrounding circuit breakers.
- Easy incorporation of bus-section and/or bus-coupler bays (that is, tie-breakers) with one or two sets of CTs into the protection scheme.
- Disconnector and/or circuit breaker status supervision.
- Check Zone CT Connections?
Minimum Connections to/from BBP

Bay / Double Busbar

Q1 Q2

Q0

T1 T5

Disconnector Status

CB Trip

CT Connections

Alarms via Comms.
Engineering Expectations

- Engineering shall be:
  - Understandable for Power Engineers
  - Easy
  - User-friendly
  - Reusable
## Primary Apparatus Position

<table>
<thead>
<tr>
<th>Primary equipment</th>
<th>Status in busbar protection</th>
<th>Alarm facility</th>
<th>Information visible on local HMI</th>
</tr>
</thead>
<tbody>
<tr>
<td>N.O. auxiliary contact status</td>
<td>Scheme 1 RADSS</td>
<td>Scheme 2 INX</td>
<td>Alarm after settable time delay</td>
</tr>
<tr>
<td>N.C. auxiliary contact status</td>
<td></td>
<td></td>
<td>yes</td>
</tr>
<tr>
<td>open</td>
<td>closed</td>
<td>Last saved position</td>
<td>yes</td>
</tr>
<tr>
<td>open</td>
<td>closed</td>
<td>open</td>
<td>no</td>
</tr>
<tr>
<td>closed</td>
<td>open</td>
<td>closed</td>
<td>no</td>
</tr>
<tr>
<td>closed</td>
<td>closed</td>
<td>closed</td>
<td>yes</td>
</tr>
</tbody>
</table>
Feeder and Bus-Interconnector Interfaces

[Diagram of Feeder and Bus-Coupler interfaces]

2017-04-25 Zoran Gajić
Possible Zone Selection Implementation

![Diagram of Possible Zone Selection Implementation]

<table>
<thead>
<tr>
<th>Bay</th>
<th>ZA</th>
<th>ZB</th>
<th>ZC</th>
<th>Section</th>
<th>ZA</th>
<th>ZB</th>
<th>ZC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bay1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Bay2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Bay3</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Bay4</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Bay5</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Some Special Aspects for Zone Selection

- Bay out of service
- CB Bypass
- CT Bypass
- Bus-Tie parallel connection
- Induction from Parallel Lines (Line disconnector/earthing switch position)

- Capability to handle bus-tie bays with:
  - two CTs
  - one CT
  - no CT

- End-fault protection
Presentation Content

- Basic Principles of BBP
- Zone Selection
- Testing of Busbar Protection
- Conclusion
RTDS System Setup

RTDS Simulator

Control Signals

Currents and Voltages
Ia, Ib, Ic, Vn (Open Delta Voltage)

Status of Primary Apparatuses

Tested IED
Primary System Setup in RTDS
RTDS Test Scope

- To validate the security of BBP during external faults associated with CT saturation,
- To validate the dependability of BBP to detect and to isolate internal faults with absolute selectivity,
- To validate the ability of BBP to correctly distinguish and isolate special fault types such as evolving fault, while remaining stable during auto-reclosing cycle on a OHL for external permanent fault.
- To validate BBP performance concerning the busbar replica in steady-state condition and during configuration changes
- To validate BBP behavior during open CT condition and its ability to prevent mal-operation during CT secondary circuit failures.
- To validate the performance of breaker failure and end fault protection functions.
RTDS Test Results

- Example for fault cases with incorrect bus replica

<table>
<thead>
<tr>
<th>Fault Location</th>
<th>Bay C1 Trip</th>
<th>Bay C2 Trip</th>
<th>Bay C3 Trip</th>
<th>Bay C4 Trip</th>
<th>Bay C5 Trip</th>
<th>Zone 1 Trip</th>
<th>Zone 2 Trip</th>
<th>Zone 3 Trip</th>
<th>Zone 4 Trip</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>ok</td>
</tr>
<tr>
<td>F2</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>ok</td>
</tr>
<tr>
<td>F3</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>ok</td>
</tr>
<tr>
<td>F4</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>ok</td>
</tr>
<tr>
<td>F5</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>ok</td>
</tr>
<tr>
<td>F6</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>ok</td>
</tr>
</tbody>
</table>

Initial condition: Bay C1_GB2 Open.
Test condition: Intermediate position (0,0).
Set value applied: Scheme 1_RADSS.
Test result: The position is treated as closed resulting in zone merg.

<table>
<thead>
<tr>
<th>Fault Location</th>
<th>Bay C1 Trip</th>
<th>Bay C2 Trip</th>
<th>Bay C3 Trip</th>
<th>Bay C4 Trip</th>
<th>Bay C5 Trip</th>
<th>Zone 1 Trip</th>
<th>Zone 2 Trip</th>
<th>Zone 3 Trip</th>
<th>Zone 4 Trip</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>ok</td>
</tr>
<tr>
<td>F2</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>ok</td>
</tr>
<tr>
<td>F3</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>ok</td>
</tr>
<tr>
<td>F4</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>ok</td>
</tr>
<tr>
<td>F5</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>ok</td>
</tr>
<tr>
<td>F6</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>ok</td>
</tr>
</tbody>
</table>

Initial condition: Bay C1_GB2 Open.
Test condition: Intermediate position (0,0).
Set value applied: Scheme 2_INK.
Test result: The last position saved is used and the isolating switch is still treated as open.
Presentation Content

- Basic Principles of BBP
- Zone Selection
- Testing of Busbar Protection
- Conclusion
Conclusion

Numerical busbar differential protection relay can:

- Properly connect CTs, Zones and Breakers!
- Handle station/sections with up to 6 zones
- User friendly engineering
- Operate quickly for internal faults
- Remain stable for external faults followed by CT saturation
- Operate correctly for evolving faults
- Detect an open CT secondary circuit and block BBP
Reliable and Fast Busbar Differential Protection

Recorded voltages in the network during three-phase, busbar fault inside 110kV GIS.

Total fault clearance time of 45ms
35kA Fault Current.

Now can cover complex station arrangements.
Questions
СПАСИБО
ZA ВНИМАНИЕ!

THANK YOU!