CROSS COUNTRY FAULTS-
PROTECTION CHALLENGES AND IMPROVEMENTS

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2021 CONFERENCE FOR PROTECTIVE RELAY ENGINEERS
Overview

• Phase Selector – Why we need it?
• Phase Selector types
• Cross Country faults
  • Solid Grounded System – Challenges and Improvements
• Cross Country faults
  • Isolated/Compensated System
• Summary
Phase Selector – Why we need it?

During faults, multiple loops can be activated

Sequence connection for phase-to-phase BC fault

Analytical expression for phase-to-phase fault BC in all 6 loops

<table>
<thead>
<tr>
<th>Element</th>
<th>Voltage</th>
<th>Current</th>
<th>Expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>AG</td>
<td>$V_A$</td>
<td>$I_A + kI_0$</td>
<td>$\infty$</td>
</tr>
<tr>
<td>BG</td>
<td>$V_B$</td>
<td>$I_B + kI_0$</td>
<td>$mZ_{L1} + \frac{mZ_{L1} + Z_{s1}}{\sqrt{3}} \angle -90^\circ$</td>
</tr>
<tr>
<td>CG</td>
<td>$V_C$</td>
<td>$I_C + kI_0$</td>
<td>$mZ_{L1} + \frac{mZ_{L1} + Z_{s1}}{\sqrt{3}} \angle 90^\circ$</td>
</tr>
<tr>
<td>AB</td>
<td>$V_A - V_B$</td>
<td>$I_A - I_B$</td>
<td>$mZ_{L1} + (mZ_{L1} + Z_{s1})\sqrt{3} \angle -90^\circ$</td>
</tr>
<tr>
<td>BC</td>
<td>$V_B - V_C$</td>
<td>$I_B - I_C$</td>
<td>$mZ_{L1}$</td>
</tr>
<tr>
<td>CA</td>
<td>$V_C - V_A$</td>
<td>$I_C - I_A$</td>
<td>$mZ_{L1} + (mZ_{L1} + Z_{s1})\sqrt{3} \angle 90^\circ$</td>
</tr>
</tbody>
</table>
Phase Selector – Why we need it?

During faults, multiple loops can be activated

Self-polarized with $R_f=0$

Self-polarized with $R_f$

$V_{1M}$ polarized with $R_f$
Phase Selector Types

Major Phase Selector Types

- Overcurrent based phase selection
  - Sensitivity issues – e.g. Weak source, high fault resistance results in low short circuit currents
- Voltage based phase selection
  - Sensitivity issues – e.g. fault impedance
- Phase selection using wave information
- Delta quantities-based phase selection
- Phase selection using sequence-components planes
Phase Selector Types

Delta quantities-based phase selection

\[ \Delta I_X = I_X - I_{X,\text{pre-fault}} \]
\[ \Delta I_Y = I_Y - I_{Y,\text{pre-fault}} \]
\[ \Delta I_{XY} = \Delta I_X - \Delta I_Y \]

- Phase-to-ground fault
  - Solid –AG,
  - Dashed-BG,
  - Dotted-CG

- Phase-to-phase fault
  - Solid –AB,
  - Dashed-BC,
  - Dotted-CA

- Phase-to-phase to ground fault
  - Solid –ABG,
  - Dashed-BCG,
  - Dotted-CAG

- 3-phase fault
# Phase Selector Types

Phase selection using sequence-components planes, single-phase-to-ground

<table>
<thead>
<tr>
<th>Fault Type</th>
<th>$I_2 \text{ Vs } I_1$ Plane</th>
<th>$I_2 \text{ Vs } I_0$ Plane</th>
</tr>
</thead>
<tbody>
<tr>
<td>AG Fault</td>
<td>$I_{A1}$ \quad $I_{A2}$</td>
<td>$I_{A0}$ \quad $I_{A2}$</td>
</tr>
<tr>
<td>BG Fault</td>
<td>$I_{A1}$</td>
<td>$I_{A2}$ \quad $I_{A0}$</td>
</tr>
<tr>
<td>CG Fault</td>
<td>$I_{A1}$ \quad $I_{A2}$</td>
<td>$I_{A0}$ \quad $I_{A2}$</td>
</tr>
</tbody>
</table>

(a) ‘Neg. Seq’ vs ‘Pos. Seq’ plane
(b) ‘Neg. Seq’ vs ‘Zero. Seq’ plane
# Phase Selector Types

Phase selection using sequence-components planes, phase-to-phase

<table>
<thead>
<tr>
<th>Fault Type</th>
<th>$I_2$ Vs $I_1$ Plane</th>
<th>$I_2$ Vs $I_0$ Plane</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB Fault</td>
<td>$I_{A2}$ $I_{A1}$</td>
<td>-</td>
</tr>
<tr>
<td>BC Fault</td>
<td>$I_{A1}$ $I_{A2}$</td>
<td>-</td>
</tr>
<tr>
<td>CA Fault</td>
<td>$I_{A1}$ $I_{A2}$</td>
<td>-</td>
</tr>
</tbody>
</table>

(a) ‘Neg. Seq’ vs ‘Pos. Seq’ plane

(b) ‘Neg. Seq’ vs ‘Zero. Seq’ plane

Not relevant
## Phase Selector Types

Phase selection using sequence-components planes, phase-to-phase-to-ground

<table>
<thead>
<tr>
<th>Fault Type</th>
<th>$I_2$ Vs $I_1$ Plane</th>
<th>$I_2$ Vs $I_0$ Plane</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABG Fault</td>
<td>$I_{A1}$</td>
<td>$I_{A0}$</td>
</tr>
<tr>
<td></td>
<td>$I_{A2}$</td>
<td>$I_{A2}$</td>
</tr>
<tr>
<td>BCG Fault</td>
<td>$I_{A1}$</td>
<td>$I_{A2}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$I_{A0}$</td>
</tr>
<tr>
<td>CAG Fault</td>
<td>$I_{A1}$</td>
<td>$I_{A0}$</td>
</tr>
<tr>
<td></td>
<td>$I_{A2}$</td>
<td>$I_{A2}$</td>
</tr>
</tbody>
</table>
Cross Country faults - Solid Grounding

Analytical expression for cross-country faults

\[ \frac{V_r}{I_r(1+k)} = Z_{L1} - (1-m)Z_{L1} \frac{I_{r,F2}}{I_r} \]

- When \( m = 1 \), it is a phase to phase to ground fault and the error term boils to zero
- When fault \( F_1 \) is removed, \( I_{r,F2} = I_r \), correct estimation is achieved as it is no longer a cross-country fault
- Error varies, when two faults move apart
Ground element behavior during cross-country faults

Cross Country faults - Solid Grounding (Contd...)
Ground element behavior during cross-country faults
Ground element behavior during cross-country faults

Cross Country faults - Solid Grounding (Contd...)
Ground element behavior during cross-country faults

Cross Country faults - Solid Grounding (Contd...)

AG
CG

m = 0.9
m = 0.1

AG
R
Phase element prone to mal-operate during Cross-country fault

AB Phase element prone to mal-operate during Cross-country fault involving AG and BG phases
Phase element prone to mal-operate during Cross-country fault involving AG and CG phases.

CA Phase element prone to mal-operate during Cross-country fault involving AG and CG phases.
Phase Selector – Challenges

Challenges with communication assisted phase selection
Challenges with communication assisted phase selection

- Correct phase selection CANNOT be achieved even with communication medium,
- This could lead to loss of both lines and system split.
Phase Selector – Challenges and Improvements

Phase Selector improvements and its performance

Symmetrical Components based phase selector

Under-reaching Max Torque (Metallic-fault)

Over-reaching Characteristic

PS – AG/BG/CG
PS – AB/BC/CA
PS – ABG/BCG/CAG

XC – AG
XC – BG
XC – CG
XC – Detected

To Supervise distance
Phase Selector – Challenges and Improvements

Phase Selector improvements and its performance

Symmetrical Components based phase selector

Under-reaching Max Torque (Metallic-fault)

Over-reaching Characteristic

PS – AG/BG/CG
PS – AB/BC/CA
PS – ABG/BCG/CAG

XC – AG
XC – BG
XC – CG
XC – Detected

To Supervise distance

3 pole trip ABG
1 pole trip AG
Isolated/Compensated – Single phase to ground faults

Solid grounded system - Single phase to ground fault

Isolated/Compensated - Single phase to ground fault
Isolated/Compensated – Single phase to ground faults

- Tripping should not happen for single phase to ground faults and the system can remain connected providing uninterrupted supply.
Isolated/Compensated – Single phase to ground faults

Faults in Isolated/Compensated system

• Tripping should not happen for single phase to ground faults and the system can remain connected providing uninterrupted supply.

• Presence of single phase to ground fault is expected to cause increase in healthy phase to ground voltages leading to cross-country faults.

Ground fault detection
Isolated/Compensated – Single phase to ground faults

- Tripping should not happen for single phase to ground faults and the system can remain connected providing uninterrupted supply.
- Presence of single phase to ground fault is expected to cause increase in healthy phase to ground voltages leading to cross-country faults.
- Phase distance is blocked during cross-country faults
Isolated/Compensated – Cross-Country faults

Phase preference tripping during cross-country faults AG @25% and CG @75% of protected line.

<table>
<thead>
<tr>
<th>Selection</th>
<th>Priority</th>
<th>Loops</th>
<th>Selected Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>C(A) acyclic</td>
<td>C before A, A before B</td>
<td>AG, BG</td>
<td>AG</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BG, CG</td>
<td>CG</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CG, AG</td>
<td>CG</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AG, BG, CG</td>
<td>CG</td>
</tr>
</tbody>
</table>
Summary

- **Solid grounded systems – Cross country faults**
  - Distance elements alone cannot ensure correct 1-pole tripping and it needs to be supervised by phase selector
  - Communication-assisted phase selection can work correctly, only if at least one end of the protected line is able to detect the phase correctly
  - Phase selection during cross-country is a challenge and it can lead to 3-pole tripping even with communication assistance, especially critical for parallel lines where both lines can be tripped 3-pole
  - Improved phase selection logic,
    - Detects cross-country faults and identify the faulted phases correctly
    - Ensures correct 1-pole tripping from both ends of the line

- **Isolated/Compensated Systems – Cross country faults**
  - Line is isolated from network based on the preferred priority, with the expectation that fault at the other location will self-extinguish
  - Phase distance is blocked during cross-country faults, however, during evolving two phase faults or three phase faults phase distance is released
Thank You

Questions?