Ground Fault Protection of Microgrid Interconnection Line Using Distance Relay with Residual Voltage Compensation

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Introduction

1. Challenges of Microgrid Protection
2. Point of Interconnection Protection
3. Proposed Method for Detecting SLG Fault on Interconnection Line
4. Case Studies and Results
5. Conclusion
Challenges

1. Fault current may change significantly between grid-connected mode and islanded mode. Low fault current contribution from microgrid for a fault at interconnection line.
2. Bidirectional power flow.
3. Detecting loss of utility.
4. Adaptive protection
5. Seamless change of grid-connected mode to islanded mode or verse versa
Current Methods

1. **DTT**: The direct transfer trip (DTT) can send trip signal from the utility substation to the microgrid protection relay to solve the above concerns.

2. **59G Relay**: The using of 59G to detect the SLG fault at the interconnection line is more challenging than the SLG fault at an ungrounded feeder due to the grounding of the interconnection line at utility side.
Current Methods

1. 59G Relay:

\[ 3V_0 = V_a + V_b + V_c \]
\[ = 0 + \sqrt{3}|V_a|\angle -150^\circ + \sqrt{3}|V_a|\angle 150^\circ = 3|V_a|\angle 180^\circ \]

May overtrip if not set properly. So set the timer and wait for the utility breaker to trip first.
Current Methods

3. 59G+67Q

67Q can be used to secure the operation of 59G

59G1
AND
67Q
59G2
OR
T1
59G3
1s
0s
SLG Fault Trip
Short Circuit Study

SLG Fault on the interconnection line - before utility circuit breaker open

Utility Feeder Relay

LV side of the Power Transformer Relay

\[ \begin{align*}
V_a &= 3.571@-39.4 & I_a &= 6920@-115.4 & Z_a &= 0.24@67.9 \\
V_b &= 20.69@-148.5 & I_b &= 394@-119.7 & Z_b &= 2.52@-47.3 \\
V_c &= 20.55@38.5 & I_c &= 388@-106.0 & Z_c &= 2.50@-171.0 \\
V_a &= 6.149@-70.9 & I_a &= 1755@-110.6 & Z_a &= 3.50@39.7 \\
V_b &= 6.014@-170.7 & I_b &= 1763@64.8 & Z_b &= 3.41@124.5 \\
V_c &= 7.837@59.9 & I_c &= 142@160.4 & Z_c &= 55.32@-100.4
\end{align*} \]
Short Circuit Study

SLG Fault on the interconnection line - after utility circuit breaker open

Utility Feeder Relay

LV side of the Power Transformer Relay

\[
\begin{align*}
V_a &= 0.000 @ 140.8 & I_a &= 0 @ 40.1 & Z_a &= 23.68@65.8 \\
V_b &= 34.51@180.0 & I_b &= 0 @ 90.0 & Z_b &= 9999.008@99.6 \\
V_c &= 34.51@120.0 & I_c &= 0 @ 30.0 & Z_c &= 9999.008@61.0
\end{align*}
\]

\[
\begin{align*}
V_a &= 7.622@-60.0 & I_a &= 1850.7 & Z_a &= 9999.008@110.7 \\
V_b &= 7.622@180.0 & I_b &= 18-110.7 & Z_b &= 9999.008@69.3 \\
V_c &= 7.621@60.0 & I_c &= 0 @ 150.0 & Z_c &= 9999.008@90.0
\end{align*}
\]
Short Circuit Study

Current Seen from LV side of the interconnection transformer. Utility protection tripped the substation breaker at 0.65s. The breaker at microgrid side is opened at 0.75s.
Potential of Distance Protection

- Limitations of existing method
  I. High cost communication channel
  II. Slow operation and lack of sensitivity

- Distance method
  I. Less affected by small fault current
  II. Inherit directionality
  III. Fixed reach setting
  IV. Independence of changing system conditions
  V. Fault location
Impedance Calculation

• Typical distance relay

\[ Z_{ag} = \frac{V_a}{I_a + k_0 I_R} \] | \[ Z_{bg} = \frac{V_b}{I_b + k_0 I_R} \] | \[ Z_{cg} = \frac{V_c}{I_c + k_0 I_R} \]

\[ Z_{ab} = \frac{V_a - V_b}{I_a - I_b} \] | \[ Z_{bc} = \frac{V_b - V_c}{I_b - I_c} \] | \[ Z_{ca} = \frac{V_c - V_a}{I_c - I_a} \]

• Distance relay with voltage and current transformation looking through a Y/D connection transformer

\[ Z_{ab} = \frac{-3V_b}{I_a + I_c - 2I_b} \] | \[ Z_{bc} = \frac{-3V_c}{I_a + I_b - 2I_c} \] | \[ Z_{ca} = \frac{-3V_a}{I_b + I_c - 2I_a} \]
Why Residual Voltage Compensation

SLG fault on the interconnection line is seen by the distance relay at DER side as phase-phase fault due to the Delta-Y connection of the step-up transformer.
Why Residual Voltage Compensation

\[ Z_{ab} = \frac{V_a - V_b}{I_a - I_b} \]

\[ Z_{ag} = \frac{V_a - V_b}{I_a - I_b} + \frac{V_0 * e^{-j30}}{2I_{1MG}} \]
Case Studies

I. Phase A to Ground Fault
II. Transformer Y-D connection
III. Simulated using PSCAD
Case Studies

- Block diagram of the distance relay with residual voltage compensation
SLG 0% fault (HV bus of the interconnection transformer)

Fault not cleared with existing distance relay

Fault cleared with proposed distance relay
Case Studies - Results

SLG fault at 0% of the interconnection line $Z_{Tx}$ only

Impedance diagram - existing distance relay

Impedance diagram - proposed distance relay
Case Studies - Results

SLG fault at 75% of the interconnection line \( (Z_{Tx} + 75\% \times Z_L) \)

Impedance diagram - existing distance relay

Impedance diagram - proposed distance relay
Case Studies - Results

SLG fault at remote bus – external fault

Impedance diagram - existing distance relay

Impedance diagram - proposed distance relay
# Case Studies - Results

## Fault Impedance Calculated Through Wye-Delta Transformer

<table>
<thead>
<tr>
<th>Fault Type (HV bus fault, 50 percent of line)</th>
<th>Phase</th>
<th>Voltage at Relay</th>
<th>Current at Relay</th>
<th>HV side V0</th>
<th>Typical Distance Relay</th>
<th>GE Distance Relay with Compensation</th>
<th>Voltage Compensation</th>
</tr>
</thead>
<tbody>
<tr>
<td>3LG</td>
<td>A</td>
<td>4.210@-62.6</td>
<td>3445@-144.1</td>
<td>1.22@81.5</td>
<td>1.22@81.5</td>
<td>1.22@81.5</td>
<td>1.22@81.5</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>4.210@177.4</td>
<td>3445@95.9</td>
<td>1.22@81.5</td>
<td>1.22@81.5</td>
<td>1.22@81.5</td>
<td>1.22@81.5</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>4.210@57.4</td>
<td>3445@-24.1</td>
<td>1.22@81.5</td>
<td>1.22@81.5</td>
<td>1.22@81.5</td>
<td>1.22@81.5</td>
</tr>
<tr>
<td>2LG (BC-G)</td>
<td>A</td>
<td>6.778@-48.3</td>
<td>1763@168.9</td>
<td>16.9@85.9</td>
<td>4.3@10.9</td>
<td>17.8@85.8</td>
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</tr>
<tr>
<td></td>
<td>B</td>
<td>6.913@167.1</td>
<td>1730@143.3</td>
<td>1.8@40.6</td>
<td>4.2@155.7</td>
<td>2.5@110.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>4.164@57.7</td>
<td>3407@-23.8</td>
<td>1.7@124.4</td>
<td>4.2@155.7</td>
<td>2.5@110.7</td>
<td></td>
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<tr>
<td>2L (B-C)</td>
<td>A</td>
<td>7.154@-47.1</td>
<td>1714@157.2</td>
<td>230.6@109.1</td>
<td>4.3@10.9</td>
<td>230.6@109.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>7.295@166.3</td>
<td>1688.2@155.4</td>
<td>1.9@34.9</td>
<td>4.2@155.7</td>
<td>1.9@34.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>4.158@57.7</td>
<td>3402@-23.7</td>
<td>1.8@130.2</td>
<td>4.2@155.7</td>
<td>1.8@130.2</td>
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</tr>
<tr>
<td>1LG (A-G)</td>
<td>A</td>
<td>6.969@-65.2</td>
<td>1046@-114.5</td>
<td>5.4@83.7</td>
<td>6.5@118.4</td>
<td>1.26@80.7</td>
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<tr>
<td></td>
<td>B</td>
<td>6.930@-175.4</td>
<td>1051@66.2</td>
<td>12.5@147.5</td>
<td>644.0@109.7</td>
<td>11.2@166.9</td>
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<tr>
<td></td>
<td>C</td>
<td>7.949@60.0</td>
<td>12.3@-49.8</td>
<td>12.7@20.5</td>
<td>6.7@49.3</td>
<td>11.5@1.5</td>
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</tr>
<tr>
<td>I1</td>
<td></td>
<td>611@-144.4</td>
<td></td>
<td>13.341</td>
<td></td>
<td></td>
<td>0@-29.8</td>
</tr>
</tbody>
</table>
Conclusion

• Methods of protecting the microgrid at POI are discussed.
• A new distance relays algorithm with residual voltage compensated is proposed. It can detect the SLG fault happened at HV side of the step-up transformer and interconnection line when the existing methods are not sensitive or fast enough to detect the fault.
• It can prevent unintentional islanding of microgrid system and protect the system from dangerous overvoltage and reducing the arcing condition at the fault location.
Thank You

Questions?