Distribution Bus Protection
Upgrade Considerations When Integrating Distributed Generation

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Bus Protection

- Isolates bus faults
- Is secure for external faults
- Minimizes arc-flash energy
- Provides backup protection for feeder faults
Distributed Generation Sources

- Photovoltaic
- Fuel cells
- Wind
- Landfill gas
- Agriculture
Bus Protection Schemes

- Time-delayed overcurrent elements
- Zone sequencing
- Percentage differential relays with dedicated CTs
- Percentage differential relays with paralleled CTs
Overcurrent Elements

Utility

51

50/51

50/51

Distributed Generation (DG)

50/51

50/51

F1

F2
Coordination of Time-Delayed Overcurrent Elements

<table>
<thead>
<tr>
<th>Current (Primary A)</th>
<th>Time (Seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus Without DG</td>
<td></td>
</tr>
<tr>
<td>Bus With DG</td>
<td></td>
</tr>
<tr>
<td>Feeder</td>
<td></td>
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</tbody>
</table>

- Bus Without DG
- Bus With DG
- Feeder
Low-Impedance Percentage Differential Calculations

\[ I_{OP} = |I_{W1} + |I_{W2}| \]

\[ I_{RT} = |I_{W1}| + |I_{W2}| \]

\[ I_{OP} > k \times I_{RT} \]
Calculating Secure Slope ($k$)

\[ V_s = (1 + \frac{X}{R}) I_r Z_b \]

\[ k = 0.824 (V_s) - 0.00242 (V_s)^2 \]
Percentage Differential Relay
With Dedicated CTs

Utility
DG
Fault
I2
I1
I3
87
Differential Calculation With Dedicated CTs

\[ I_3 - I_1 - I_2 \]

1-Cycle Cosine Filter

\[ I_{W1} \]

\[ I_{W2} \]

\[ I_{W3} \]

\[ \sum |I_{W1}| + |I_{W2}| + |I_{W3}| \rightarrow I_{RT} \]

\[ \sum |I_{W1} + I_{W2} + I_{W3}| \rightarrow I_{OP} \]
Current Simulations

CT1

CT2

CT3
Apply Digital Filtering

CT3

CT3 Filtered
Calculate Operate and Restraint Currents
Differential Quantities Without DG

Operating Value

45% Slope

$I_{RT} (A)$

$I_{OP} (A)$
Percentage Differential Relay
With Paralleled CTs

Utility
DG
Fault
I2
I1
I3
Differential Calculation With Paralleled CTs

\[ I_{3} - I_{1} \rightarrow \Sigma \rightarrow \text{1-Cycle Cosine Filter} \rightarrow |W_1| \rightarrow \Sigma \rightarrow |W_1 + W_2| \rightarrow I_{OP} \]

\[ I_{2} - I_{1} \rightarrow \Sigma \rightarrow \text{1-Cycle Cosine Filter} \rightarrow |W_2| \rightarrow \Sigma \rightarrow |W_1 + W_2| \rightarrow I_{RT} \]
Differential Quantities With Paralleled CTs

\[ I_{RT}(A) \]
\[ I_{OP}(A) \]

52% Slope
45% Slope
Operating Value
Conclusion

- Inverse-time overcurrent elements are delayed with DG
- Zone sequencing requires modifications
- Percentage differential relays require:
  - Wiring modification
  - Settings adjustment
  - Relay replacement
Questions?