Field Experience With Open-Phase Testing at Sites With Inverter-Based Resources

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Overview

Review IEEE 1547.1-2020 for staged single-phase testing and system protection  
Review field events of open-phase commissioning tests at PCC  
Propose new protection scheme using 3V0 and V-THD elements to detect open-phase conditions
Open-phase detection test
IEEE 1547.1-2020

Open-phase condition must be tested while IBR is operating at greater of the following two levels
- Five percent of rated output current
- DER minimum output current

Typical pole-top recloser installation
Recloser R1

Current transformers
Typical ratio 1000:1

Low-energy analog voltage sensors

Potential transformers

Microprocessor-based recloser control
### IEEE 1547-2018 voltage protection

Traditional voltage elements may not be enough

<table>
<thead>
<tr>
<th>Shall trip function</th>
<th>Default settings</th>
<th>Ranges of allowable settings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Voltage (pu of nominal voltage)</td>
<td>Clearing time (s)</td>
</tr>
<tr>
<td>OV2</td>
<td>1.2</td>
<td>0.16</td>
</tr>
<tr>
<td>OV1</td>
<td>1.1</td>
<td>2</td>
</tr>
<tr>
<td>UV1</td>
<td>0.7</td>
<td>10</td>
</tr>
<tr>
<td>UV2</td>
<td>0.45</td>
<td>0.16</td>
</tr>
</tbody>
</table>

#### Analysis of field events
Event analysis overview

- Events were collected from open-phase commissioning tests performed at PCC sites across the U.S.
- Similar observations could be made after analyzing several field events
- Results of event analysis can be summarized and clearly explained by presenting five events from five different PCC sites

Site 1
Open-phase commissioning test on B-phase
Site 1 measured phase voltages and currents

Site 1 measured voltage magnitude and THD
Site 2
Open-phase commissioning test on A-phase

5 MW IBR
3 total phases

All three phases open

T1
YNy0
29.74 kV/480 kV

R1
CTR 1000:1

VAZ VBZ VCZ

VA
VB
VC

Site 2 measured phase voltages and currents

<table>
<thead>
<tr>
<th>Voltage (kV)</th>
<th>0</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAY VBY VCY</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>Voltage (kV)</th>
<th>0</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAZ VBZ VCZ</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Current (A)</th>
<th>0</th>
<th>200</th>
</tr>
</thead>
<tbody>
<tr>
<td>IA IB IC</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Time (s)

0 0.1 0.2 0.3 0.4 0.5

Utility

A B C

Feeder

A-phase opens

Lightning arrestors conduct during overvoltage conditions
Site 2 measured voltage magnitude and THD

![Graph showing voltage magnitude and THD over time](image)

Site 3
Open-phase commissioning test on B-phase

![Diagram showing electrical connections and phase commissioning](image)
Site 3 measured phase voltages and currents

Site 3 measured voltage magnitude and THD
Site 4
Open-phase commissioning test on C-phase

Site 4 measured phase voltages and currents
Site 4 measured voltage magnitude and THD

![Graph showing voltage magnitude and THD over time](image)

Site 5
Open-phase commissioning test on C-phase

![Diagram showing electrical connection and C-phase opens](image)
Site 5 measured phase voltages and currents

Site 5 measured voltage magnitude and THD
Proposed open-phase detection scheme

Undervoltage securing logic
A-phase

VAY
0.45 * VNOM

VBY
0.7 * VNOM

VCY

VBUV2 and VCUV2 logic is similar

SV01T
60
SV01
0
Zero sequence overvoltage element
Operating quantity

- 59N pickup threshold was to set ten percent of nominal secondary voltage for analysis
- Pickup setting can be set by users
- Pickup should be set above system unbalance created during maximum load for security reasons

Zero sequence overvoltage element
current and voltage supervision

- Load current detector threshold (50L) was set to 0.05 A secondary during analysis
- Relay Word bits 50L and 51G were inverted to prevent element from operating during load or fault conditions
- SV01T is voltage supervising logic
V-THD open-phase detection scheme

Operating quantity

- V-THD pickup setting of 7.5 percent was used for analysis
- Pickup value was selected to coordinate with IEEE 519-2014

V-THD open-phase detection scheme

Voltage and inrush supervision

- Timer (SV03) has pickup timer of 60 cycles, allowing scheme to restrain during inrush
- Undervoltage securing logic and breaker status are timer inputs
# Open-phase detection scheme performance

<table>
<thead>
<tr>
<th></th>
<th>Site 1</th>
<th>Site 2</th>
<th>Site 3</th>
<th>Site 4</th>
<th>Site 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum V-THD</td>
<td>9.56%</td>
<td>139.3%</td>
<td>4.50%</td>
<td>28.27%</td>
<td>101.6%</td>
</tr>
<tr>
<td>V-THD scheme</td>
<td>True</td>
<td>True</td>
<td>False</td>
<td>True</td>
<td>True</td>
</tr>
<tr>
<td>Maximum 3V0</td>
<td>0.43 pu</td>
<td>1.69 pu</td>
<td>0.23 pu</td>
<td>3.16 pu</td>
<td>1.11 pu</td>
</tr>
<tr>
<td>3V0 scheme</td>
<td>True</td>
<td>True</td>
<td>True</td>
<td>False</td>
<td>False</td>
</tr>
<tr>
<td>Maximum voltage magnitude</td>
<td>1.11 pu</td>
<td>1.70 pu</td>
<td>1.11 pu</td>
<td>2.14 pu</td>
<td>1.43 pu</td>
</tr>
<tr>
<td>IEEE 1547-2018 scheme</td>
<td>False</td>
<td>False</td>
<td>False</td>
<td>True</td>
<td>False</td>
</tr>
</tbody>
</table>

# Conclusion

- IEEE 1547.1-2020 requires detection for an open-phase condition that may lead to dangerous overvoltage conditions on power systems and subsequent equipment failure.
- These conditions can be difficult to detect with phase-overvoltage elements or current-based detection schemes.
- 3V0 and V-THD elements applied together can provide secure and dependable protection schemes that detect and operate for open-phase conditions at PCC.
Questions?