Control-Hardware-in-the-Loop Study of Islanding, 3Vo and 3Io Events
Under Contract PON 3404-111076

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Objectives

• Provides a CHIL platform for better understanding and evaluation of the critical issues that are unique to New York electric systems

• Demonstrate approach and methodology for performing assessment of Islanding, 3V0 and 3I0 for real feeders in NY and actual inverters hardware

• The procedure presented herein may also be adapted to studying other forms of technical issues.

Related software based study can be found at ITWG website:

Date: 6/20/2018
Title: Pterra 3Vo Study
Cover 3Vo background and other technical details
What is CHIL?

• Control-Hardware-in-the-Loop (CHIL) is real-time simulation which connect and test actual hardware devices (e.g. inverter controller) with network model

• Since the simulation runs in real time, the physical control equipment can be connected in closed-loop with the power system model

• Provides insight on both the performance of the inverter controller(s) as well as its effect on the power system

• This allows users to perform realistic closed-loop tests without the need for testing on a real system
Setup

REAL-TIME SIMULATOR (OPAL-RT OP5600)

Run the simulations on 12 Cores based on the software circuit models and actual inverter controllers

Actual Inverter Controllers (500 kW & 1000 KW)

A host computer is used as the human-computer interface. The circuit models are built, edited, and downloaded to the simulator via the host computer.

Distribution Circuit Models with Inverters
Three Distribution Circuits: 2 from NG and 1 from NYSEG

OP5607 – Interface & Fast simulation
I/O Interface between the simulator (OP5600) and the two actual inverter controllers. The trigger signals of the PV circuit are obtained from inverter controllers. The analog signals of inverter voltage and current are measured in the inverter circuit model and sent to the hardware controller.
Unintentional Islanding

• Prior opening the breaker, inverters output are adjusted to meet power balance (worst case & avoid operation of passive anti-islanding)
• Both inverters have active anti islanding scheme and introduce an alternating pulse about every 0.5 sec with constant pulse duration and period

• In addition to other factors (multiple inverter cases), the inverter trip time is also a function of when the islanding occurs
  • Islanding event occurs just before a pulse, trip faster
  • Immediately after the pulse, trip slower
The trip time can vary but remain within a specific number of pulses:
- 1-2 pulses ~ 0 to 0.965s
- 2-3 pulses ~ 0.483 to 1.448s
- 3-4 pulses ~ 0.965 to 1.93s.
- 3-4 pulses happens only on multiple inverter cases.

<table>
<thead>
<tr>
<th>Test ID</th>
<th>Location of Inverter(^1)</th>
<th>Feeder (^2)</th>
<th>Trip Time(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1000 kW</td>
<td>500 kW</td>
<td>1000 kW Inverter</td>
</tr>
<tr>
<td>1-8</td>
<td>A</td>
<td></td>
<td>Within 2-3 pulses</td>
</tr>
<tr>
<td>1-9</td>
<td>D</td>
<td></td>
<td>Within 1-2 pulses</td>
</tr>
<tr>
<td>1-10</td>
<td>A</td>
<td></td>
<td>Within 2-3 pulses</td>
</tr>
<tr>
<td>1-11</td>
<td>D</td>
<td></td>
<td>Within 2-3 pulses</td>
</tr>
<tr>
<td>1-12</td>
<td>A</td>
<td>D</td>
<td>Within 2-3 pulses</td>
</tr>
<tr>
<td>1-13</td>
<td>D</td>
<td>A</td>
<td>Within 1-2 pulses</td>
</tr>
<tr>
<td>2-3</td>
<td>A</td>
<td>D</td>
<td>Within 1-2 pulses</td>
</tr>
<tr>
<td>2-4</td>
<td>D</td>
<td>A</td>
<td>Within 1-2 pulses</td>
</tr>
<tr>
<td>3-3</td>
<td>A</td>
<td>D</td>
<td>Within 2-3 pulses</td>
</tr>
<tr>
<td>3-4</td>
<td>D</td>
<td>A</td>
<td>Within 1-2 pulses</td>
</tr>
</tbody>
</table>

\(^1\) Location of inverter: A = near the sub, D = remote end

\(^2\) Feeder 1: Within 2-3 pulses

Feeder 2 and 3 have similar trip time ranges.
Unintentional Islanding – Findings Summary

• Both inverters introduce an alternating pulse with constant pulse duration and period. However, their response times to an islanding event are dissimilar

• The 1000 kW inverter tends to trip slightly faster than the 500 kW

• The slower trip times for an inverter apply to certain system conditions including: (a) presence of another inverter on the circuit, (b) when the islanding occurs in relation to the point in time within the inverter pulse period

• Regardless, all the tests conducted showed inverters trip less than 2 seconds

• For cases with two inverters on the feeder, once the first inverter trips, the remaining inverter trips could trip on its passive anti-islanding function (unbalanced voltage and frequency)
GFOV on Sub-transmission System (3V0)

Voltage on Subtransmission System

- **Va**
- **Vb**
- **Vc**

SLG fault on phase A

Spike after SLG fault
Islanding – breaker opens at 470.086s
GFOV follows

Voltage on inverter terminal

- **Va**
- **Vb**
- **Vc**

0.344 PU for 0.08 s During the fault before islanding is formed

Voltage goes to 1 PU after islanding / GFOV is formed

Feeder Test Circuit #1 or #2 or #3

6/20/2018
**GFOV on Sub-transmission System (3V0) - Findings**

- When there is no load and arresters modeled on sub-transmission, the CHIL tests confirm that following the SLGF and formation of the island, GFOV of 1.7 PU - consistent with the PSCAD software simulation.

- For the specific inverters tested here, the inverter trip occurs due to the anti-islanding protection and can be as long as 1.93 sec. These particular inverters do not detect the GFOV, other types and designs of inverters may be able to trip faster - demonstrated in PSCAD simulation software models that were studied previously.

- The duration may be long enough to affect equipment.

- Two remedial measures were evaluated. For faster trip times, remedial measures, such as 3Vo and the negative-sequence voltage (NSV) protection schemes, are needed for this situation.
GFOV Mitigation Options

3V₀ Scheme
- Detection: Subtransmission System / HV
- Need additional high voltage PT and relaying
- About 6 – 12 months installation / $500K

NSV Scheme
- Detection: Inverter side / LV
- Use existing CT/PT
- Potentially faster to install / inexpensive due to low voltage equipment and installation
GFOI on Sub-transmission System (3I0)

Customer transformer acts as alternate grounding source (AGS)

- W/O AGS TX – GFOV = 1.732 pu, $I_N = 0$ / NA
- W AGS TX – GFOV = 1 pu, $I_N = 12$ A RMS

Each leg of the transformer winding carries one-third of the neutral current ($I_N$)

2.5 MVA rated current 21 Amps

Consideration for short term rating criteria:

**IEEE std C57.109** damage characteristics/curve for liquid-immersed
Typ. 8 - 25 * rated current for 2 seconds depending on the category and fault frequency (precaution – confirm with manufacturer)

**ANSI/IEEE Std. 32-1972:**
Require a short-term rating (10sec) of 33 times the continuous rating for transformer grounding bank
Application Example to Industry and Utilities

- No 3VO or 3IO Mitigation Needed for this circuit

34.5 kV System showing 34.5 kV Line feeding four 34.5 kV distribution substations

Scenario:
1) SLG Fault at F1 causing recloser R-1 to open/stop
2) DG fed by transformer T1 lost its grounding source from the Source (115/34.5 kV Substation). The island is formed with DG and Transformer T1 through T4 isolated from the Source
3) Utility concerns about GFOV on the isolated 34.5 kV system

Source: Substation 115 kV / 34.5 kV

Facts:
1) Transformer T2 and T4 can provide alternate grounding source
2) Total DG on the Island = 1000 kW (Fed from transformer T1)
3) Total minimum load on the Island = 4000 kW
4) Total DG/Minimum Load = 25%

Sample of Alternate Grounding Source.

Sample of Alternate Grounding Source.
GFOI(3IO) - Findings

- With alternate grounding source, GFOV does not occur and GFOI/3IO are less likely to be an issue even with small (less than 3 MVA) transformer
- The magnitude of the 3l0 current contribution from inverters in the transformer is generally significantly less than the short-term rating. For all scenario tested, there is no enough ground fault current from inverter-based PV to overload the transformer
- The alternate grounding source is generally in the form of a customer transformer with a wye-grounded/delta connection, a three-winding transformer or an autotransformer