ELECTRIC POWER RESEARCH INSTITUTE

Neutral-Grounding for Inverter-Connected DER

For NY ITWG

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NYSERDA Effective Grounding Project

- **TASK 1. Assess Current Utility Practice To Inform Objectives**
  - Determine Current Utility Practice (Guided interviews/Survey)
  - Clarify Grounding Objectives and Specific Requirements, Dec 4,2019
- **TASK 2. Develop Relevant Scenarios and Models to be Analyzed** (includes Laboratory and HIL Test, and Modeling Objectives)
- **TASK 3. Coordinated and Concurrent Analysis, Simulation, and Testing**
- **TASK 4. Develop Guidelines for Inverter Effective Grounding by July 19**
- **TASK 5. Deliver Final Report, Outreach and Education** (proposed ITWG workshop in 2020)

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Q3 – Do you require additional ground sources for DER (either by a grounding transformer or a grounded-wye/delta transformer)?

	Answers	Results	%
A	Never	10/76	13
B	Depending on DER size	19/76	25
C	Depending on DER type (i.e., inverter, synchronous generator)	12/76	16
D	Other criteria	13/76	17
	No Answer	22/76	29

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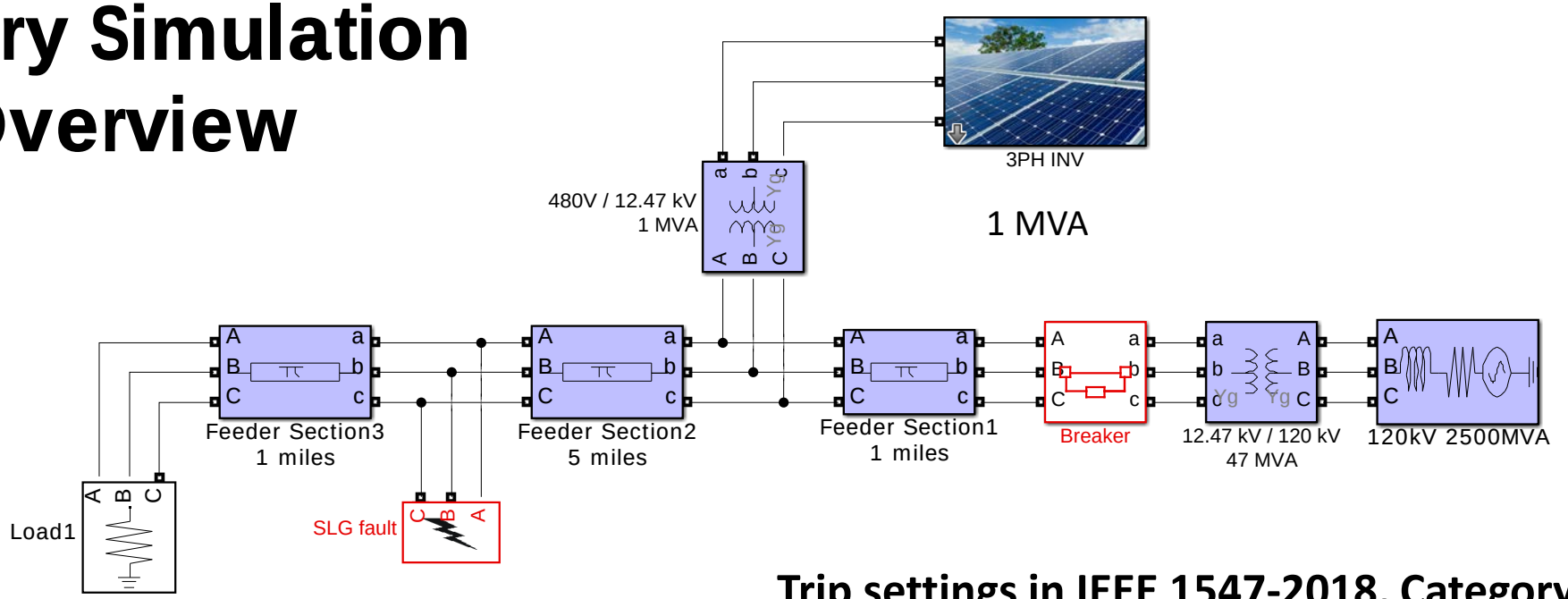
Preliminary Simulation Study – Overview



Inverter overvoltage (TOV) trip settings

Element	Pickup	Time Delay (cumulative)
TOV	2 pu	0.0016 sec
TOV	1.7 pu	0.003 sec
TOV	1.4 pu	0.016 sec
TOV	1.3 pu	0.166 sec

Trip settings in IEEE 1547-2018, Category III

Element	Pickup Range	Time Delay
Undervoltage (27)	0.5 pu	1 sec
Undervoltage (27)	0.7 pu	10 sec
Undervoltage (27)	0.88 pu	20 sec
Overvoltage (59)	1.1 pu	12 sec
Overvoltage (59)	1.2 pu	0.16 sec
Underfrequency (81u)	56.5 Hz	0.16 sec
Underfrequency (81u)	58.8 Hz	299 sec
Overfrequency (81o)	61.2 Hz	299 sec
Overfrequency (81o)	62.5 Hz	0.16 sec

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Overvoltage Scenarios and Grounding

1. ***Load Rejection Overvoltage (LRO) in balanced 3-phase system***
   - Yg/Yg DER transformer (effective grounding does not matter)
   - Main breaker opens (no ground fault)
   - Load varies from 0 pu -1 pu (Δ or Y connected load)
2. ***Combined LRO and ground fault overvoltage (GFO)***
   - Yg/Yg and Δ/Yg DER transformers (with and w/o supplemental grounding)
   - Permanent ground fault and main breaker opens
   - Load varies from 0 pu -1 pu (ungrounded load, spot check with 30% grounded)
3. ***GFO with varying amount of grounded load***
   - Yg/Yg and Δ/Yg DER transformer (no supplemental grounding)
   - Permanent ground fault occurs and main breaker opens
   - Load to generation ratio = 1, grounded load % varies from 0% –100%

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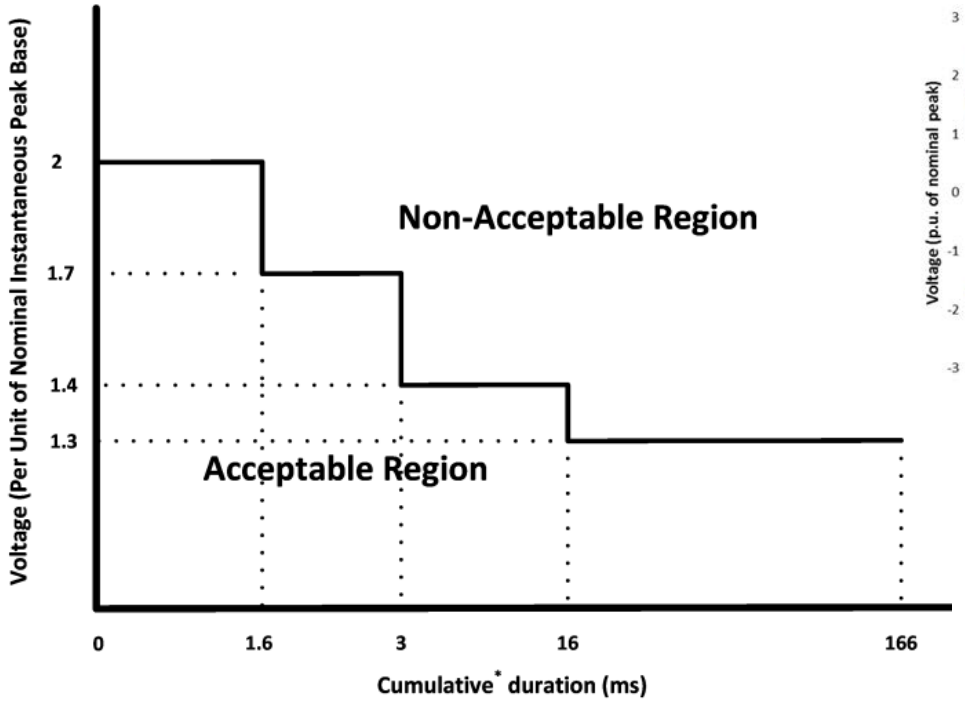
7.4 Limitation of Overvoltage Contribution (1547-2018)

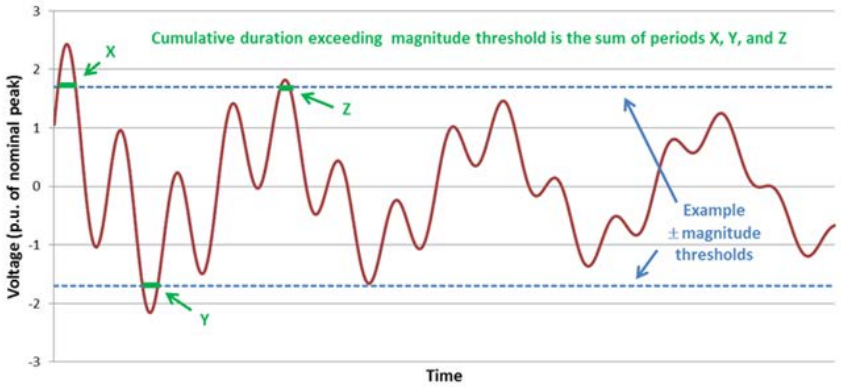
7.4.1 Limitation of overvoltage over one fundamental frequency period

- For Ground Fault Overvoltage (GFO) - on any portion of the Area EPS that is designed to operate effectively grounded to exceed 138% of its nominal line-to-ground fundamental frequency voltage for a duration exceeding one fundamental frequency period.

7.4.2 Limitation of cumulative instantaneous overvoltage

- For Load Rejection Overvoltage (LRO)





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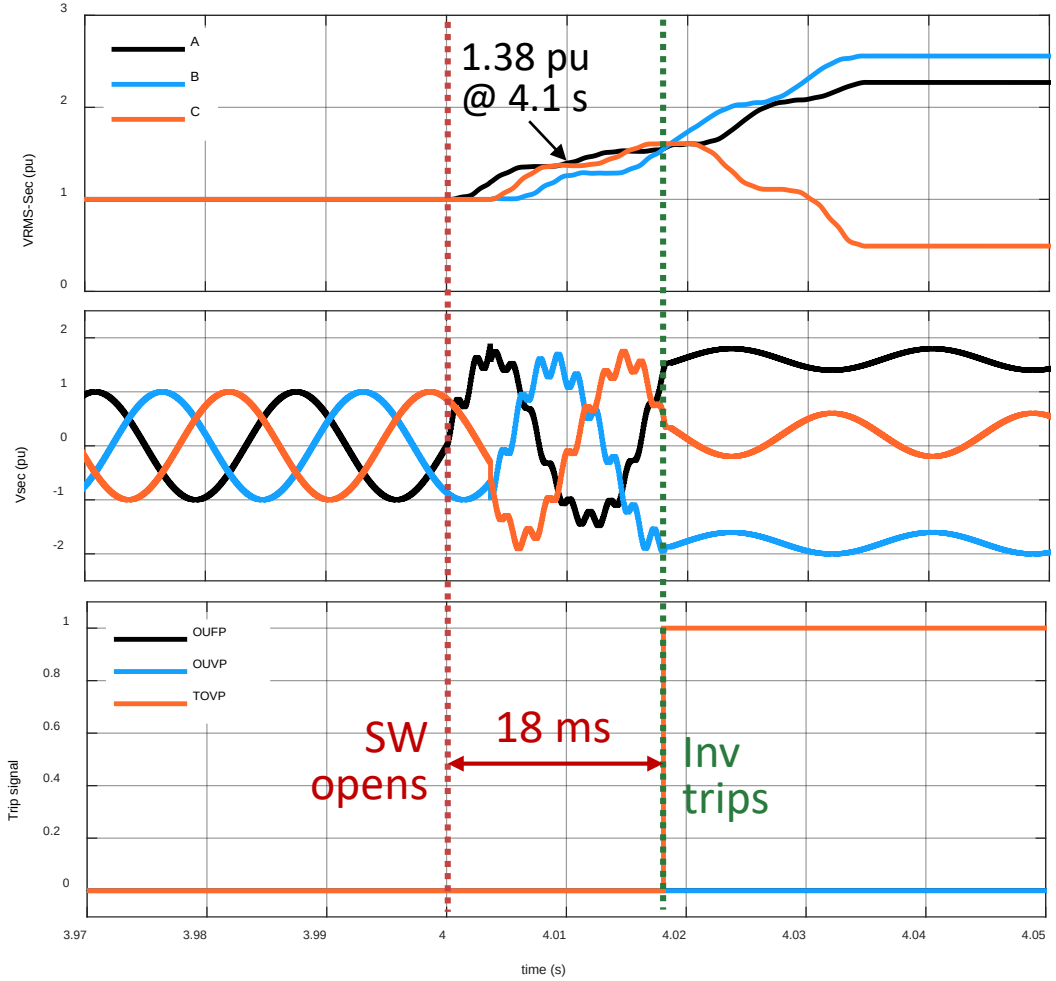
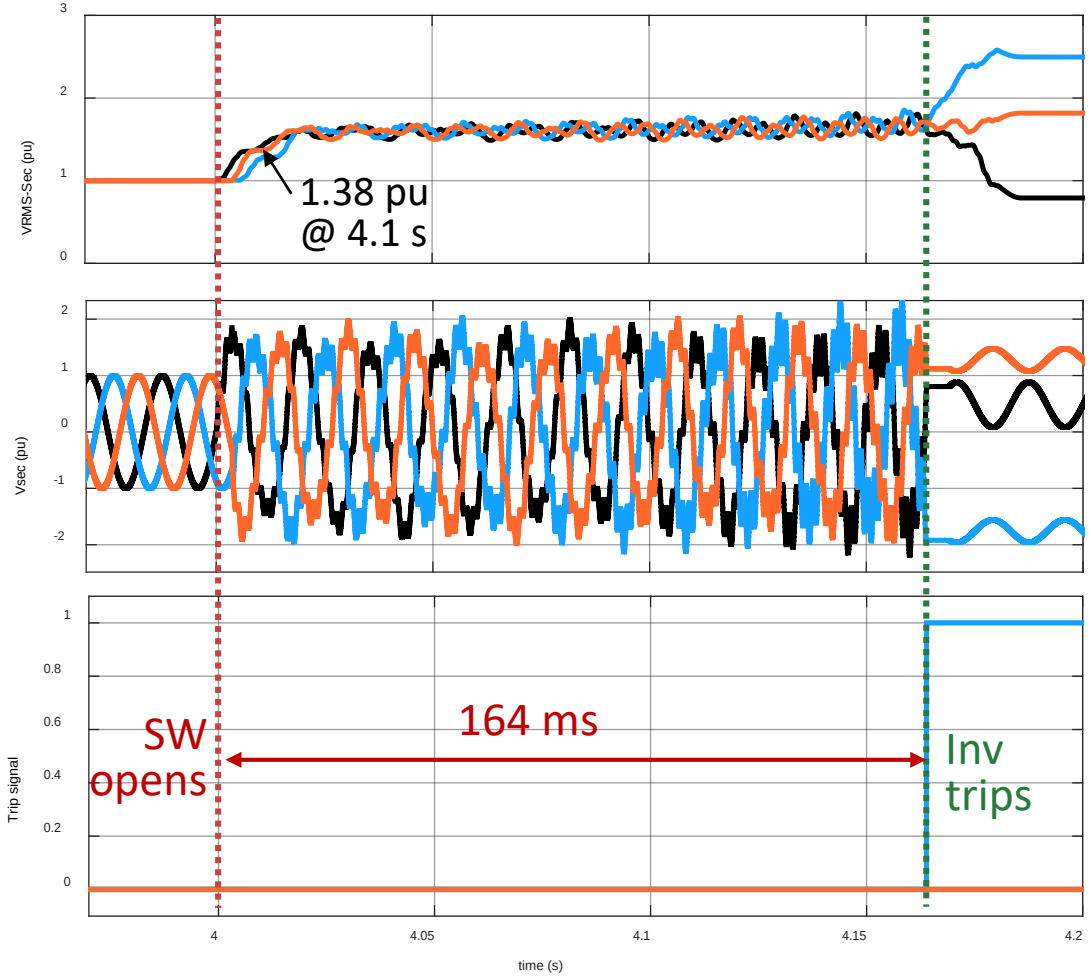
PV System LRO Events two different inverter simulations.

Pass 1547.1 LROV Test



- With transient overvoltage protection (TOVP)
- Inverter is able to trip within the required time

Fail 1547.1 LROV Test



- TOVP **disabled**
- Inverter fails to trip within the required time

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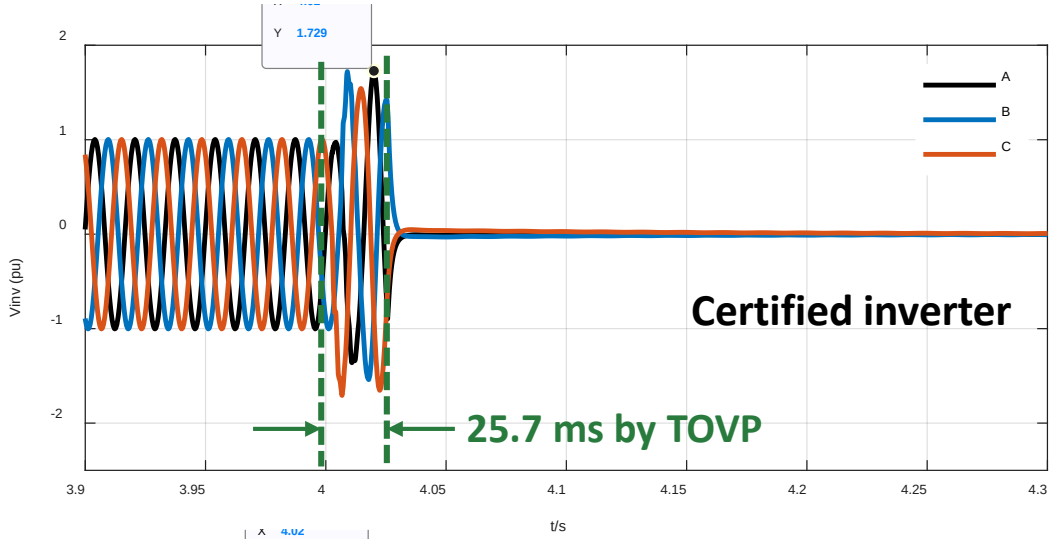
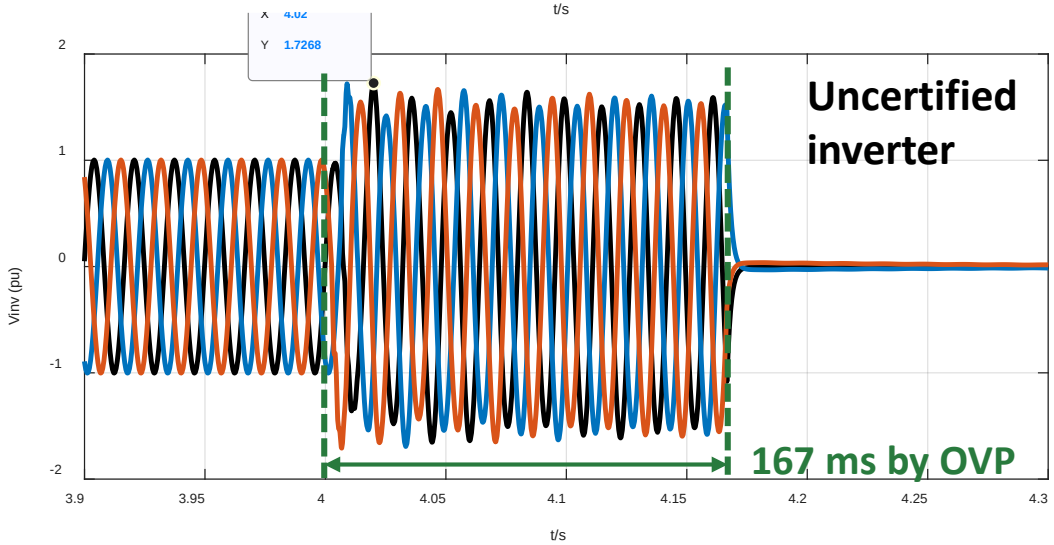
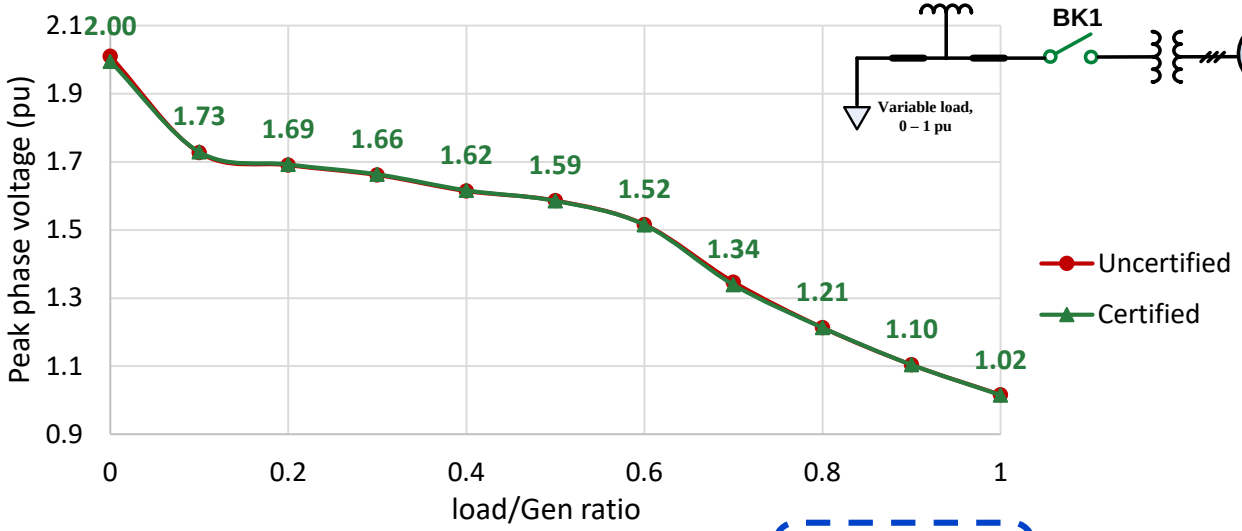
Scenario 1 – LRO

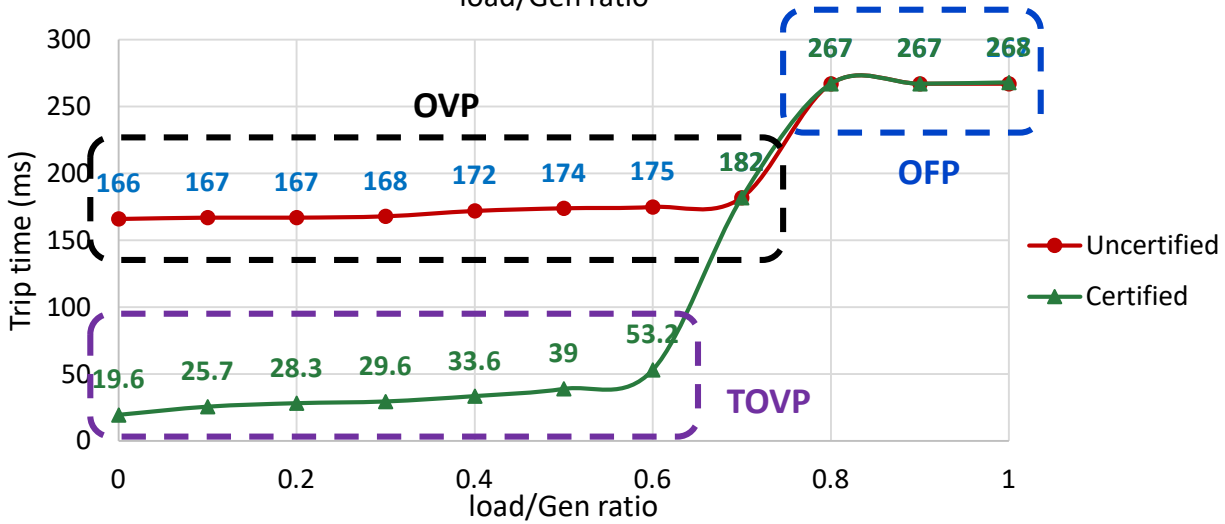




TOVP - Transient overvoltage protection
OVP - Overvoltage protection
OFP - Overfrequency protection

Test condition: No grounding transformer (GT), delta connected load, No ground fault





- Peak LRO decreases with higher load/gen ratio
- Uncertified inverter causes longer trip time, but similar LRO

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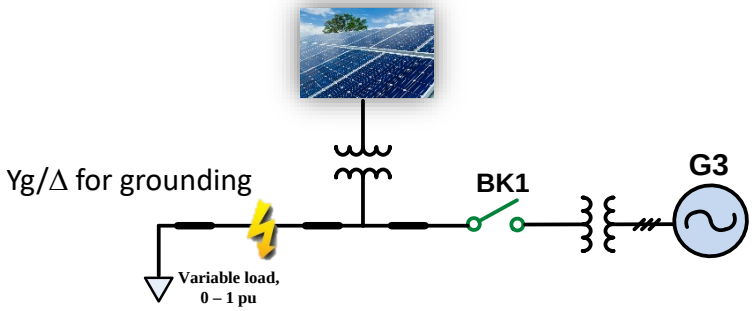
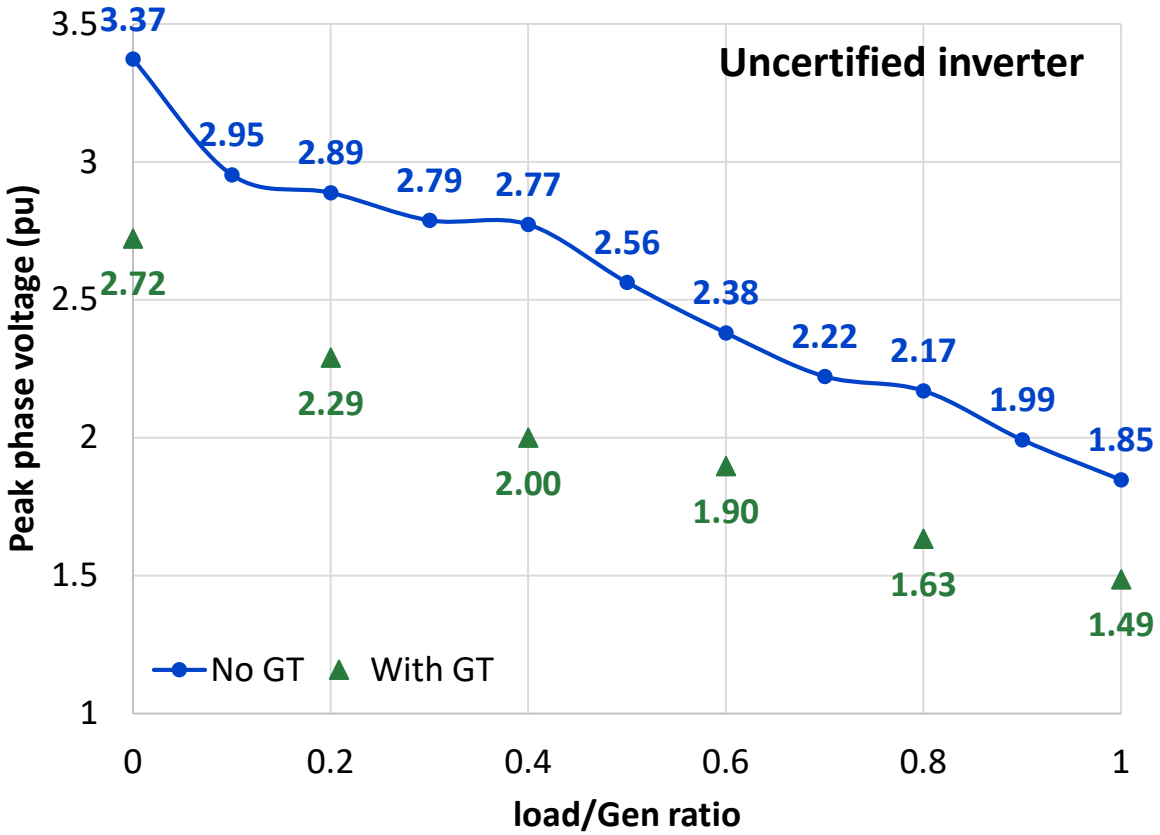
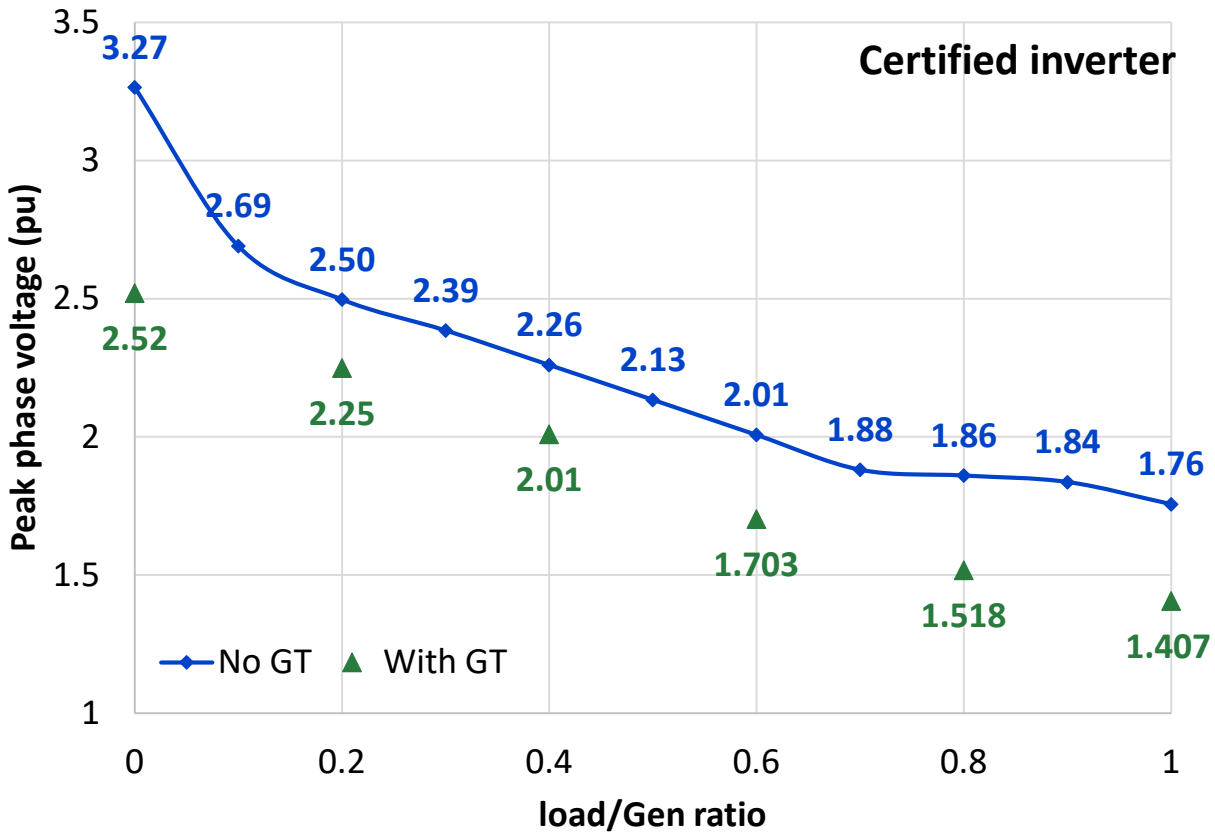
Scenario 2 – LRO + GFO



Test condition: w/wo grounding transformer (GT), delta connected load, permanent ground fault





- Uncertified inverter suffers higher overvoltage in this case due to the longer trip time
- Grounding transformer helps to mitigate the overvoltage

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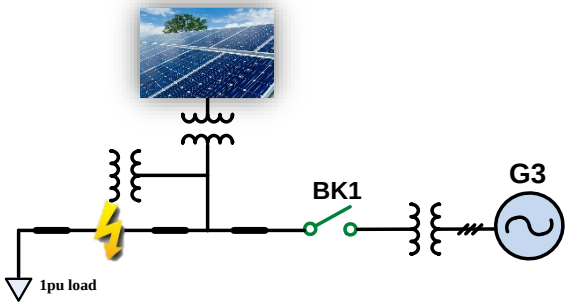
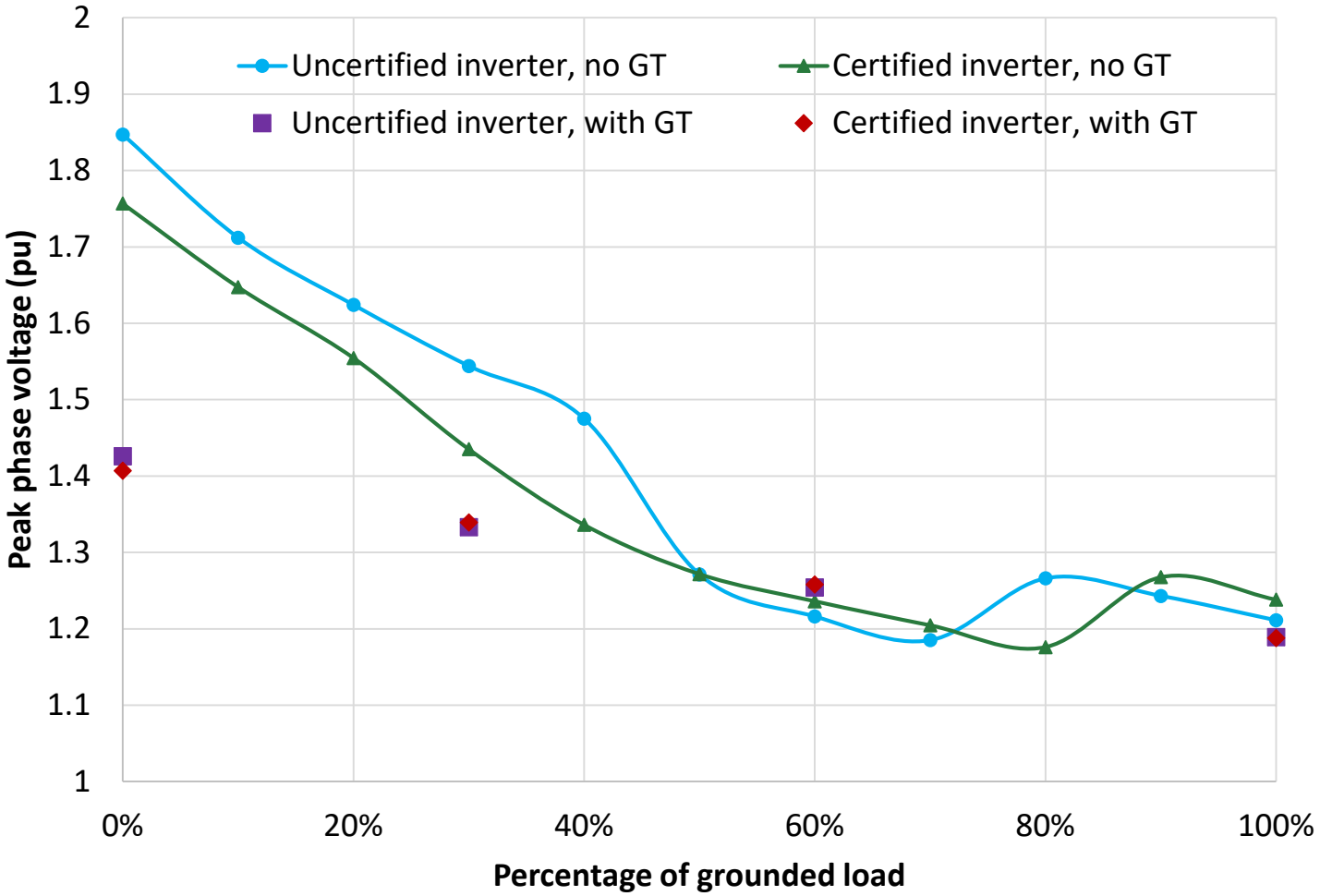
Scenario 3 – GFO



Test condition: w/wo grounding transformer (GT), load/generation ratio = 1, delta ang Yg connected load, permanent ground fault



- Overvoltage caused by ground fault (GF) tends to reduce with higher portion of ground load (Yg connected)
- Grounding transformer (GT) helps with overvoltage mitigation when grounded load is light, but this effects drops with increasing grounded load. Specially, GT slightly increase GFO when 60% loads are grounded
- Further investigation is needed to study the different overvoltage change trend in uncertified inverter, when 40%-80% grounded load and no GT exist

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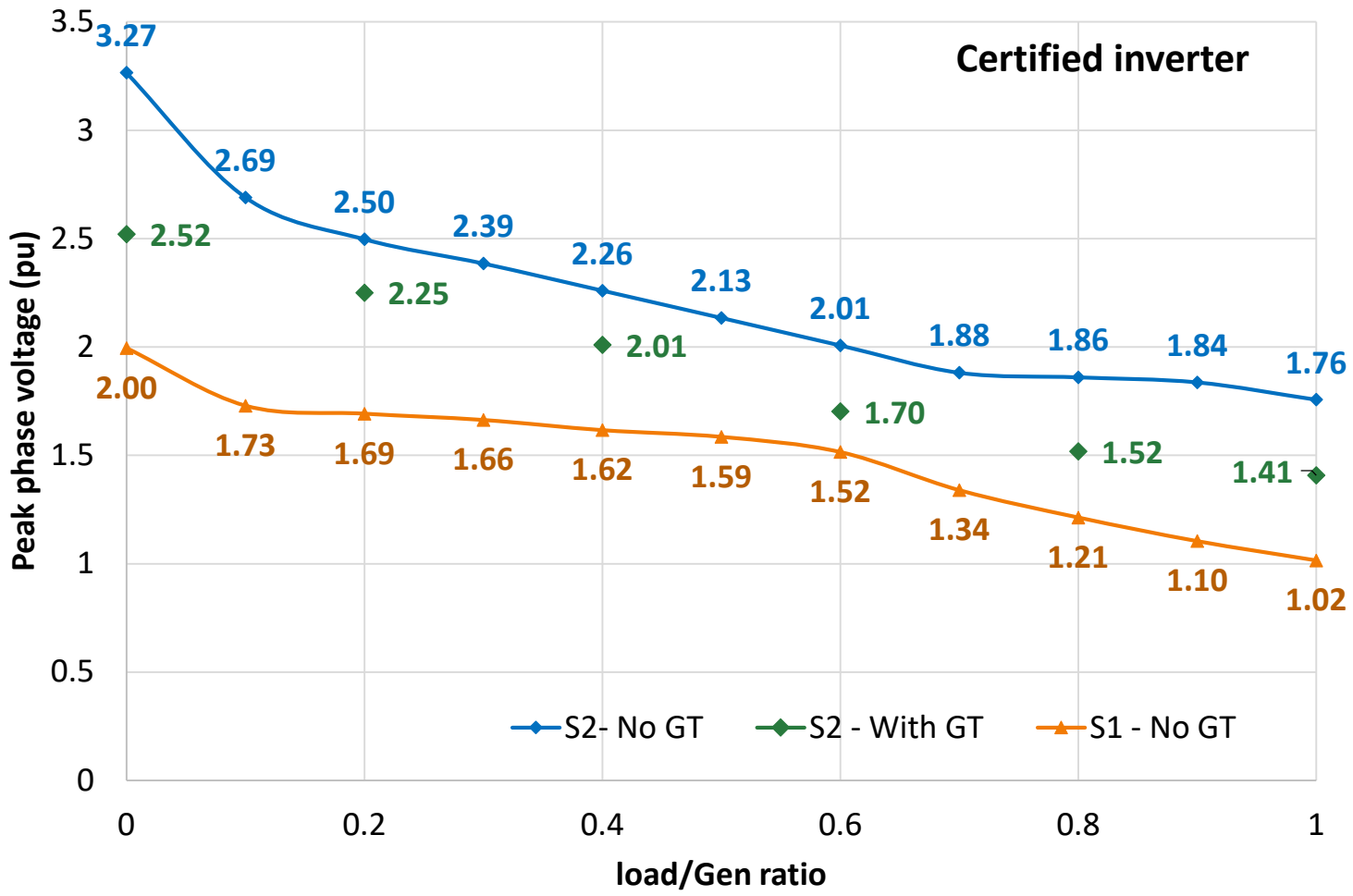
Comparison between Scenario 1 and 2

Scenario 1 (S1): No grounding transformer (GT), delta connected load, No ground fault

Scenario 2 (S2) : w/wo grounding transformer (GT), delta connected load, permanent ground fault



- Overvoltage caused by ground fault and load rejection cannot be simply superposed
- Even with grounding transformer, the ground fault overvoltage (GFO) is higher than the load rejection overvoltage (LRO)

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Test Plan

- ***Objective***
  - Characterize the inverters' dynamic response to voltage changes
  - Estimate equivalent negative sequence impedance for theoretical analysis
  - Identify impact of volt-var function on inverter response
- ***Test scenarios (with and without volt-var)***
  - Response to step change of positive sequence grid voltage
  - Response to negative sequence voltage variation
    - Magnitude variation
    - Phase angle variation
- ***Test approach***
  - Lab test of commercial inverters
  - Controller hardware-in-the-loop (CHIL) with different negative sequence current control schemes
  - Will be performed in parallel
- ***Expected outcomes***
  - Validated inverter simulation model with accurate dynamic response
  - Characteristics of inverter negative sequence impedance when different control schemes are implemented

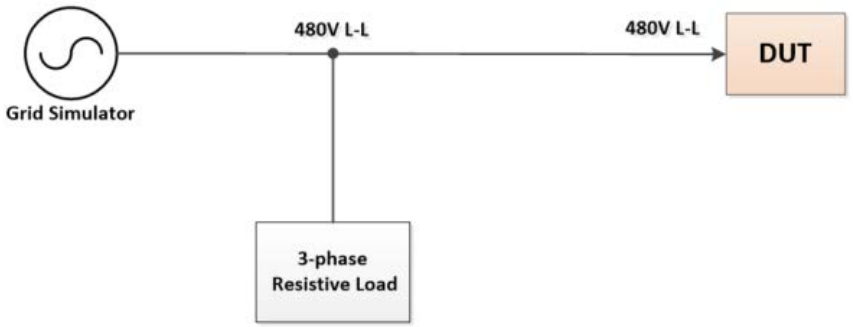
Assessing Inverter Response to Positive and Negative Sequence Voltage Variation – Test Plan

1. OBJECTIVE

This test plan is prepared to characterize the inverters' dynamic response to voltage changes, when volt-var function is enabled and disabled, and to estimate their equivalent negative sequence impedance for effective grounding analysis.

2. TEST SETUP

2.1 SINGLE LINE DIAGRAM



Resistive load is used to absorb active power generated by DUT and prevent power flow into the grid emulator.

2.2 MEASURE POINTS (WITH AND WITHOUT DUT)

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Future Work

- Perform lab and CHIL tests per designed test plan
- Simulation model refinement
  - Arrester
  - Capacitor bank
  - ….
- Simulation of other scenarios
  - Yg/Δ transformer for grounding
  - Varying generation before island forms
  - Inverter with grid-support functions
  - ….

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