Study the Control and Protection Improvements for a Weak Grid Area with High IBRs

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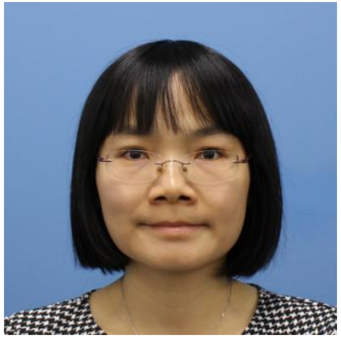
Photo by Josh Bauer, NREL 61725

Project Team



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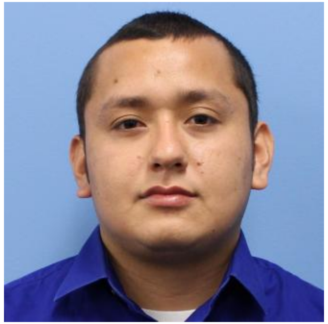

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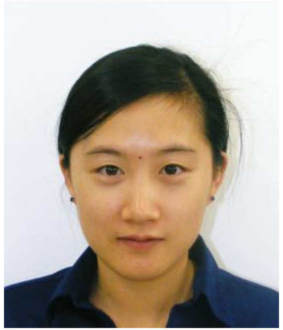

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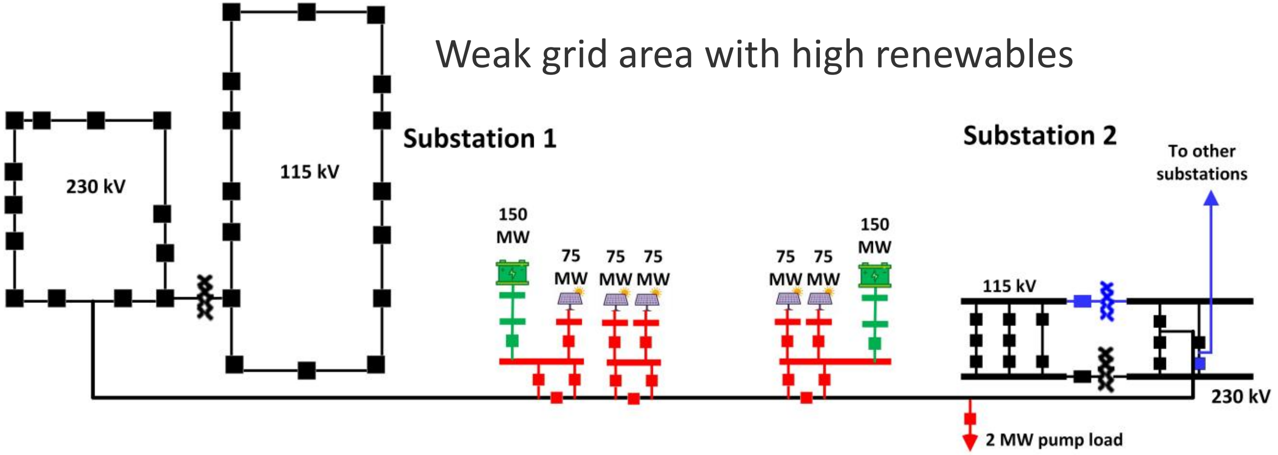
Project Overview

Challenges:

- Very low short-circuit ratio (≦1.5), typical weak grid with high renewables
- Existing system instability (e.g., oscillations)
- Frequent maloperation and tripping of power quality and protective relays.



Project goal: We will identify and predict the power system stability and protection reliability issues for a weak grid area with high renewables and develop mitigation solutions to resolve those issues.

Project objectives: Develop solutions to improve power system stability and the reliability of power system protection for a weak grid area with high penetrations of inverter-based resources (IBRs): (1) Use hardware inverters to validate the black-box grid-following (GFL) and grid-forming (GFM) inverter models. (2) Evaluate IBR fault ride-through performance and perform system stability analysis. (3) Evaluate the reliability and adequacy of existing protection schemes.

Technical Approach

Develop high-fidelity IBR model

- Hardware inverter test using PEGI
- PSCAD black-box modeling improvements

- Original equipment manufacturer (OEM) GFM and GFL inverters
- LV5+ inverter controller will be modified by OEM.

- Small-signal and transient stability studies

Comprehensive system stability study and analysis

System stability and improvement solutions

- Identify weak grid operation challenges and solutions.
- Identify needed GFM capacity for system stability.

Fault study and protection scheme evaluation

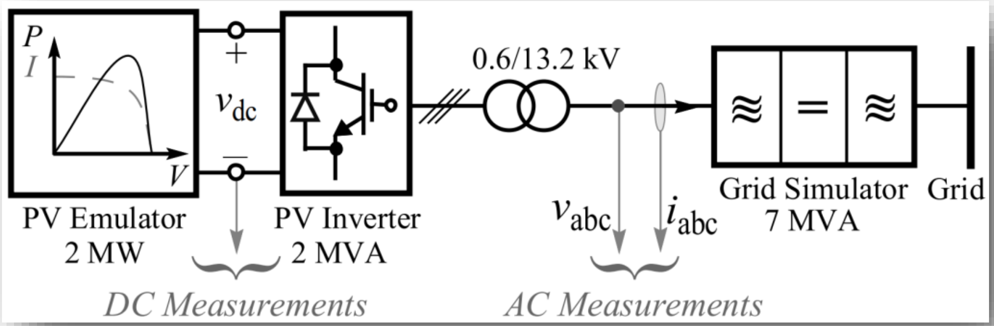
- Recreate fault events in the field.
- Evaluate the existing protection schemes.

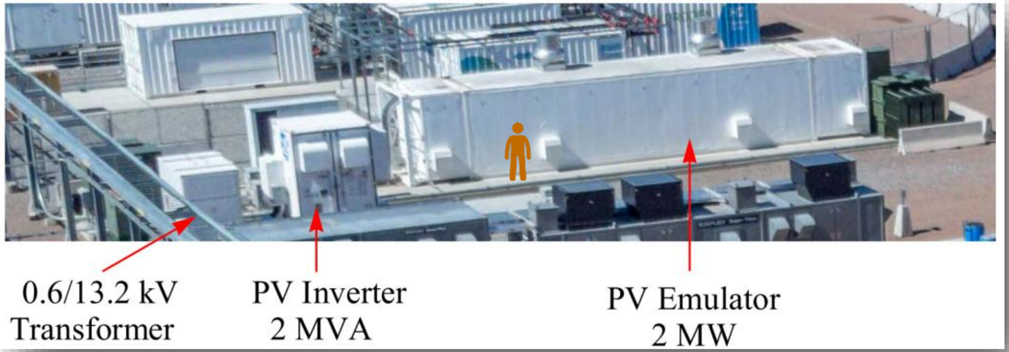
Protective scheme enhancement

- Evaluate reliability and adequacy of existing protection.
- If additional protective device needed.

EMT Model Validation & System Stability Analysis

Setup for Testing of a 2 MVA PV Inverter



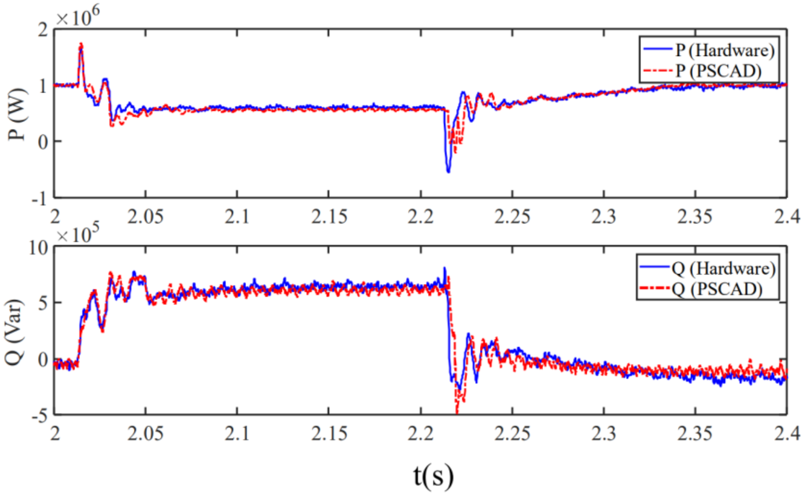


- 2 MW PV emulator is used to supply the dc bus of the 2 MVA PV inverter
- 7 MW grid simulator is connected at the medium voltage ac bus for transient and frequency-domain testing of the inverter
- High-res measurements at 50 kHz sampling frequency are performed on ac and dc bus
  - *P* and *Q* derived from v_{abc} and i_{abc}

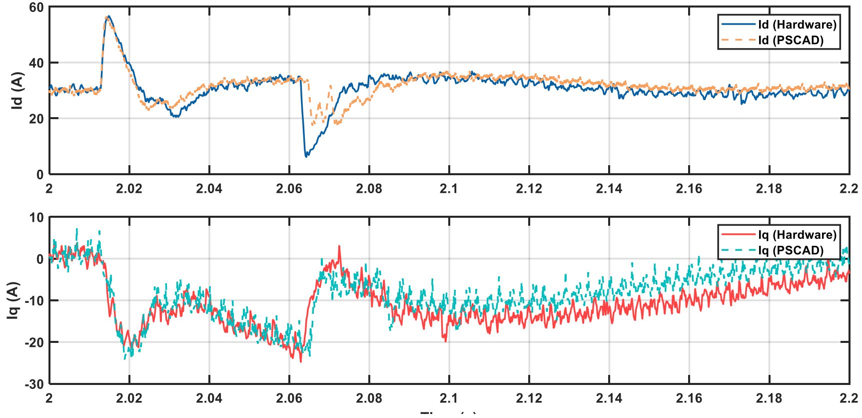
Voltage Dip Test

- 7 MW grid simulator instantaneously reduces the voltage magnitude at the ac terminal
  - Voltage dips of 10% to 60% lasting for 50 ms and 200 ms are tested

30% voltage dip of 200 ms duration



10% voltage dip of 50 ms duration

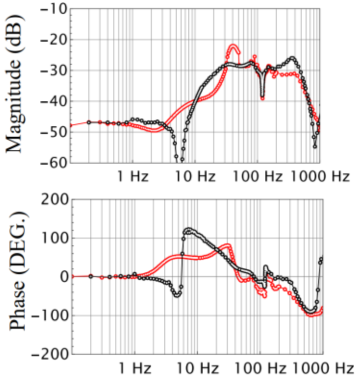


GIST

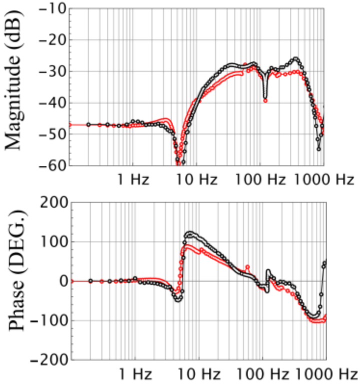
DQ Admittance Scan

ARIES Test Setup for 2 MVA PV Inverter

Before Model Revision



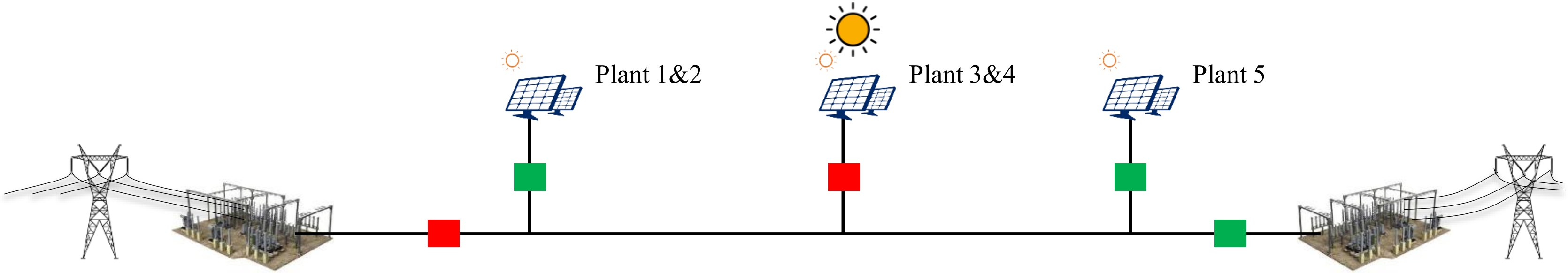
After Model Revision



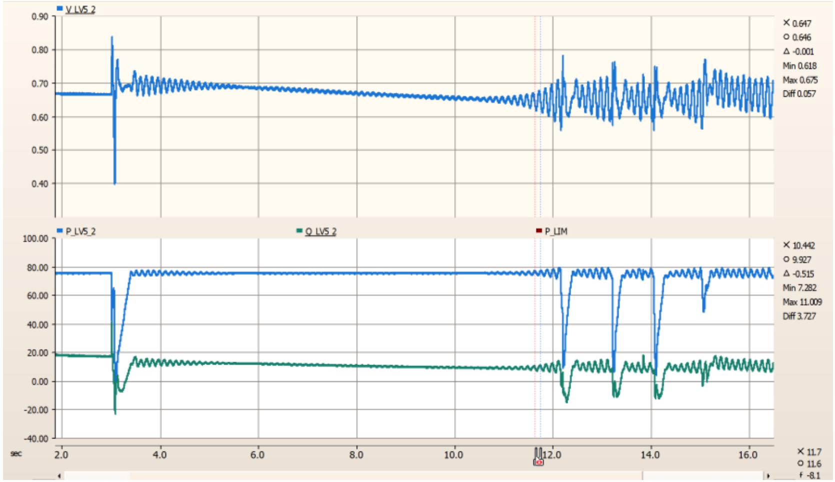
Red: Model; Black: Hardware Measurements at ARIES

GIST

Weak Grid Instability at 8 to 10 Hz

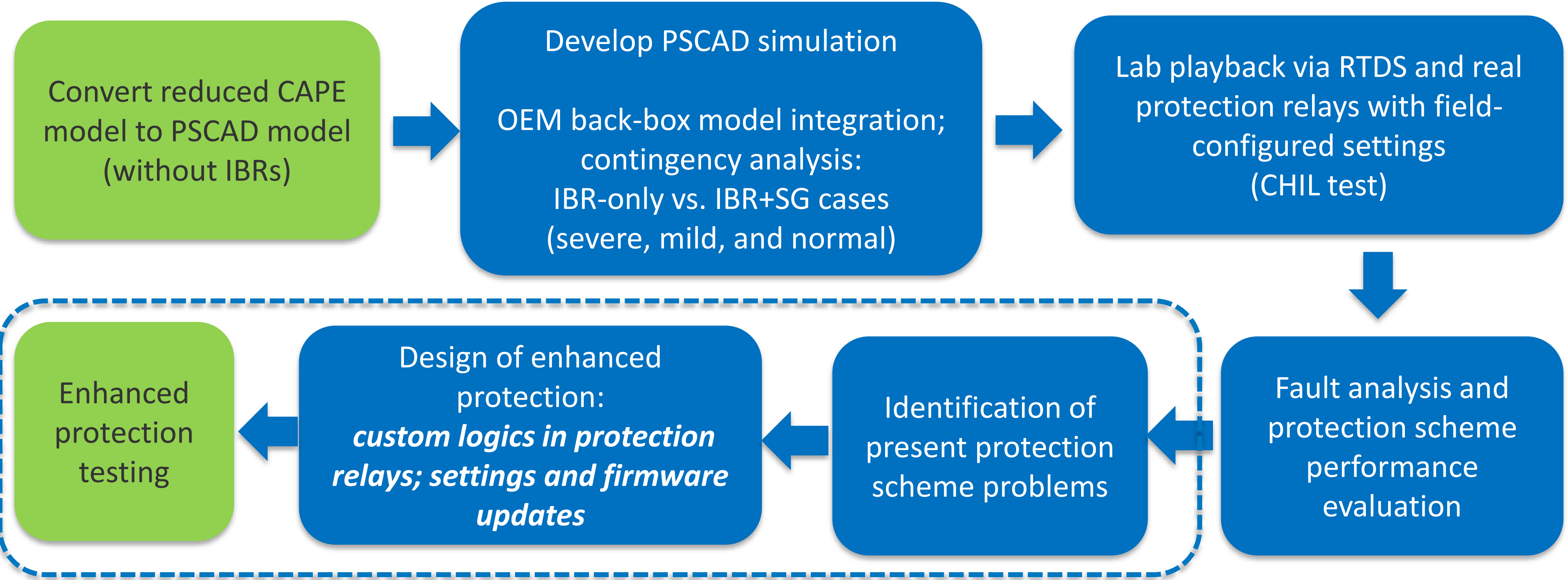


- Plant 5 cannot operate stably when one terminal is open
  - The plant is switched to the network at 3s
  - Exhibits oscillations at ~8 Hz
  - Instability appears only for high IRR



Fault Study and Protection Scheme Evaluation through Relay Hardware-in-the-loop Testing

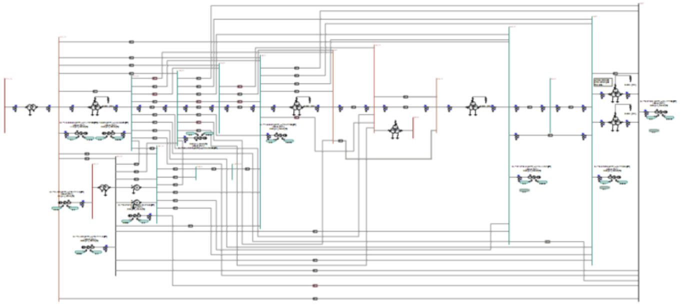
Methodology of Enhanced Protection Scheme



<u>**Goals**</u>: (1) 87 differential elements work reliably; (2) local elements: distance and directional elements also work reliably; (3) both 87 and local elements operate within four cycles.

Develop PSCAD EMT Model for Fault Study

Full CAPE Model → Reduced CAPE Model → PSCAD Model



Comprehensive Validation

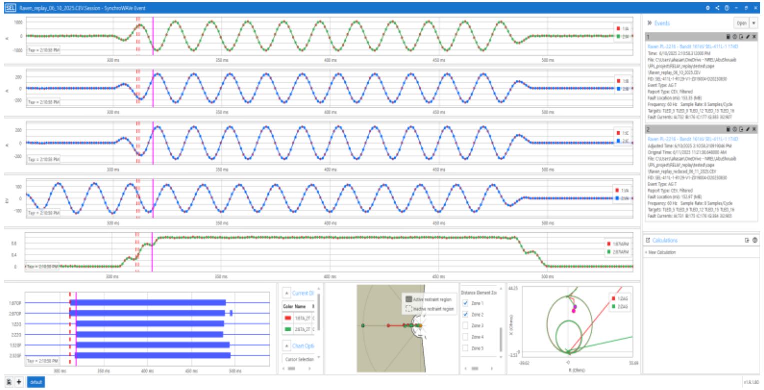
Full CAPE

Phasor	Mag.	Ang.
VA	91.885	0
VB	80.3615	-123.36
VC	80.8401	123.34
IA	9.3208	-83.81
IB	1680.69	171.71
IC	1589.32	18.78
ZDAB	90.1519	34.85
ZDBC	42.3539	85.25
ZDCA	95.5957	134.54

Reduced CAPE

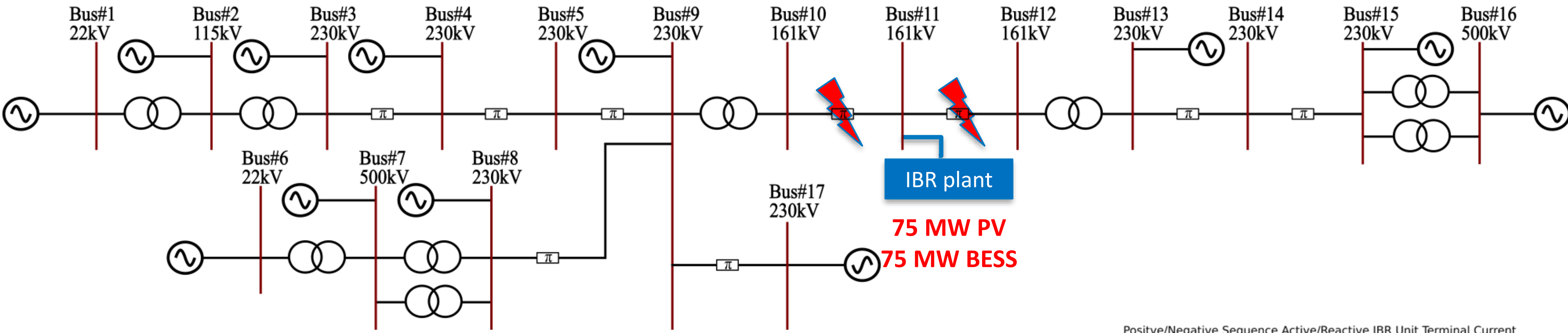
Phasor	Mag.	Ang.	
VA	91.7848	0	0.11%
VB	80.1232	-122.96	0.30%
VC	81.0728	123.65	0.29%
IA	99.9742	-3.03	90.68%
IB	1710.46	172.27	1.74%
IC	1563.03	19.62	1.68%
ZDAB	83.5033	33.88	7.96%
ZDBC	42.3539	85.25	0.00%
ZDCA	103.623	132.6	7.75%

Fault study comparison



COMTRADE Replay

The Power System Under Study

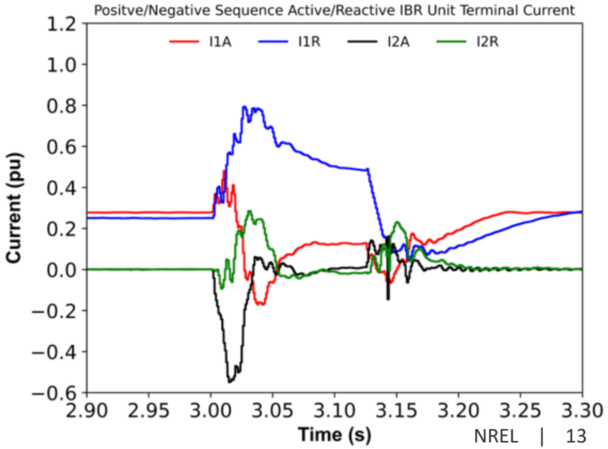


General challenges for protection

- IBRs have oscillatory fault current (should be tuned)
- IBRs don't inject negative sequence current (not IEEE Std 2800 compliant)

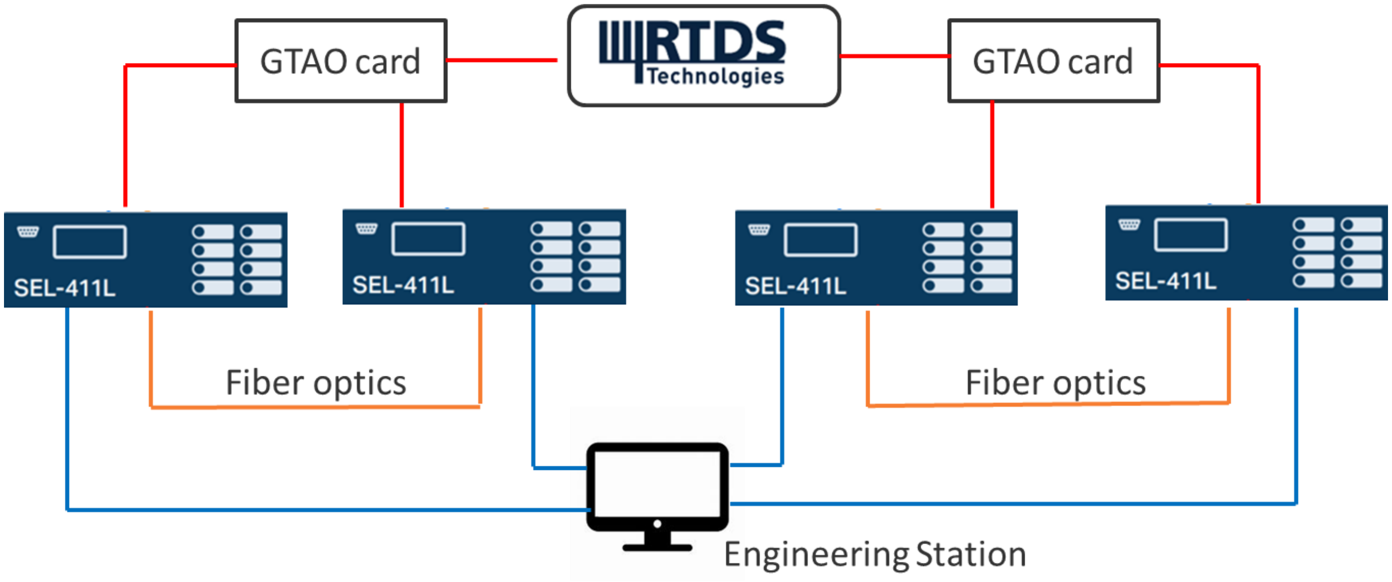
Scenarios under study

- Normal, N-1 contingency, and IBR only sever contingency
- AG, BC and BCG fault at 5%, 80% and 95% distance



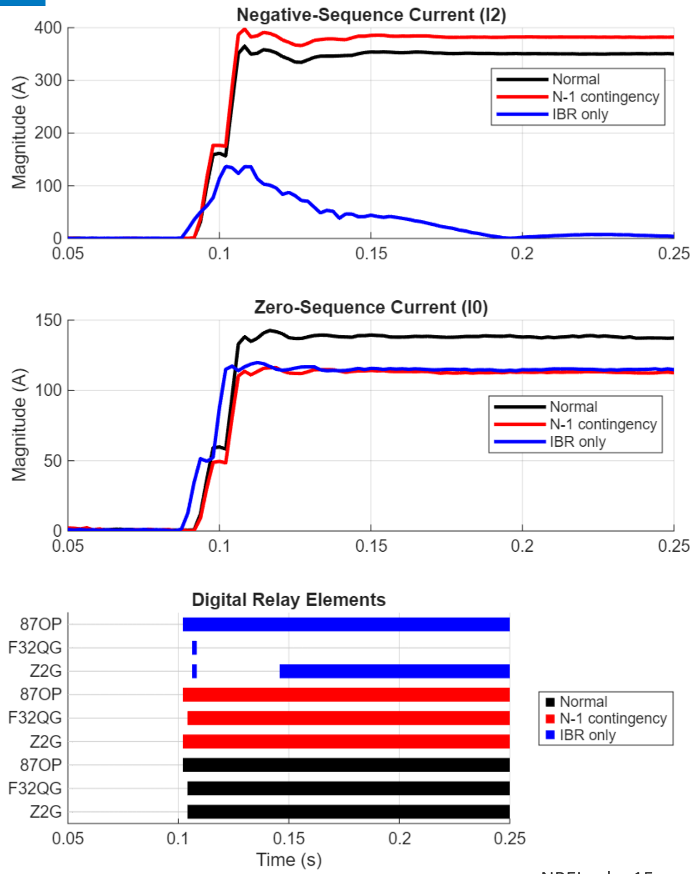
Laboratory Controller-Hardware-in-the-Loop (CHIL) Setup

- Three field events (Solar plant wasn't operational) were used to validate the relay settings, CT/PT ratios in RTDS etc. to replicate the field relay response
- Automated PSCAD-RTDS relay testing



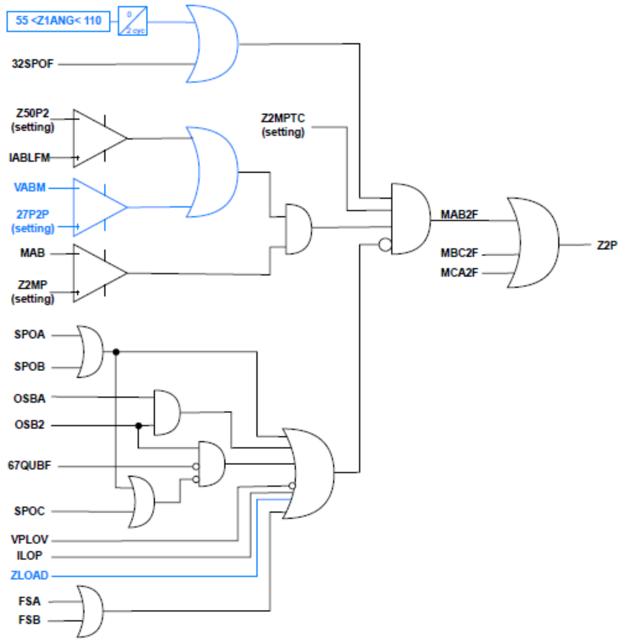
Identified Protection Challenges

- All four relays operate reliably under normal and less severe contingency scenarios.
- Under the most severe contingency, the IBRs are the only source for the fault current. Differential elements still operate reliably, but there are a few challenges as shown below:
  - There is no negative-sequence current injection→ directional elements such as 32Q and F32P not working.
  - The fault current is low → IBC is less than Z50P, and the mho element will not work.
  - Very oscillatory current (should be tuned) → delayed responses (asserts after four cycles).
  - FID uses 87 differential elements → no problem.



Proposed Solutions

1. Design enhanced protection:
   - Use V instead of QV for ground directional element priority; increase threshold to block supervision elements with I2 (a2 and k2).
   - Design customized protection logics.
2. Work with inverter vendor to:
   - Add negative-sequence current control.
   - Test the IBR fault responses to ensure I2 is IEEE Std 2800-2022 compliant: I2 magnitude is proportional to V2, I2 leads V2 90°~100° and settles within four cycles.
   - Increase K-factor to increase the magnitude of I2.
3. Add traveling wave-based protection:
   - Use SEL-400 L relays.



Example of customized logic for mBC

Key Takeaways

- The GFL PV inverter PSCAD model matches well with the hardware inverter.
- The system stability study with five PV plants shows one major stability issue: 8-Hz oscillation with weak grid operation.
- There are several challenges for protection studies with IBRs:
  - There is no good power system model.
  - IBRs do not inject I2.
- This project explores a framework to address the gaps in protection:
  - It develop a PSCAD model equivalent to the reduced CAPE model.
  - It updates the protection settings/logic.
  - It develops customized logics to resolve the challenges of lacking I2.
- This work provides feasible solutions for industries to address IBR-related issues in stability and protection.

Thank you !

Q & A

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