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Opportunities and Challenges of Using Local Measurements for Protecting LV Networks with DER

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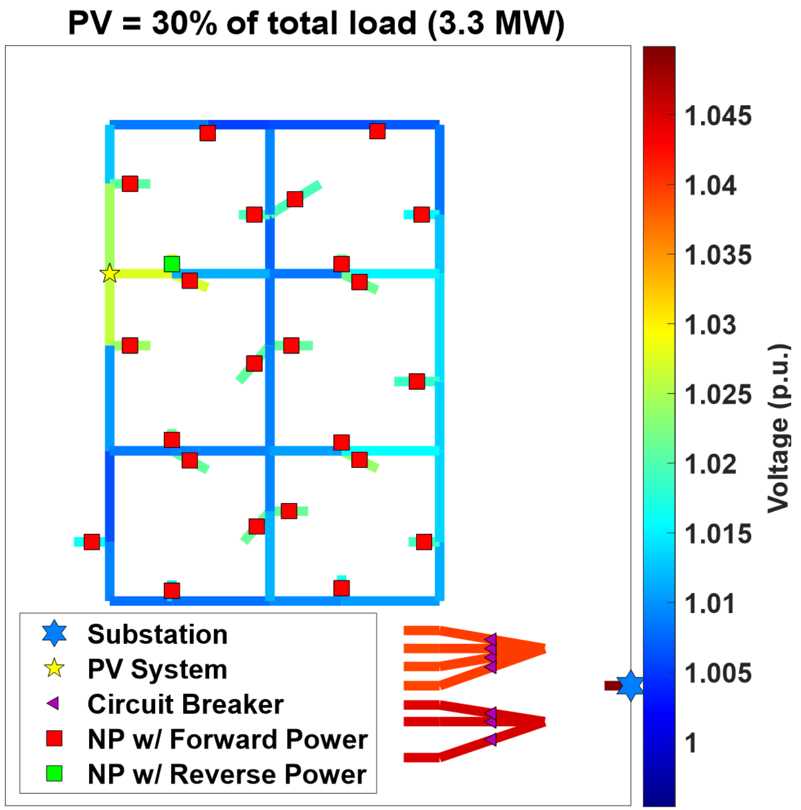
Background

DER on Low-Voltage (LV) Networks

- Conventional LV network protection schemes prohibit backflow of power on medium-voltage (MV) feeders
- Unlike radial systems, backflow can occur even when generation on the LV network is less than the total load
- Thus, the guidelines in existing standards (e.g., IEEE 1547.6) significantly limit DER installed capacity on LV networks
  - Up to 6.6% penetration of the annual minimum load
  - Up to 11 kW w/ aggregate limit of 2% of minimum load



Background

Why use local measurements?

1. **Budgetary constraints**
   - Adding communication or new equipment can be prohibitively expensive
2. **Space constraints**
   - Underground vaults may not have enough room for new equipment
3. **Leverage existing capabilities**
   - NP reverse power relays already rely on local measurements to calculate positive-sequence current
   - New protection schemes based on other sequence components are feasible with existing equipment
4. **Resilient to communication outages**
   - Can also provide backup protection to communication-based schemes

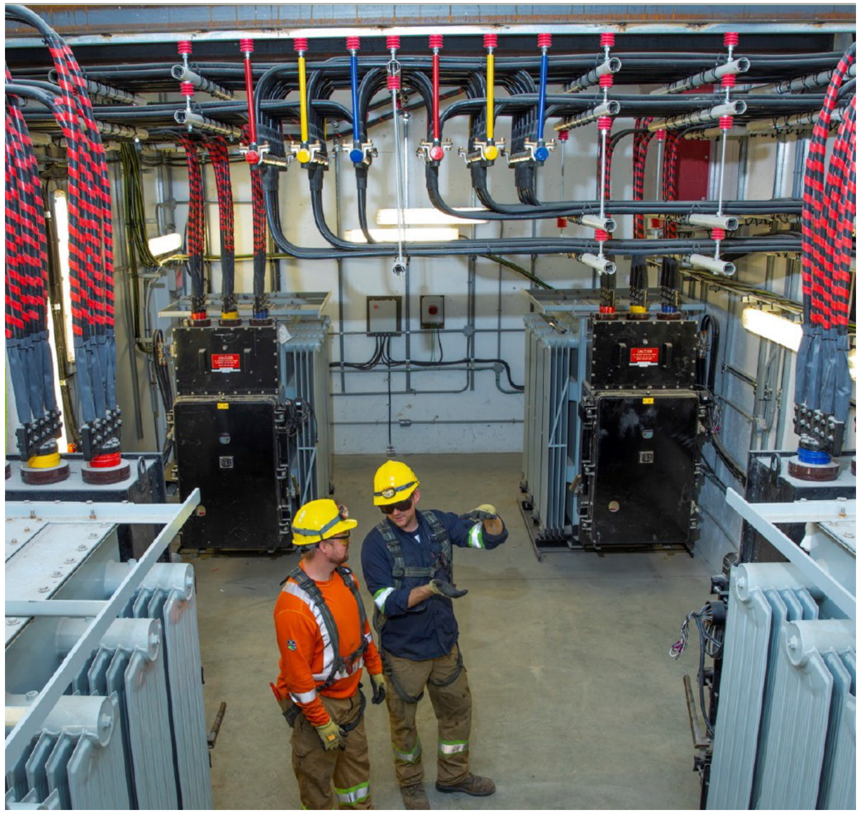


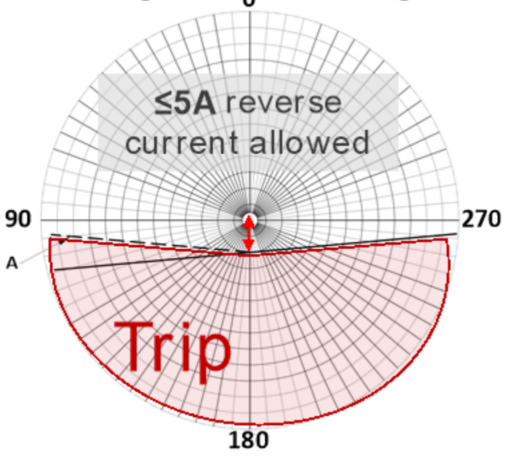
Photo courtesy of EnMax

Opportunity

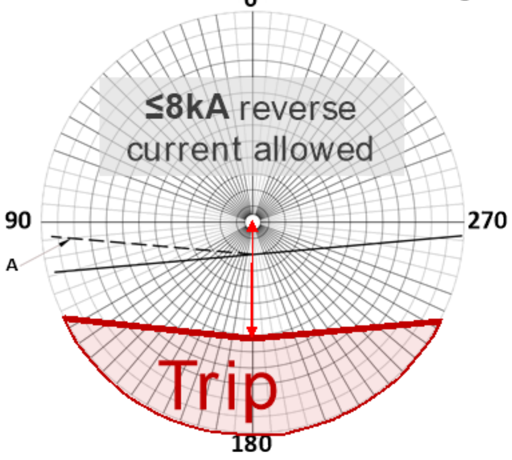
Desensitizing Relay Settings

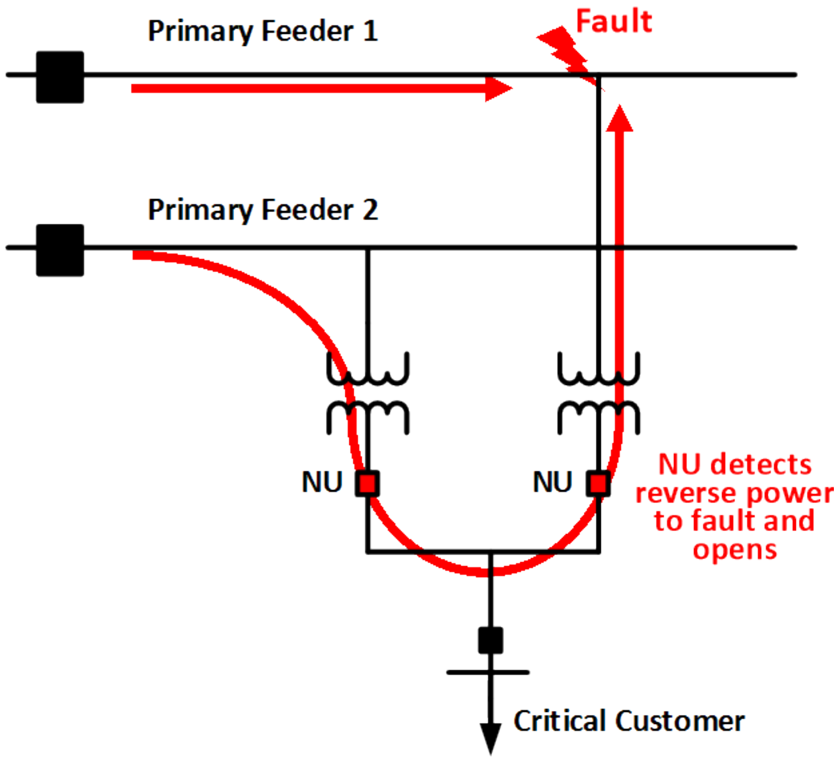
- Most fault types (LL, 2LG, 3LG) result in reverse currents that are greater than network transformer (NT) ratings
  - E.g., a NT of 1MVA/208V$_{LL}$ is rated for 8.3kA, but a LL fault causes ~10kA
- So, desensitizing would enable up to 1MVA of DER to be installed without affecting the ability to see LL, 2LG, and 3LG faults

Original Settings



Desensitized Settings



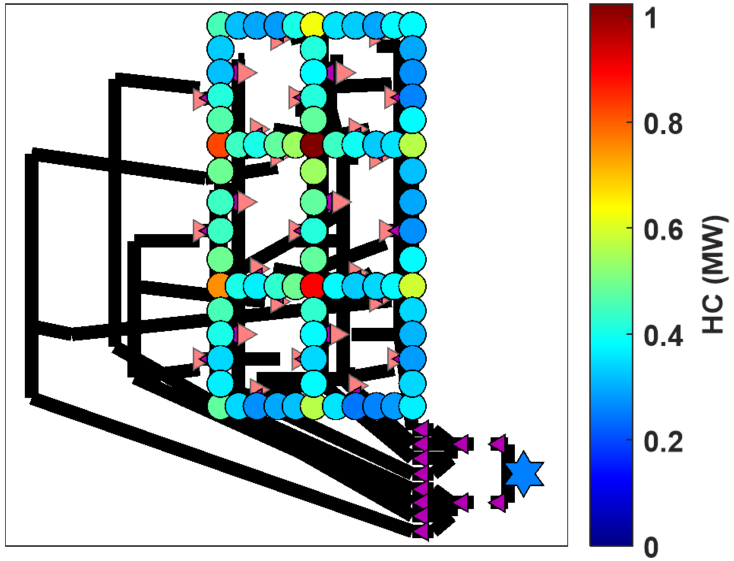


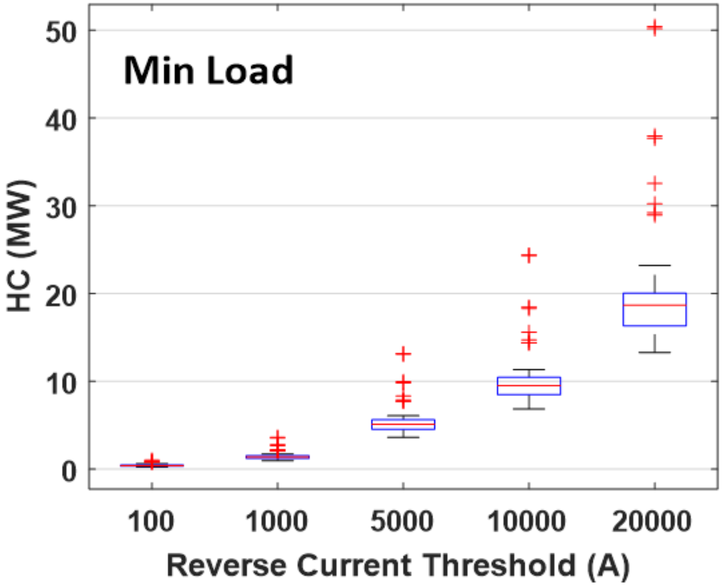
Opportunity

Under Min Loading

Desensitizing Relay Settings

Under Min Loading:
Min HC = 0.247 MW
Max HC = 1.020 MW
Mean HC = 0.413 MW



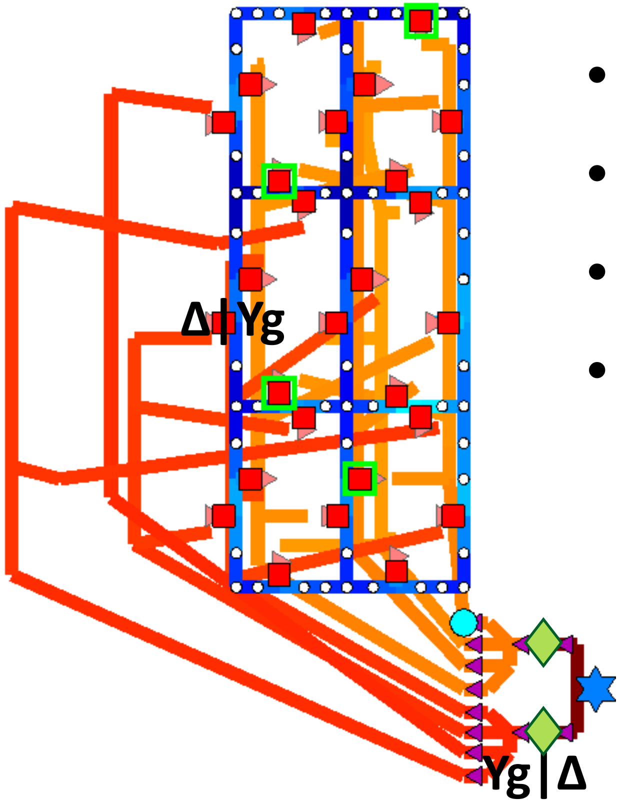


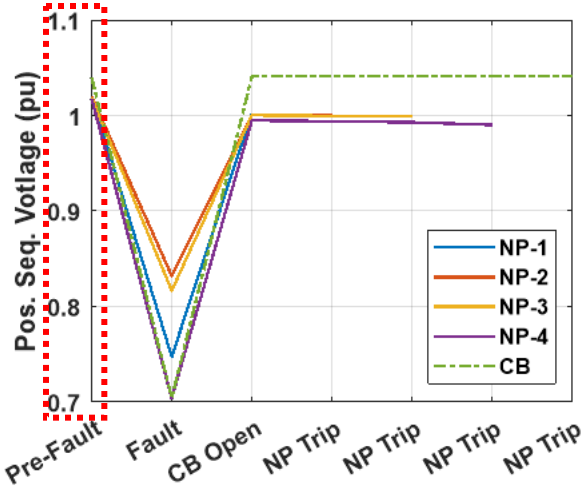
Network Transformers: Δ/Yg		Feeder							
Fault Type	**Min Pickup (kA)**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
3LG	21.498	27.921	**21.498**	25.983	27.631	28.033	27.916	34.86	34.561
2LG	10.339	13.562	**10.339**	12.619	13.546	13.751	13.772	17.218	17.170
LL	10.341	13.566	**10.341**	12.625	13.550	13.755	13.777	17.234	17.178

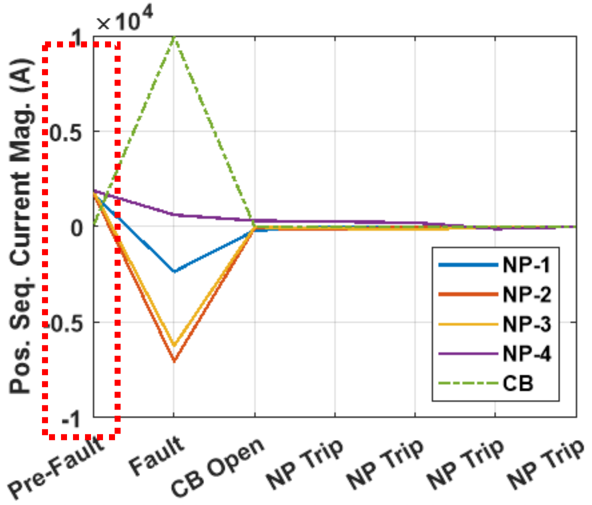
Challenge: Detecting 1LG Faults

Sequence of Events: 1LG Fault on MV Feeder

1. **Pre-fault:** nominal conditions on the modified IEEE 342-node test system
   - 8 MV feeders supply the LV network
   - Sub. Xfmrs are Δ|Yg (HV|MV)
   - Network Xfmrs are Δ|Yg (MV|LV)
   - Feeder 1 NP relays marked in green squares are shown in plots



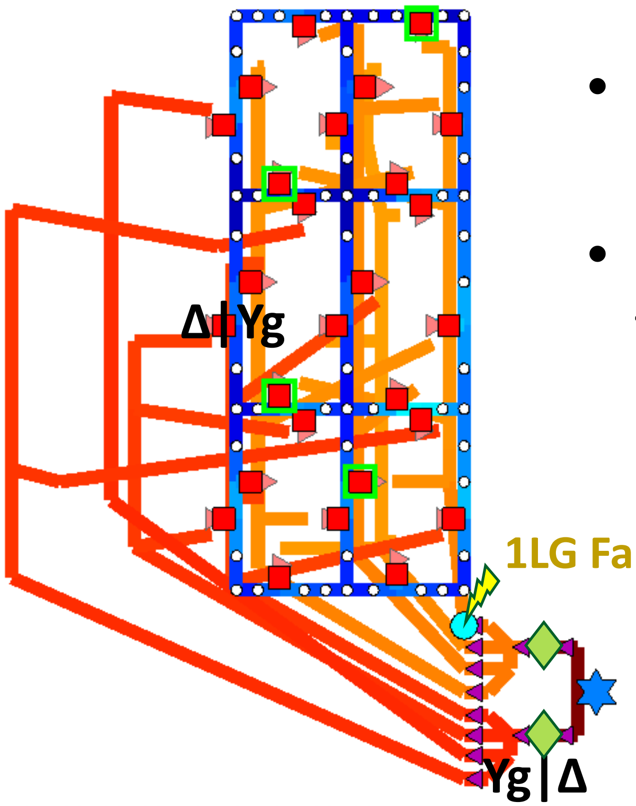


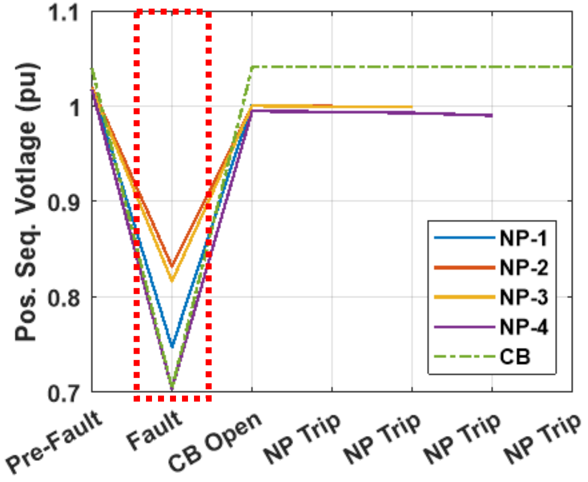


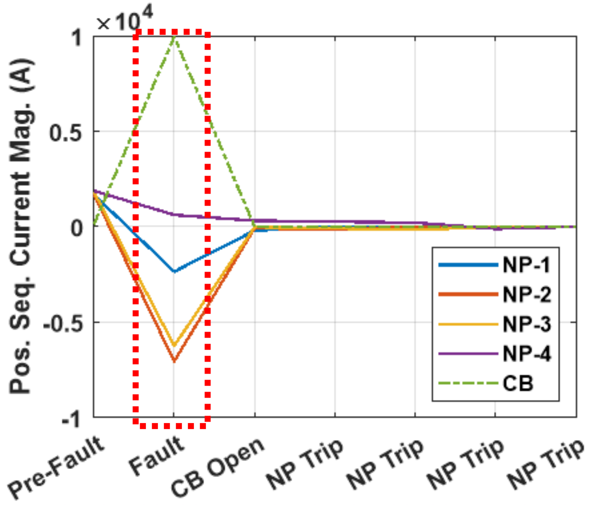
Challenge: Detecting 1LG Faults

Sequence of Events: 1LG Fault on MV Feeder

2. **Fault:** 1LG fault on MV Feeder 1
   - Positive sequence voltages dip
   - High fault current through Feeder 1 circuit breaker (CB)
   - Fault is also being fed by other non-faulted feeders through the LV network, causing reverse current through Feeder 1 NP relays



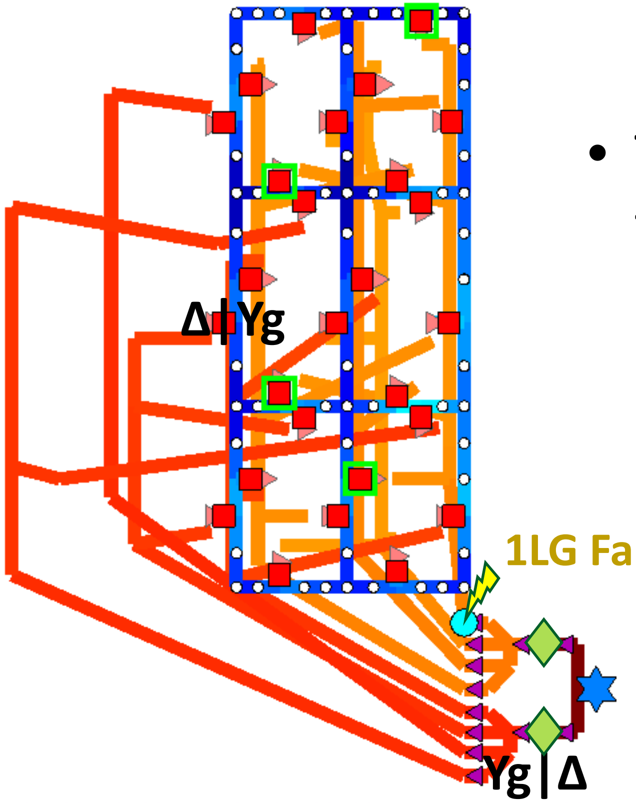


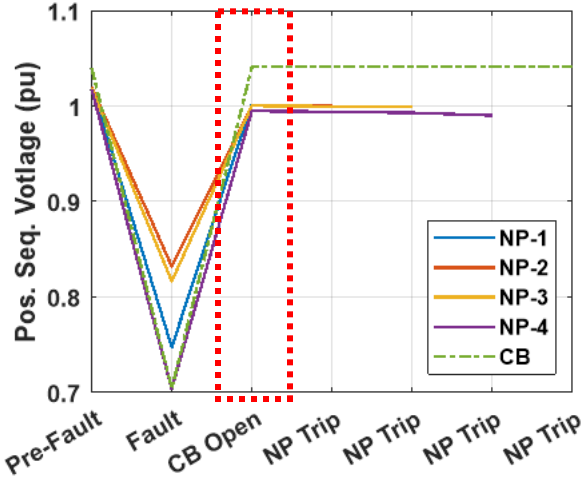


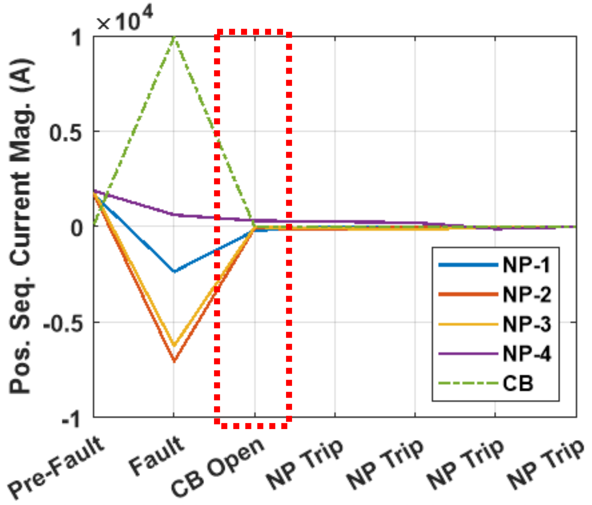
Challenge: Detecting 1LG Faults

Sequence of Events: 1LG Fault on MV Feeder

3. **CB Opens:** Feeder 1 CB Trips Open
   - For proper coordination, substation CB always operates before NP relays
   - This prevents false trips at NP relays on un-faulted feeders which may also be seeing reverse current

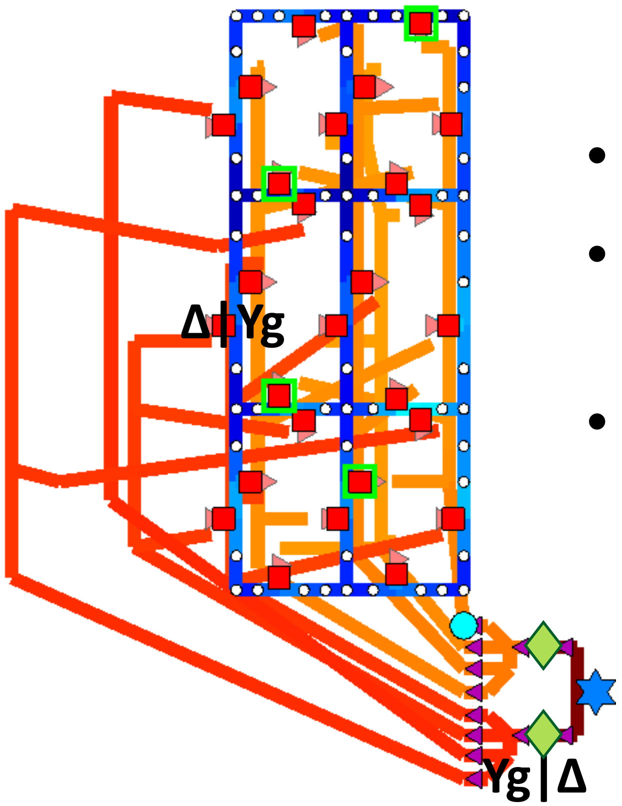






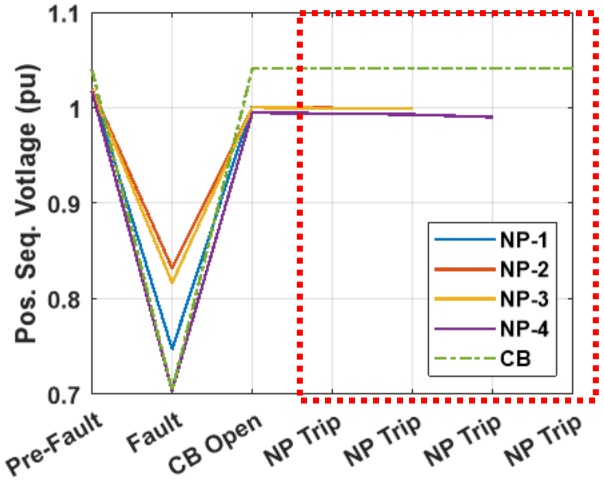
Challenge: Detecting 1LG Faults

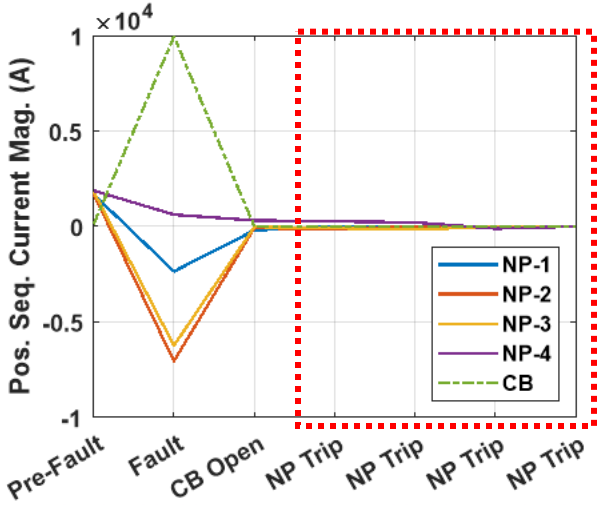
Sequence of Events: 1LG Fault on MV Feeder



4. NPs Can Trip:

- After the CB opens at the substation end of Feeder 1, there is no grounding source
- Voltage on the LV network mostly recovers
- The fault is still present, but draws little to no fault current
- Due to the sensitive reverse current pickup settings, all 4 NPs on the faulted feeder eventually trip open and isolate the fault

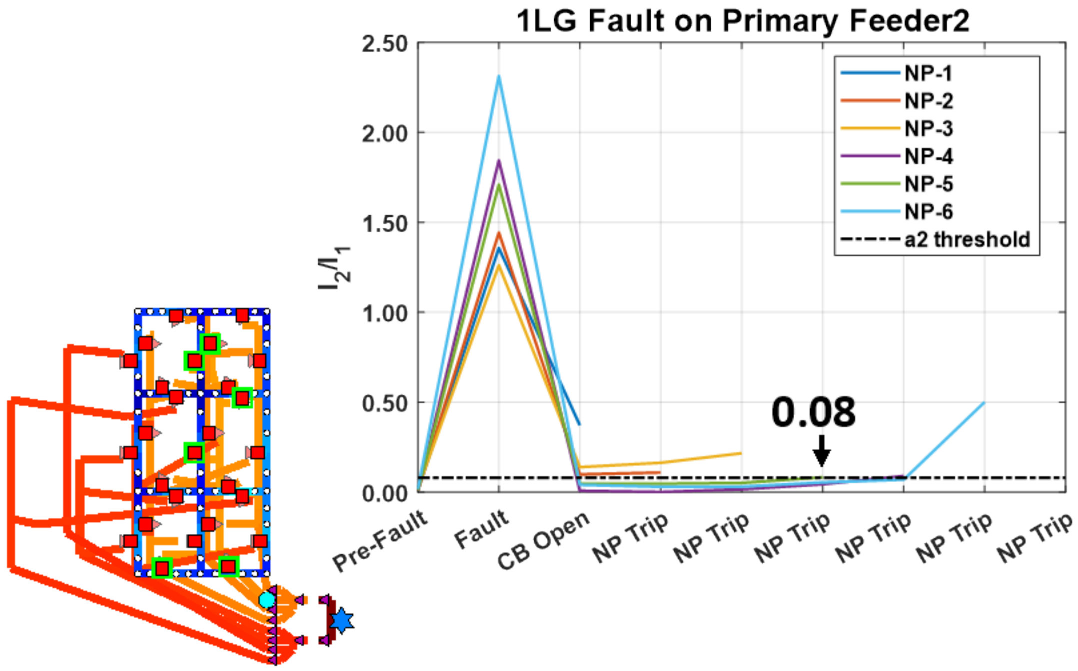


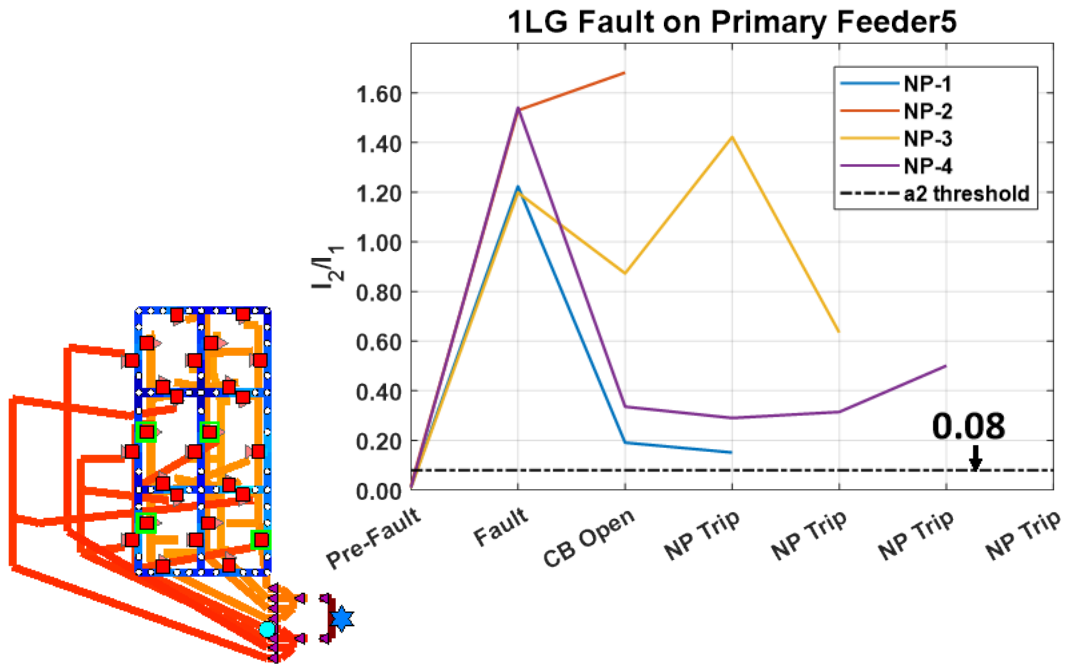


Opportunity

Detecting 1LG Faults – I_2/I_1 Method

- Normally, I_2/I_1 is near-zero, but it increases by orders of magnitude under 1LG fault conditions
- Setting a threshold of 0.08 enabled 1LG faults to be cleared on all feeders

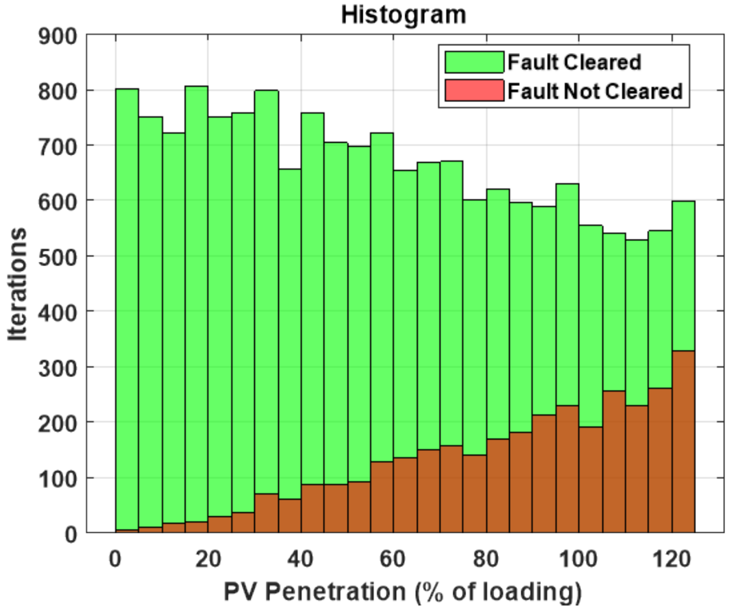


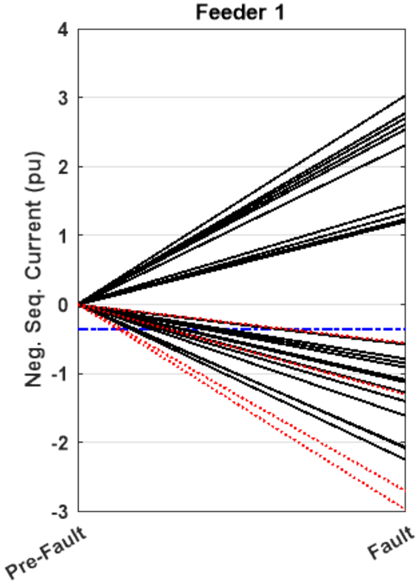


Challenge: Accommodating DERs

Detecting 1LG Faults – I_2/I_1 Method

- When DERs offset enough load, the positive-sequence current at certain NP locations may be near-zero, mimicking a 1LG fault condition
- Monte-Carlo testing showed that the probability of faults being fully cleared decreased as PV penetration was increase
- Other signals (like $-I_2$) could be used to improve performance but can't solve all edge cases

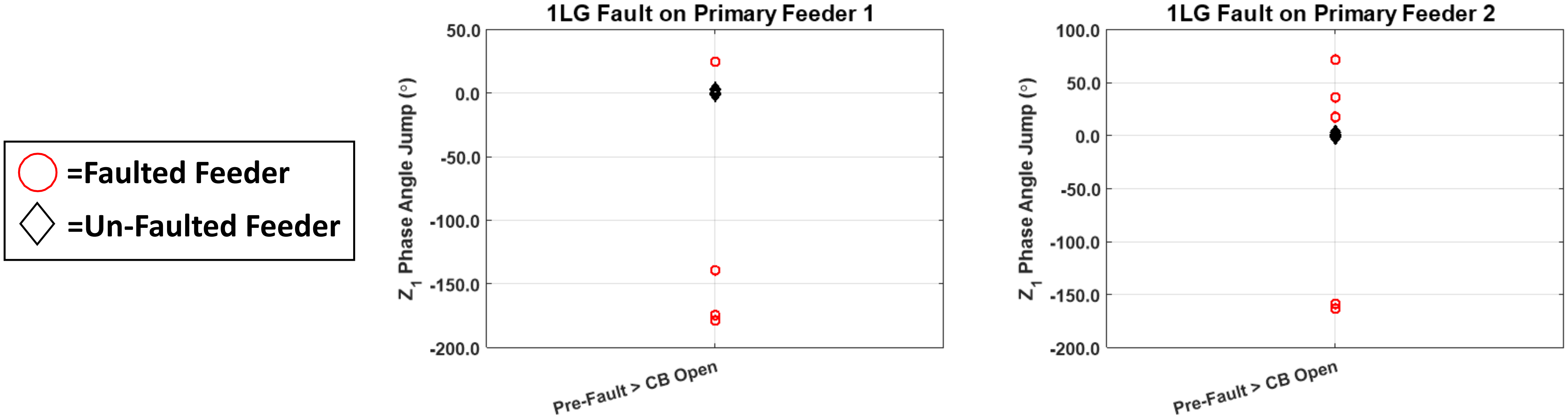




Opportunity

Detecting 1LG Faults – ∠Z_1 Phase Angle Jump Method

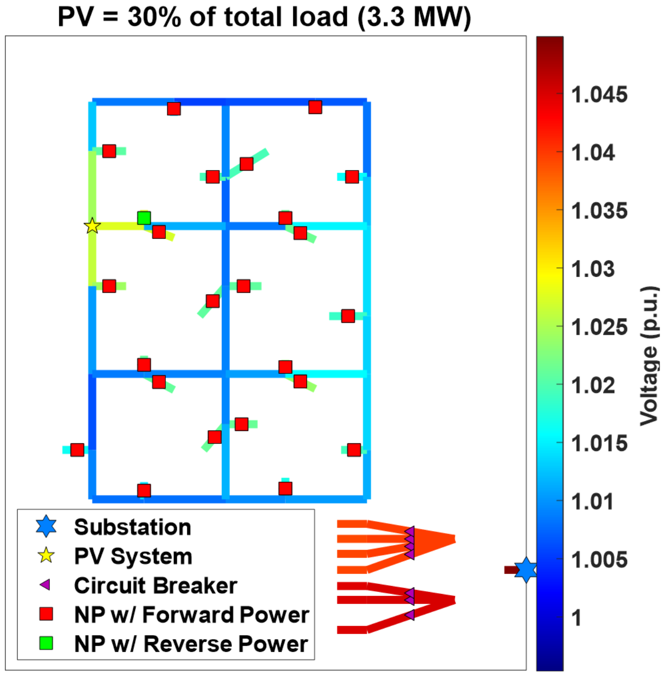
- When substation CB opens to clear a 1LG fault, the changes in phase angle of the positive-sequence impedance (∠Z_1) should be most pronounced at NP relay locations connected to the faulted feeder
- Again, -I_2 magnitude can be utilized as an arming signal, then the relay can compare the value of ∠Z1 from post-fault to pre-fault (i.e., calculate the phase angle jump)



Challenge: Accommodating DERs

Detecting 1LG Faults – $\angle Z_1$ Phase Angle Jump Method

- Further testing required, but same issue with DER causing “zero-crossings” may cause trouble
- Possibly sensitive to other transients, such as large loads turning on/off or other switching events



Conclusions

- Desensitization can increase DER hosting capacity in LV networks but detection of 1LG faults remains a challenge
- Local detection using sequence components can work in most cases (e.g., no DER or high DER export) but “zero-crossings” cause issues
- Other methods are under development (i.e., communication-based) that would not be impacted by “zero-crossings”
- Local detection presented here may still be good enough to provide back-up protection during communication outages

Questions?

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