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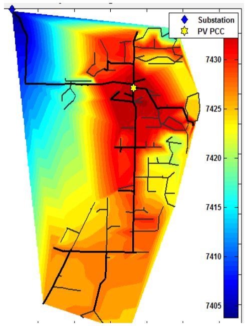

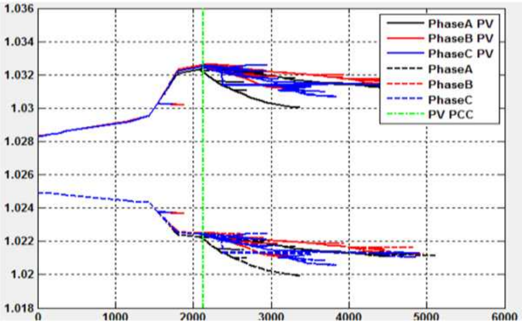

PV Distribution System Impacts Part 2

UVIG Contemporary Grid Issues for Photovoltaics

Matthew J. Reno

Sandia National Laboratories

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

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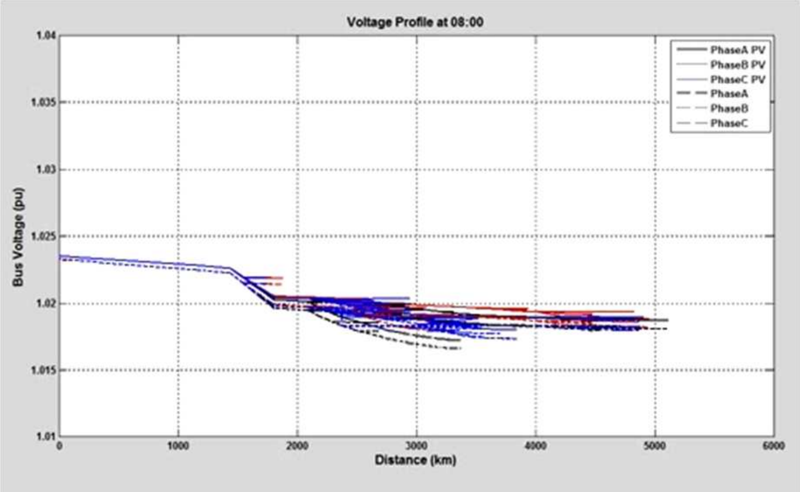
Outline

- Introduction
- PV Impacts to Distribution System Protection
- Low Voltages Caused By PV
- Determining a Feeder’s PV Hosting Capacity
- Results of PV Hosting Capacity
- Conclusions

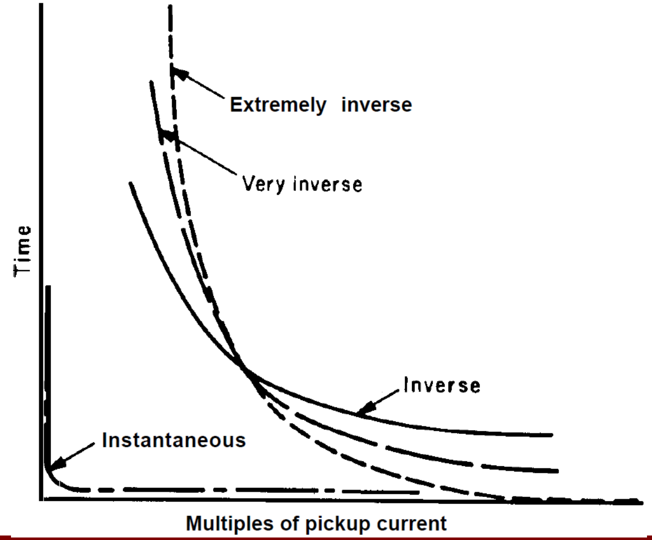
Introduction

- High penetrations of PV on a distribution system can impact power quality, reliability, and the standard grid operation
  1. Designed for radial flow in one direction from the substation
  2. Designed for aggregated loads with little short-term variability
- Distribution system impacts
  - Voltage Regulation Device Operations
  - Steady State Voltage (High or low voltage)
  - Voltage Flicker
  - Protection Coordination



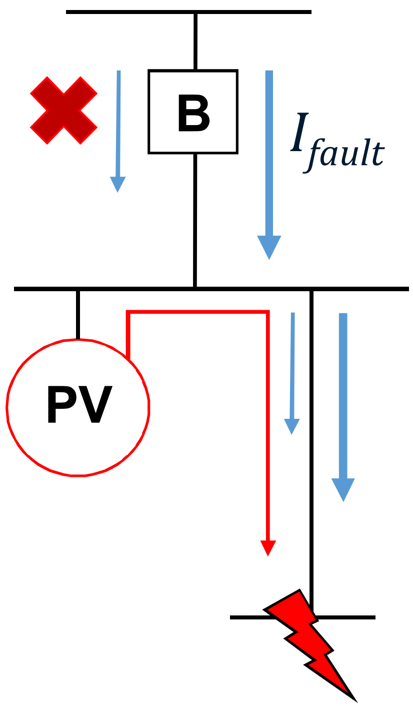
Distribution System Protection

- Objective of protection systems and equipment is to maintain safe operation of the grid and reliable service
  - Must rapidly and automatically disconnect the faulty sections of the power network
  - Minimize the disconnection of customers
- Conventional distribution system protection is done with over-current protection – fuse, breaker, recloser
  - Could be instantaneous overcurrent or time-overcurrent operating on time-current curve (TCC)
  - Easy to setup and coordinate for radial distribution system with single source (substation)

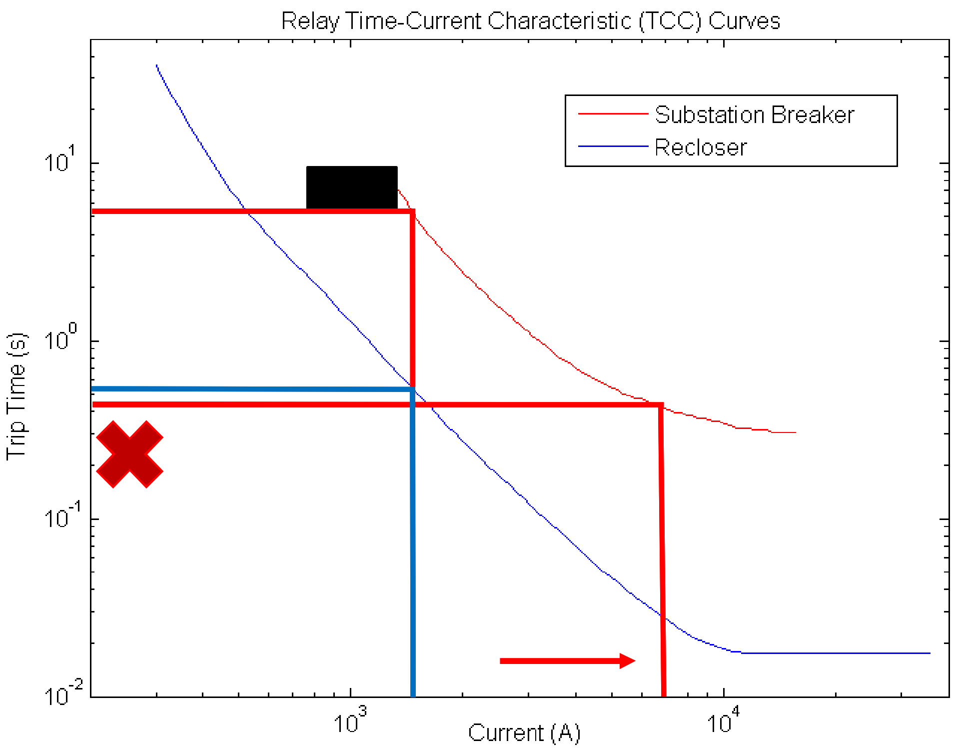


PV Impact on Protection

Under-Reach

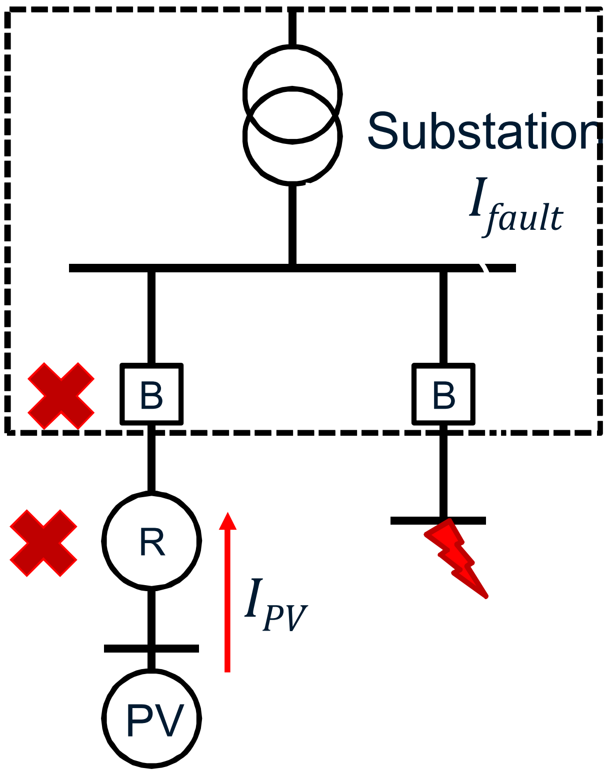


Coordination Loss

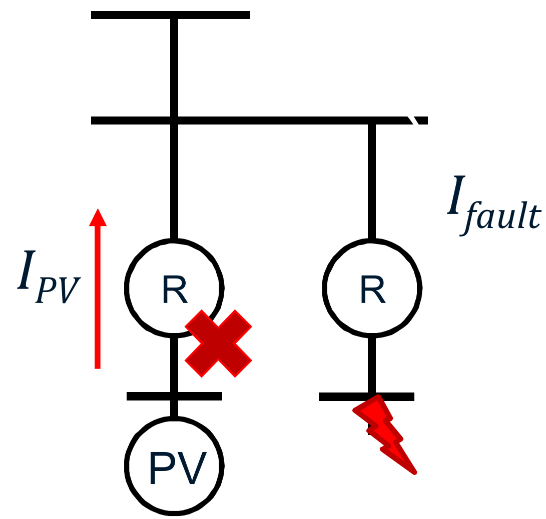


PV Impact on Protection

Sympathetic Tripping



Nuisance Tripping

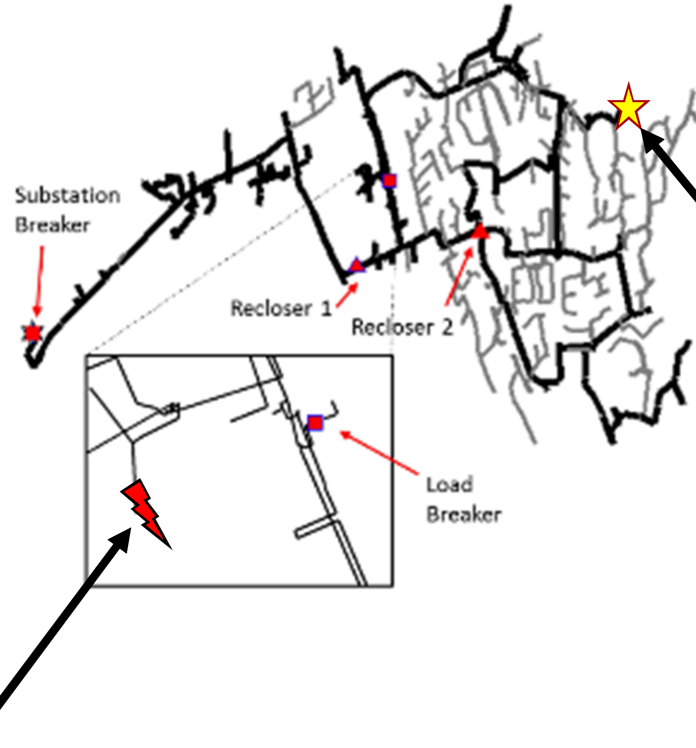


Protection Analysis

Example of Real Feeder Circuit

Faults to be placed at:

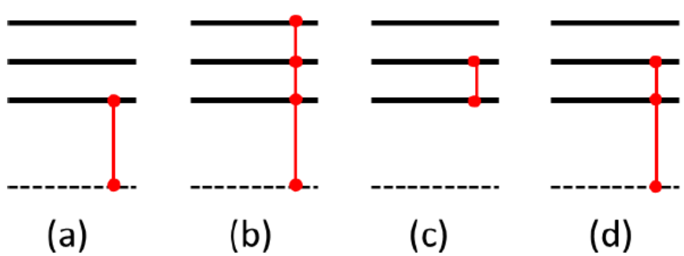
- 1168 1ϕ buses
- 608 2ϕ buses
- 583 3ϕ buses



583 suitable PV placements

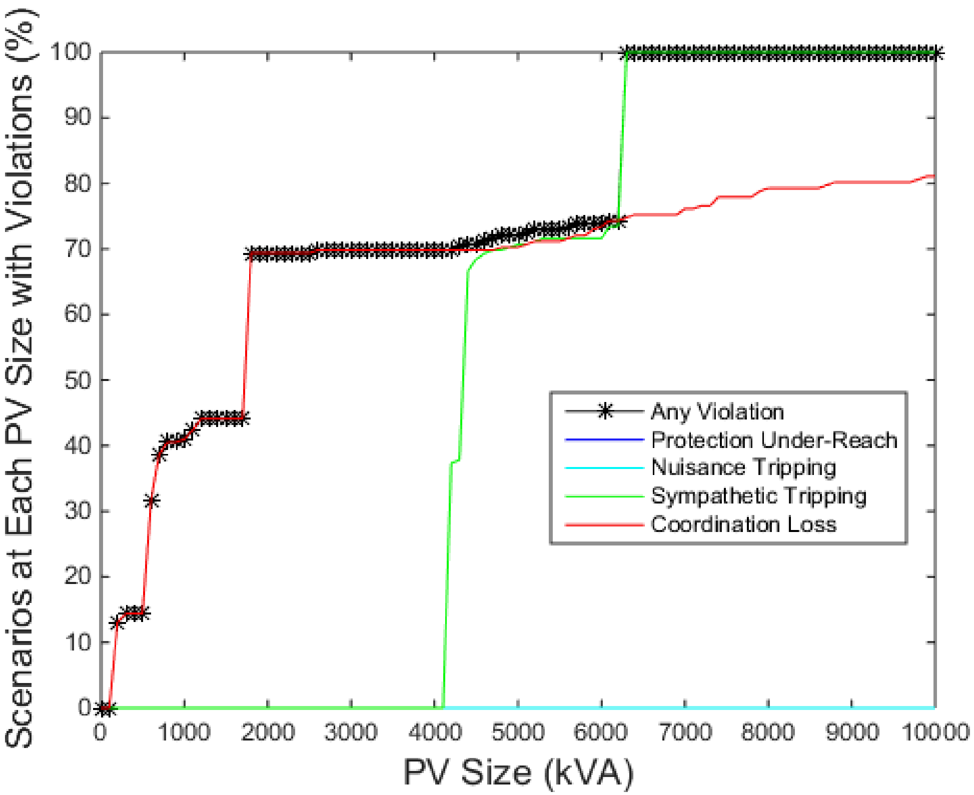
- 1,375,297 solves
- **8.52 hours to only test one PV size!**

Fault Types Tested



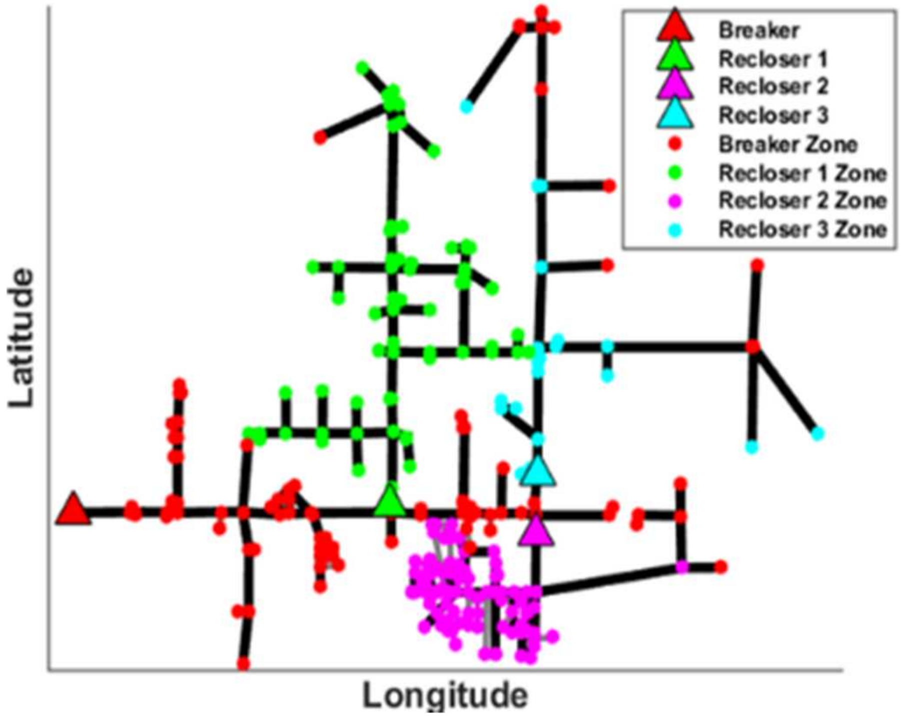
a) Single-phase-to-ground
b) Three-phase-to-ground
c) Phase-to-phase
d) Two-phase-to-ground

Protection Case Study



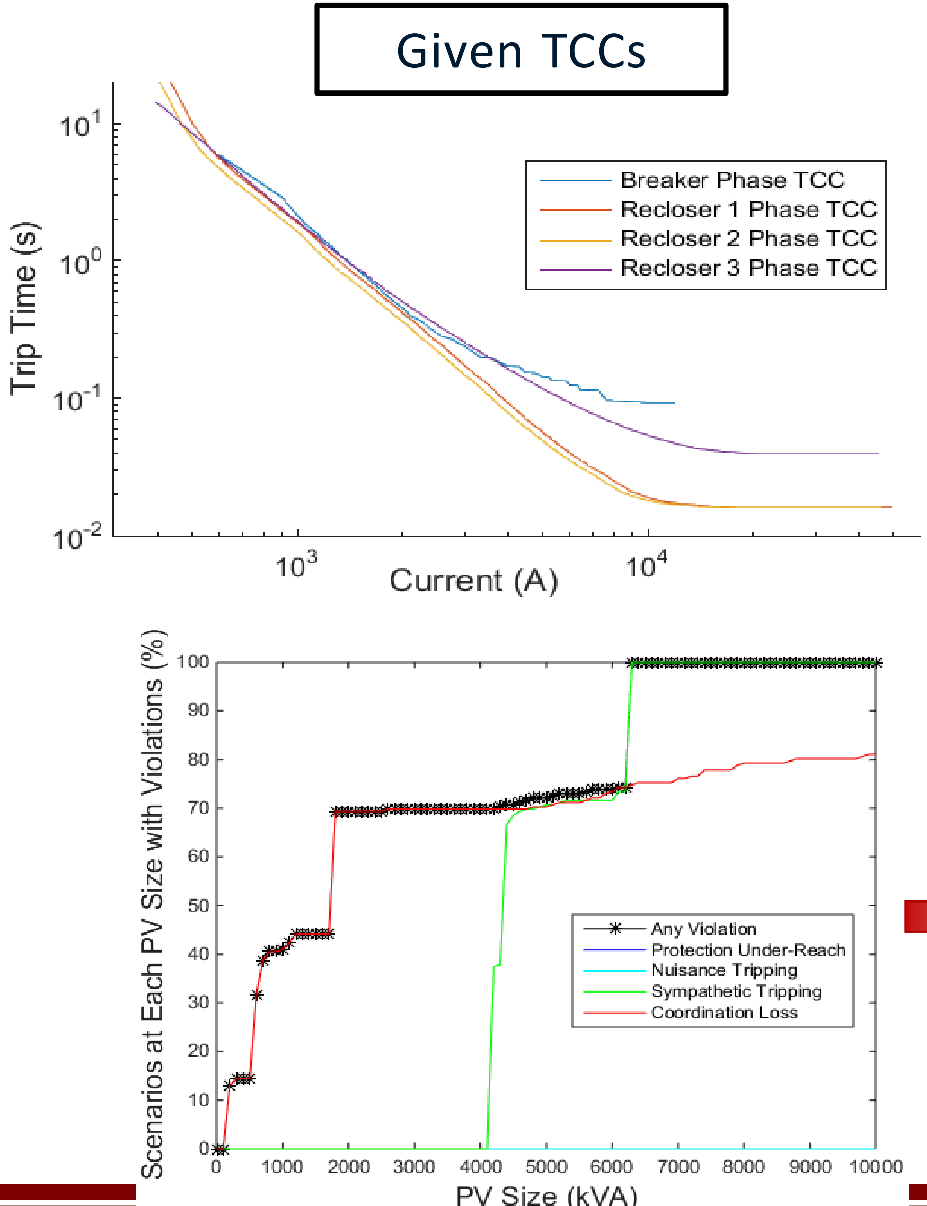
Hosting capacity summary

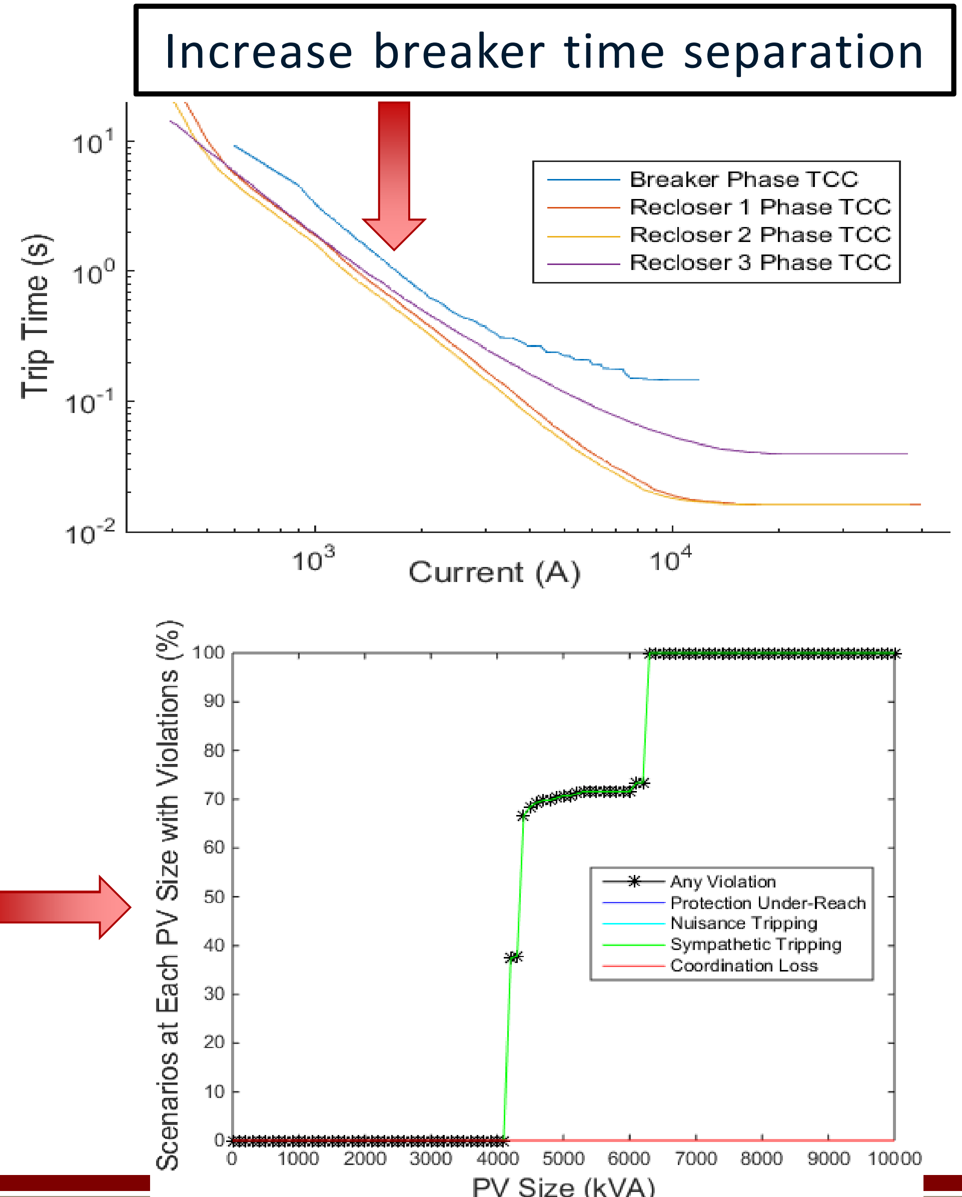
Distribution Feeder QS1



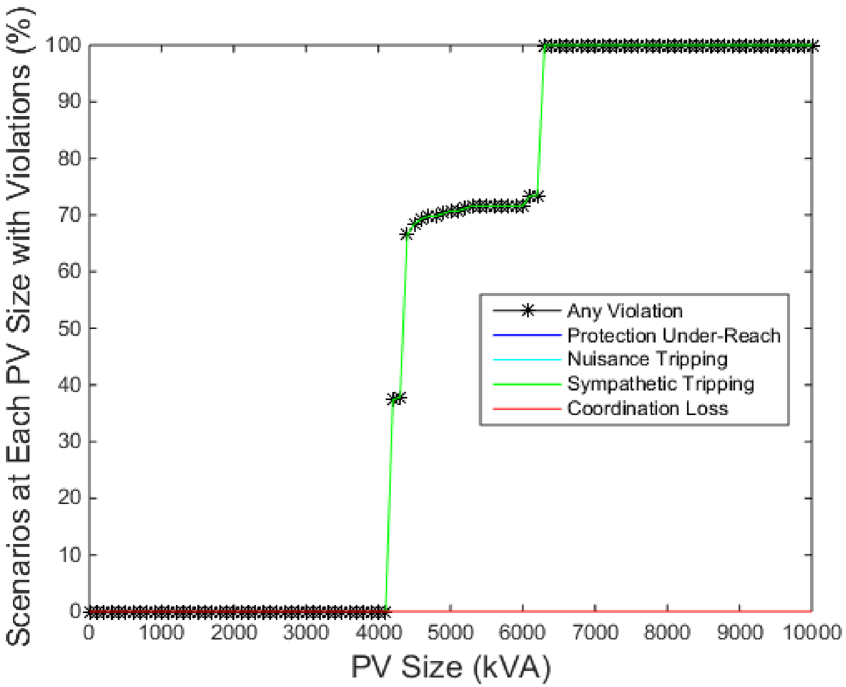
Base case tripping zones

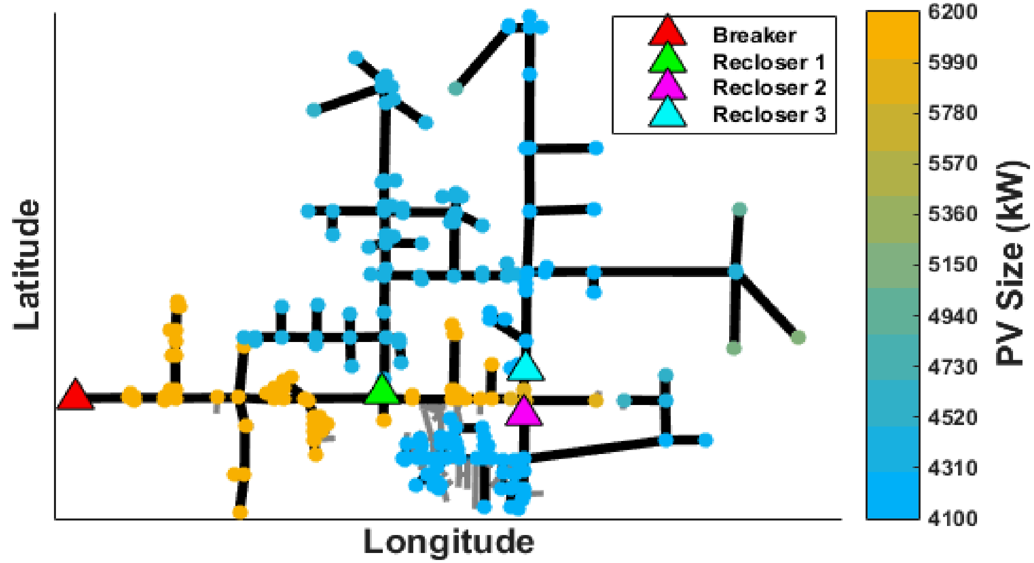
Protection Case Study

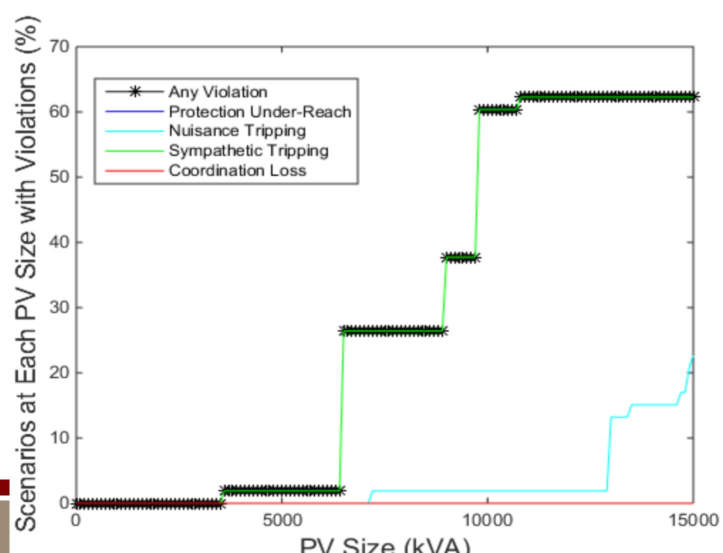




Sympathetic Tripping







Limited Impact on Protection

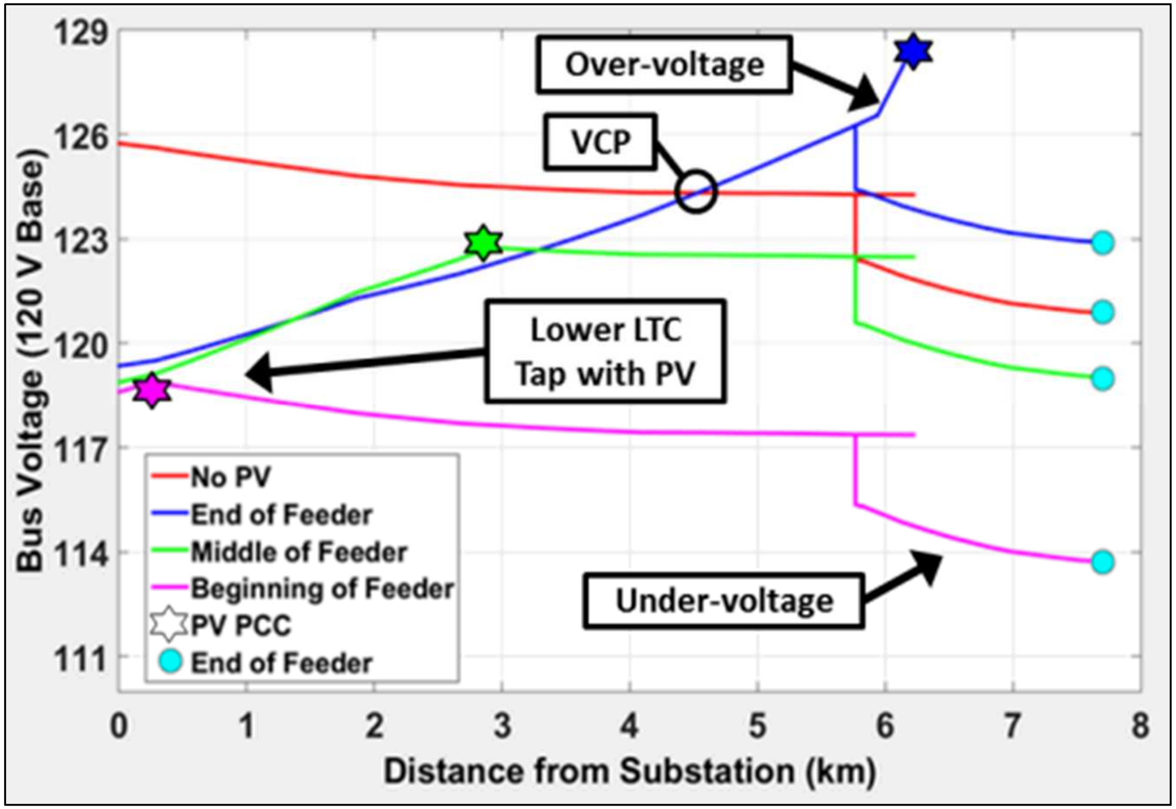
- Under-reach
  - Devices are generally set to detect faults at twice the impedance to the end of the feeder (pickup is set to less than half the expected end-of-line fault current). Therefore PV would need to inject half of the normal substation fault current (generally thousands of amps)
  - For single-line-ground faults, depending on the grounding, the PV still injects fairly balanced fault current, so the reverse current or ground current still trips the breaker
- Sympathetic and Nuisance Tripping
  - Requires that the adjacent breaker on the faulted section is much slower so that it does not trip first, even though it has significantly more fault current
- Coordination Loss
  - PV increases the fault current in the downstream device. This should never cause issues for break/recloser coordination.
  - Only an issue for fuse saving schemes

Low Voltages Caused By PV

- The common concern with PV is high voltages due to the PV injection. In certain cases, PV can create low voltages, even at unity power factor
- This situation only occurs on distribution systems with voltage regulators that include load drop compensation (LDC).
- Using current measurements, the LDC raises the voltage on the feeder at high load and reduces the voltage at low load
- PV masks the load on the feeder, hiding the potential voltage drop from the voltage regulators
- With high penetrations of PV, the LDC lowers the feeder voltage, potentially causing under-voltages at high load times

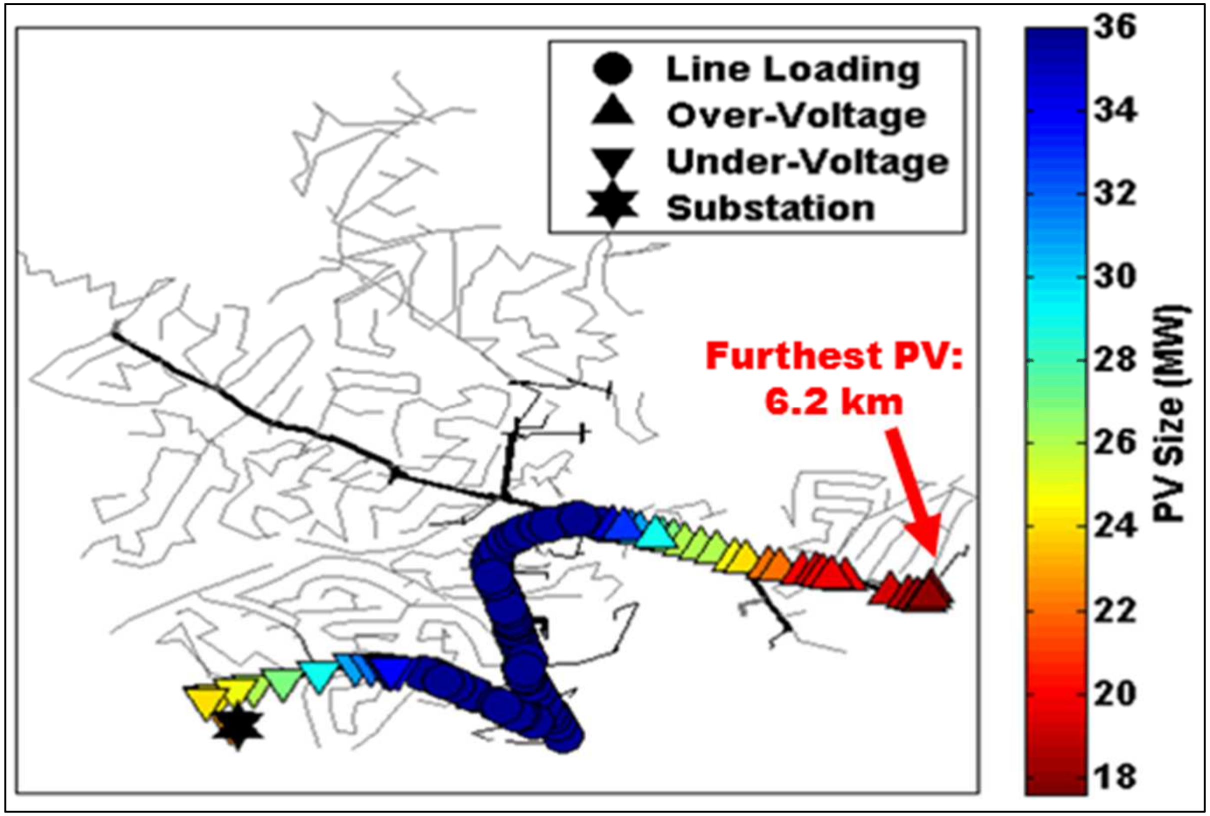
Low Voltages Caused By PV

- Ckt24 voltage profiles for basecase and with 25 MW PV near the beginning, middle, and end of feeder with LDC on the LTC.



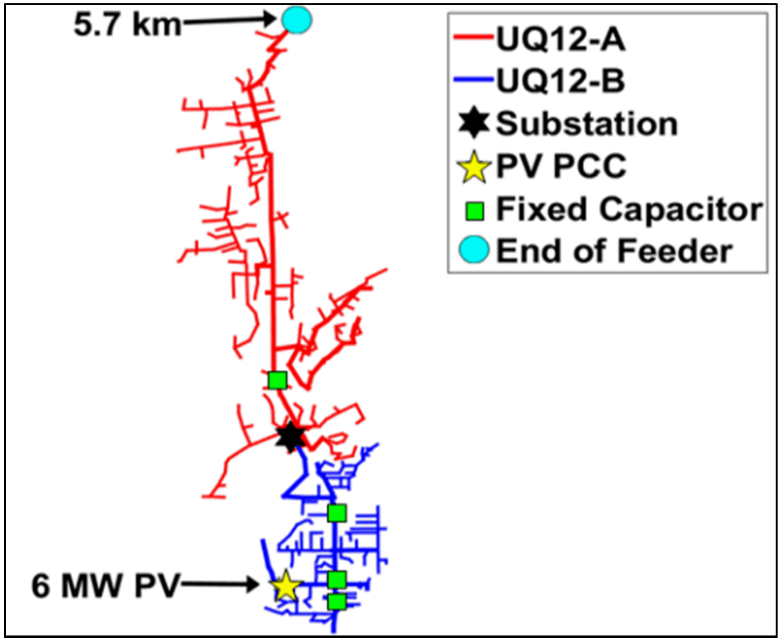
Low Voltages Caused By PV

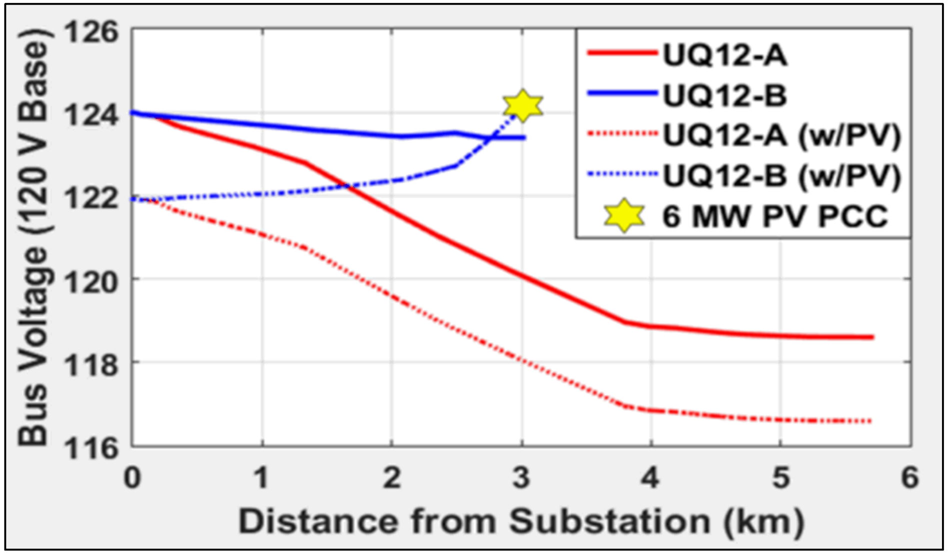
- Limits the hosting capacity
- Cannot be mitigated using advanced inverters (volt/var)



Low Voltages on Adjacent Feeders

- Can cause low voltages on adjacent feeders served by the same substation transformer
- Potentially could have over-voltages on the PV feeder and under-voltages on adjacent feeder





Low Voltages Conclusions

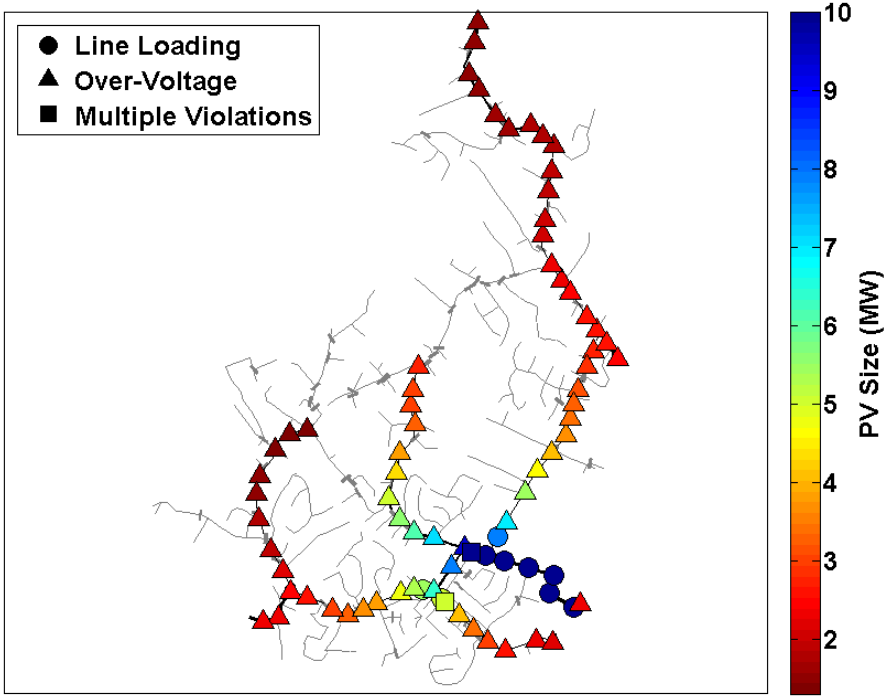
- Advanced inverter voltage regulation functions cannot mitigate PV-induced under-voltages, since they do not occur at the PCC
- Only mitigation of under-voltages is to remove the LDC
- PV-induced under-voltage depends on interconnection location and magnitude

Hosting Capacity Overview

- Hosting Capacity: the maximum amount of PV that can be accommodated on a feeder without impacting reliability
- Locational Hosting Capacity: the maximum allowable PV size that can be interconnected at a given bus on the feeder
- Evaluates PV impact on the grid (voltage, regulation equipment, protection, thermal loading/reverse power)
- Better understanding of when, where, and why problems might occur on a feeder, and what are the limiting factors
- Examples:
  - EPRI's DPV analysis – stochastic simulation of distributed PV
  - Sandia's Feeder Impact Risk Score Technique (FIRST) – comprehensive analysis of large utility-scale 3-phase systems

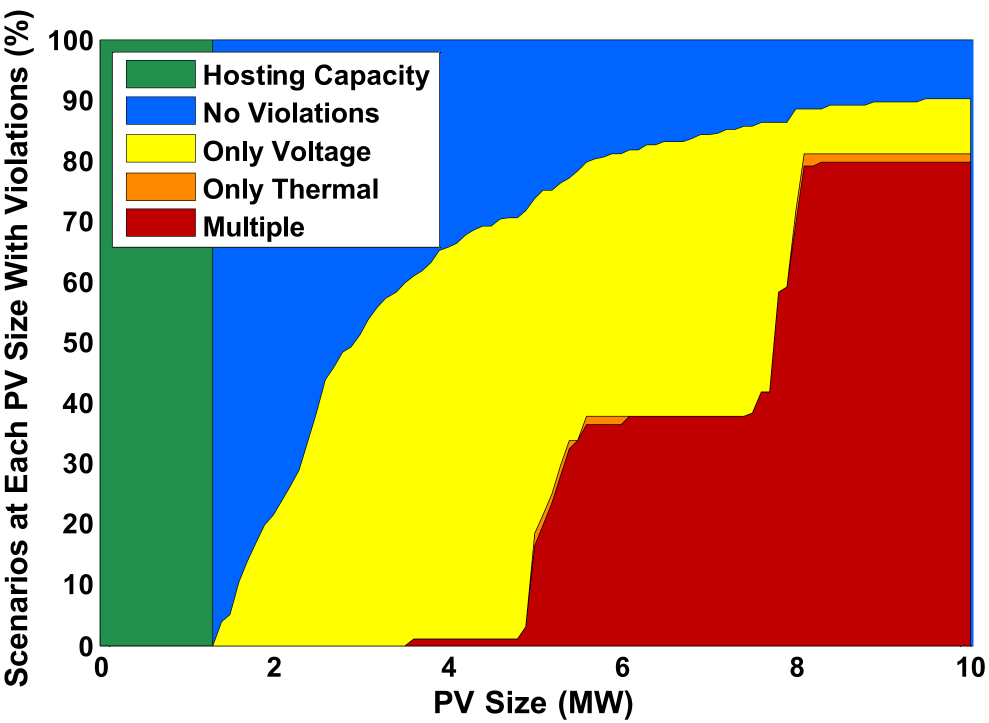
Hosting Capacity Methodology

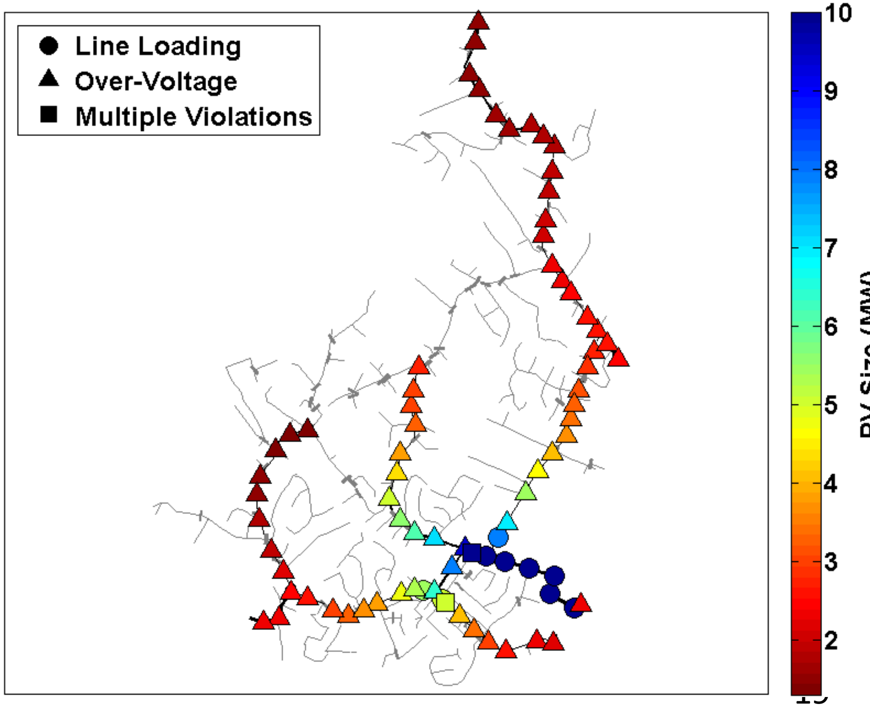
- Detailed analysis of a large number of potential PV scenarios (combinations of PV size and location) to determine if there is any impact to the operation of the distribution system
- For each PV scenario, a series of simulations are performed in OpenDSS to detect any potential violations caused by the PV interconnection
  - Range of feeder load values that occurred during daytime hours of 10am to 2pm in the year
  - Range of all potential states of the feeder (regulator taps and switching capacitor states)
  - Temporary over-voltages are considered with extreme ramps in PV output faster than the voltage regulation equipment can react



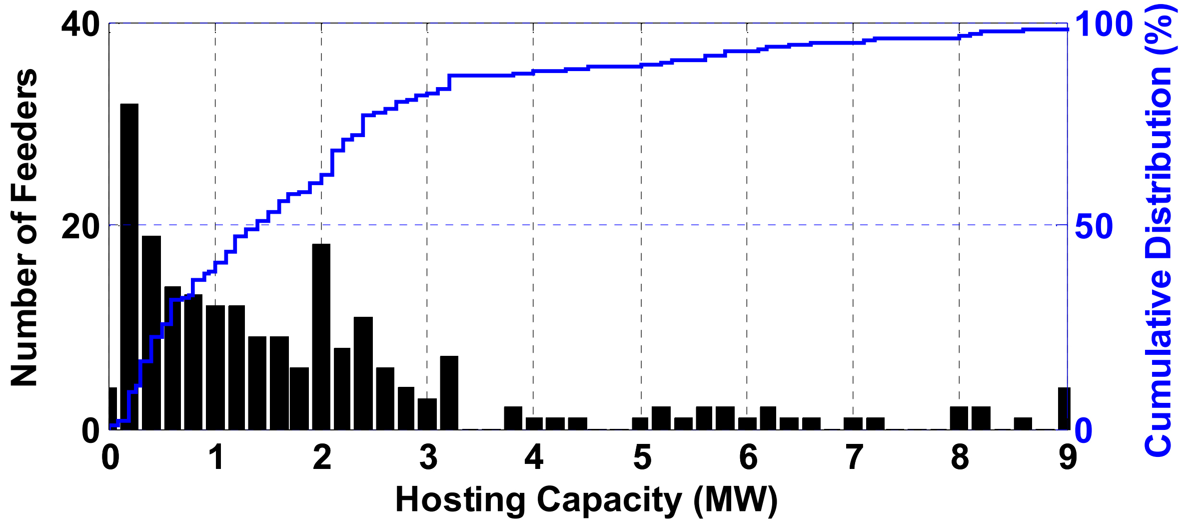
Hosting Capacity Results

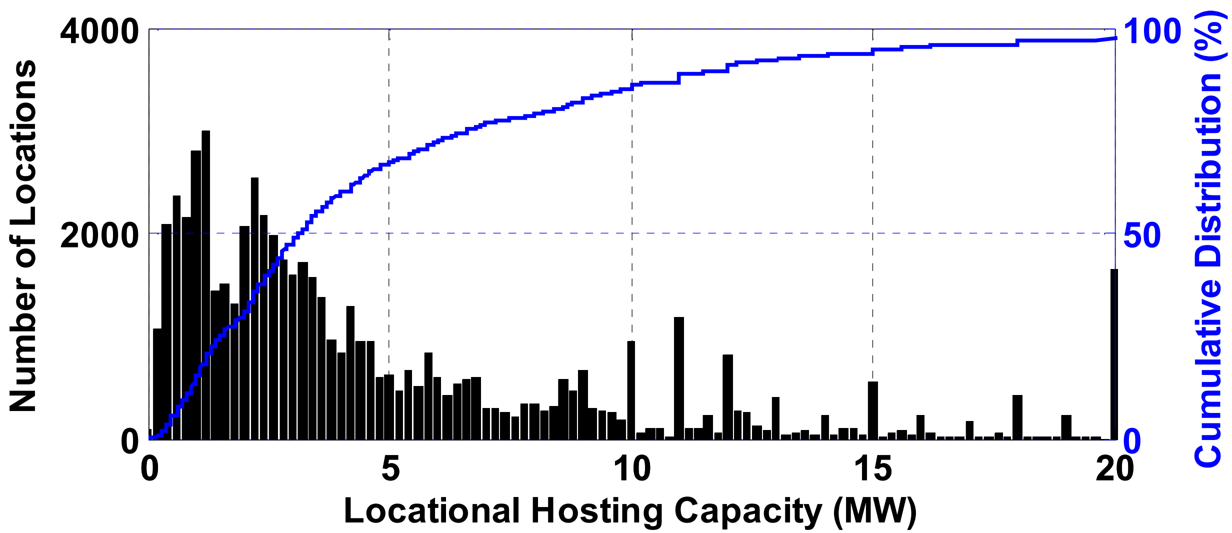
- The hosting capacity and feeder impact signature is determined for each feeder
- This includes a percentage of the feeder that can handle that size PV system, and what type of issue was caused (risk)



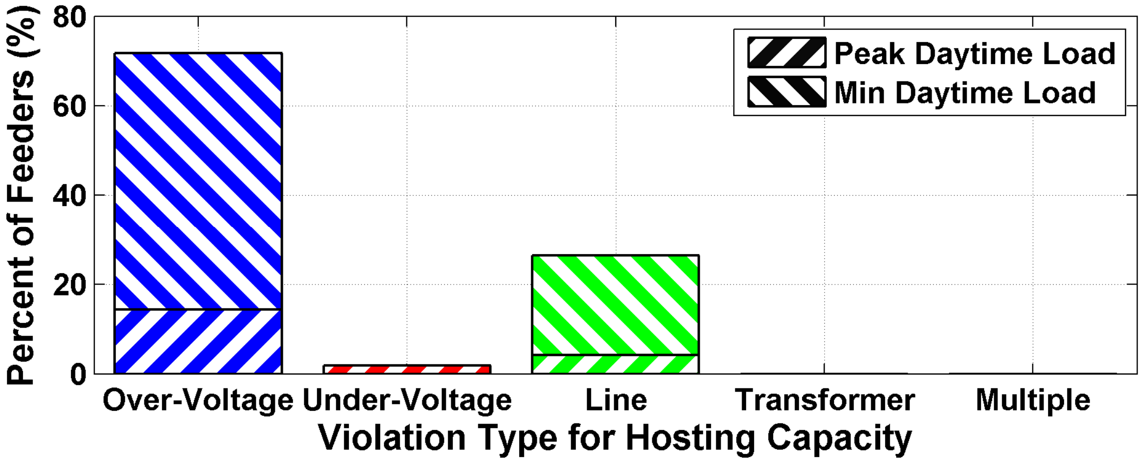


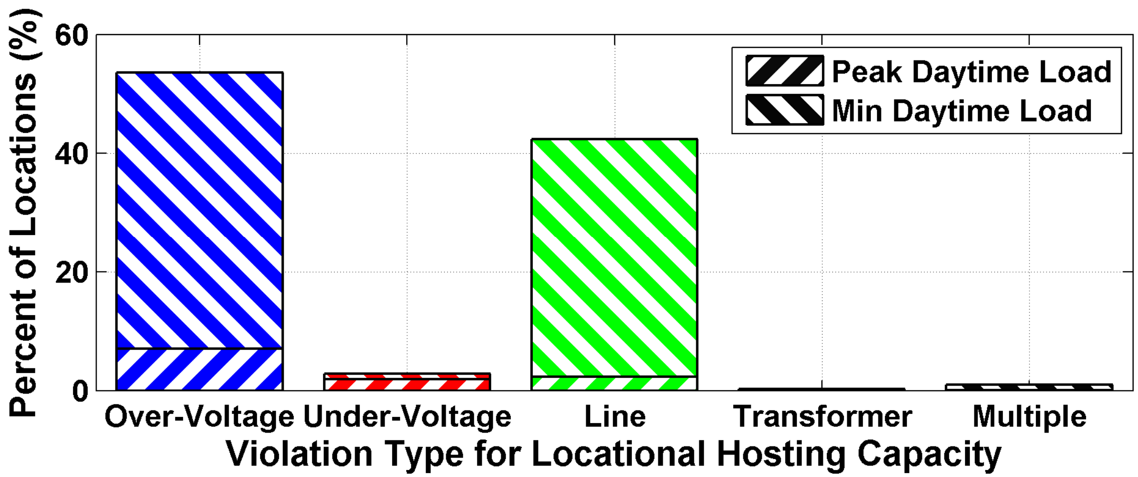
Hosting Capacity of 216 Feeders



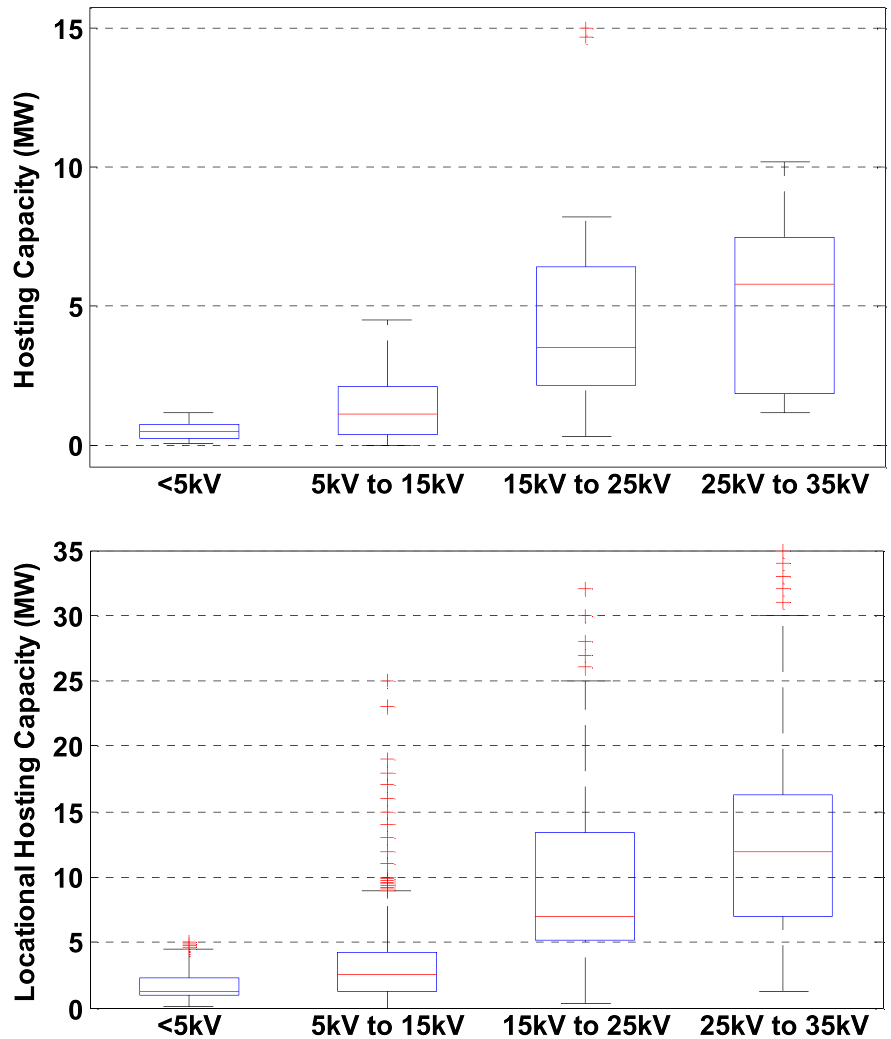


Limiting Factor that Determines HC





Correlation with Voltage Level



Conclusions

- PV impact on the system protection is a major concern to utilities. The impact depends on the original protection design and coordination separation.
- PV on feeders with load drop compensation (LDC) can create low voltage situations. Advanced inverters cannot mitigate PV-induced under-voltages.
- Hosting Capacity (HC) evaluates PV impact on the grid and the maximum PV that can be interconnected. Compiling HC results from a large number of feeders provides a better understanding of when, where, and why problems might occur on a feeder, and what are the limiting factors

QUESTIONS?

Sandia National Laboratories

Matthew J. Reno

mjreno@sandia.gov