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Voltage Regulation with Customer-Sited Resources

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Julieta Giraldez

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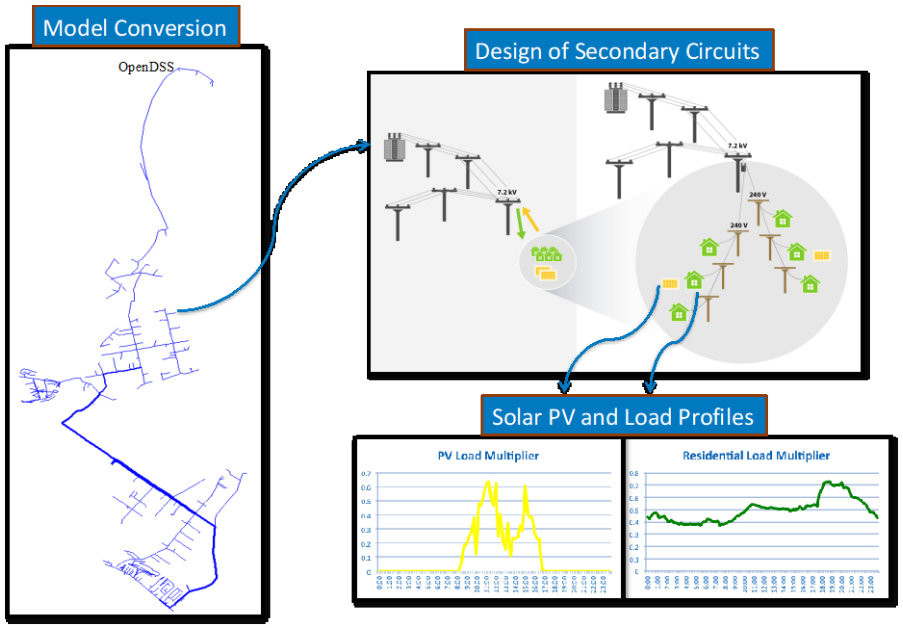
HECO/NREL CRADA -Voltage Regulation Operating Strategies (VROS) Project

- **Objective**: simulation of feeder operations with advanced inverter grid support functions (GSF) to understand operational and customer curtailment impacts
- **Approach**: Add secondary circuits to two HECO feeders and use of annual quasi-static time-series analysis with various GSF (volt-VAR, constant power factor (CPF) and volt-watt) and varying PV penetration levels
- **Metrics**
  - Annual energy PV curtailment to all rooftop PV customers with advanced inverters
  - Increase in reactive power demand at the feeder-head from GSF
  - DeltaV metric for the highest-voltage week of the year



$$\Delta Vratio = \frac{V_{\max,AI} - V_{\min,AI}}{V_{\max,baseline} - V_{\min,baseline}}$$

Summary of Findings from VROS Study

- **Final report**
  - https://www.nrel.gov/docs/fy17osti/68681.pdf
- **Volt-Var benefits over CPF 0.95**
  - Volt-Var is always as effective or more than CPF 0.95 in reducing over-voltages
  - Volt-Var results in significantly less reactive power absorption (good for utilities)
  - Volt-Var results in less PV kWh curtailment (good for customers)
- **Activating GSF in rooftop PV systems**
  - With reactive power priority, as opposed to active power priority, is recommended to avoid momentary over-voltages
  - Have no adverse impact in legacy utility voltage regulation equipment
  - Do not fix voltage violations due to existing legacy PV systems with no GSF

Summary of Findings from VROS Study

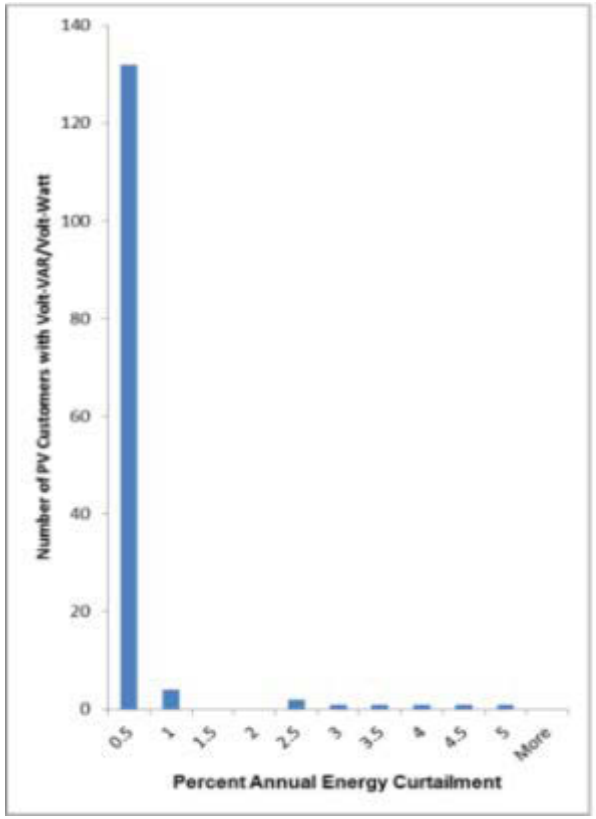
- **Volt-Var is recommended to be used in combination with Volt-Watt to protect the system from over-voltages**
  - Results in more total customers able to interconnect
  - Can avoid the need for traditional upgrades

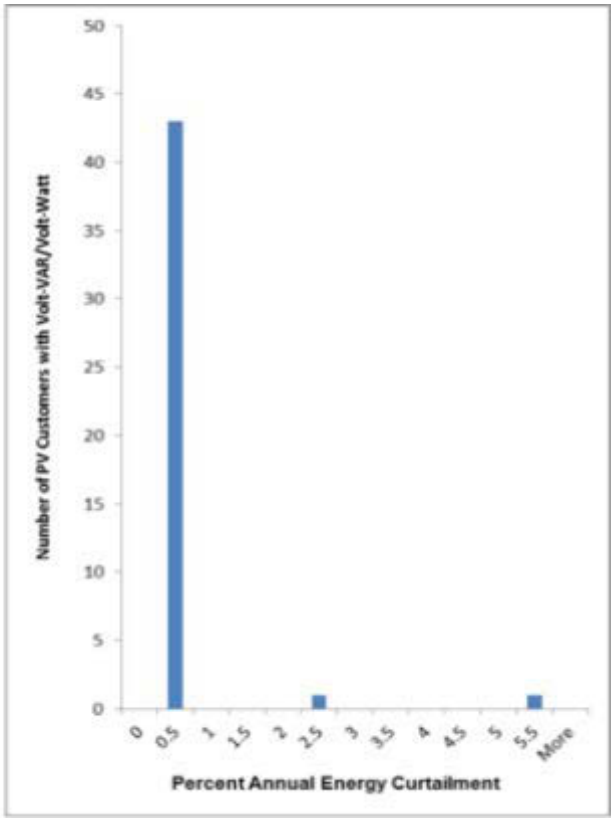
➢ Max. PV curtailment values much lower than expected

➢ Volt-Watt showed minor increase in PV curtailment

➢ Annual curtailment < 0.5% for 95% of customers

➢ Annual curtailment < 5% for remaining 5% of customers





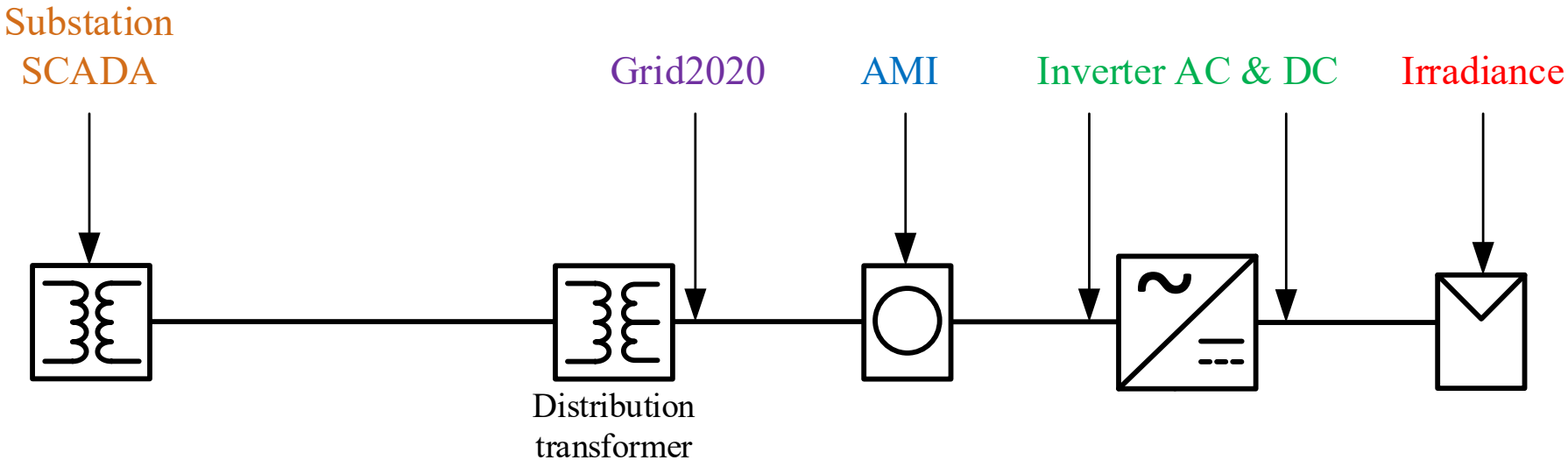
Caveats and Additional Scope

- Secondary low-voltage circuits are approximated and modeled up to the customer meter, but further voltage drop/rise could occur between the meter and the PV system generator terminals
  - *The field data from the advanced inverter pilot project is expected to calibrate* ***and validate the findings of this VROS Project, including analyzing the behind-the-meter voltage rise impacts on kWh curtailment***
- PV penetration cases include all PV systems interconnected with the ability to export (as in NEM or customer-grid-supply (CGS) tariffs offered by the Companies')
  - *BS modeling including customer-self-supply*
- DER Parties concern about % customer energy reduction
  - *BS and load control impact on kWh curtailment*
  - *Update future scenarios with non-exporting tariffs (VROS models all PV systems exporting!)*
  - *Pilot project to verify kWh reduction from Volt-Watt*

Advanced Inverter Pilot Project Overview

- NEM customers offered ability to connect without paying for secondary system upgrade in exchange for participating in the Advanced Inverter Pilot
- Objective: Field validation of inverter-based voltage regulation functions
  - Investigate impacts on feeder voltages (mainly secondaries)
  - Investigate curtailment impacts on PV kWh production
  - Validate VROS project feeder models with field data
  - Confirm that there are no undesired interactions among inverters or between inverters and utility equipment
- Functions under test:
  - Non-unity fixed power factor (FPF) operation
  - Volt-var control (VVC)
  - Volt-watt control (VWC)
  - Combinations: FPF+VWC, VVC+VWC
- Plans to expand this project to a larger number of customers

Existing pilot data collection points



- Irradiance: 1-second intervals (selected locations)
- Inverter measurements: V, P, Q, pf, frequency, etc at inverter terminals
  - SolarEdge: 1-second intervals; Enphase: 5-minute intervals
- AMI: V, P, Q at customer meter; 1-minute intervals
- Grid2020: V, P, Q on LV side of transformer; 1-minute intervals
- Feeder SCADA data (V, P, Q, PF, LTC setting)
- All four data streams operational as of August
- Live feed to NREL's ESIF and remote control of GSF for participants

Additional Research Questions

- How will utility and customer impacts of rooftop PV with GSF change with different scenarios of BS deployment?
- How will the charging and discharging of distributed BS under non-exporting and smart export tariffs affect day and night-time voltages?
- How much will GSF be activated with distributed BS?
- Can load control be used to minimize customer kWh curtailment from GSF?

Thank you!

julieta.giraldez@nrel.gov

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