Transitioning PV Inverters from Unbalanced to Balanced Power Flow Models

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BEW Engineering

- A recognized international engineering company specializing in solar (PV), wind electrical component design and transmission/distribution engineering
- Transmission and Distribution
  - Solar & wind energy grid penetration assessments
  - Renewable portfolio standard studies
  - Transmission-Resources-Distribution grid impacts from high penetrations of variable renewable resources
  - Grid impacts on operating and planning reserves, unit ramping, frequency, flicker, harmonics, dispatching, high/low voltage, protection equipment-transmission load tap changers-capacitor banks & protection equipment
  - Locational value analysis of optimal locations for renewable
  - Technology assessment – solar, geothermal, ocean wave-thermal, wind, biomass, biofuels, hydroelectric

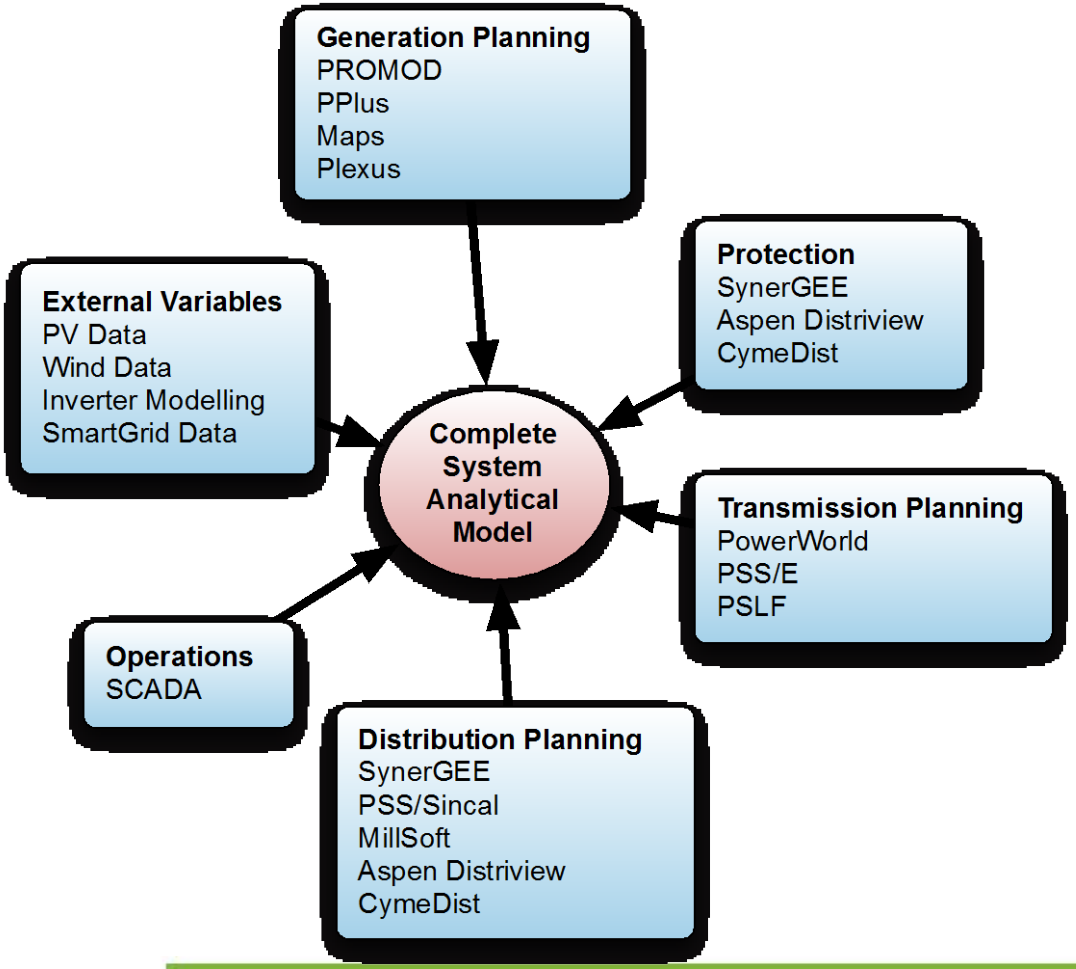
Learning Goals

- Methodology for rolling results from single phase level impact, to three phase (and rolling back)
  - Conversion of single phase and poly-phase PV inverter characteristics from an unbalanced distribution model to a balanced transmission model.
  - With the high penetration of PV systems on the distribution grid, the existing models are not designed to simulate the operation of large numbers of distributed resources.
- Engineers must be able to convert data sets between unbalanced and balanced systems to evaluate all of the potential impacts to the grid – how?
- Rough guide to distribution and transmission level impacts
- Example analysis from HECO/SMUD

Objectives and Overview

- Assess potential system wide PV penetration on the distribution system
- Feeder and System wide penetration limits
  - PV penetrations per individual feeders will vary
  - Summation of feeder PV not equals system total
- Study of individual feeder impacts provide insight to the potential barriers and issues, restricting high penetrations
  - Provide analysis framework on both a feeder and system wide scale

Graphical Flow of Model Interfaces



Why model the 12 kV distribution?

- Current models discount DG PV generation (treats as negative load) so utilities will never be able to separate and account for contributions in models
- Distributed feeder PV over a wide area can not be treated like a large central PV site
  - Lack of smoothing and averaging of power output
  - Less predictable due to climate and utility control
- Quantification of detailed feeder impacts on a per-feeder basis
  - Protection/Fault Current
  - Harmonics
  - LTC/Capacitor/Inverter interactions
  - Voltage and regulation implications
  - Seasonal impacts of high penetrations on the distribution side
- Distribution results transferred to transmission grid
  - Reduces data set size and run time
  - Provides detailed DG impacts to be considered
  - Allows for continued distribution studies with bi-directional flow of information and data consistency

PSLF Gen/Inverter Modeling and Integration

Objective

Develop a series of generic single phase and poly phase inverters to represent existing and future inverter characteristics for PV installations

* Developed using WECC standards

- 3 PSLF modules are required to accurately model a PV unit
- All three modules are required for each PV unit modeled
- PSLF and PSS/E modules are not identical

Goal of Dynamic/Transient Stability Studies from a distribution perspective

- To assess the ability of generators to remain synchronized, in the event of a large disturbance
- At what level is PV impact considered a large disturbance?
  - Generally fault + line tripping, major conventional generator fault + trip, bus fault are considered large events
  - At some point the combination of all PV units on the system, will contribute to the large event and could impact the system more significantly

What benefits to transmission and generation planning?

- Determine major events or operations on distribution that could impact total system
- Simulate high risk case scenarios, to inform new operations and emergency plans for most efficient system recovery with high penetration
- Consistent methodology to address PV penetration limits before impact is more severe
- Get head start with tools to create remediation plans, for larger PV penetrations
  - Equipment replacement/upgrades

Determine Time Periods of Interest for Transmission and Distribution

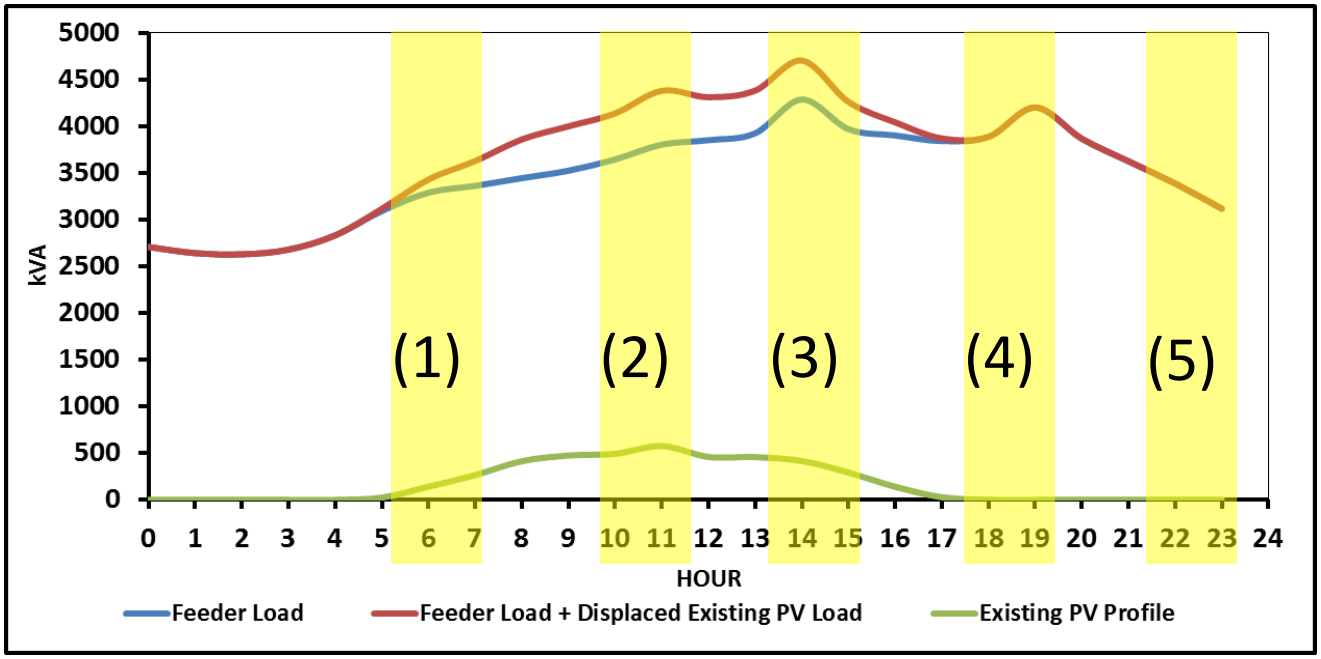
(1) Demand daytime increase

(2) PV Peak generation time

(3) Demand Super Peak time

(4) Evening Demand Peak

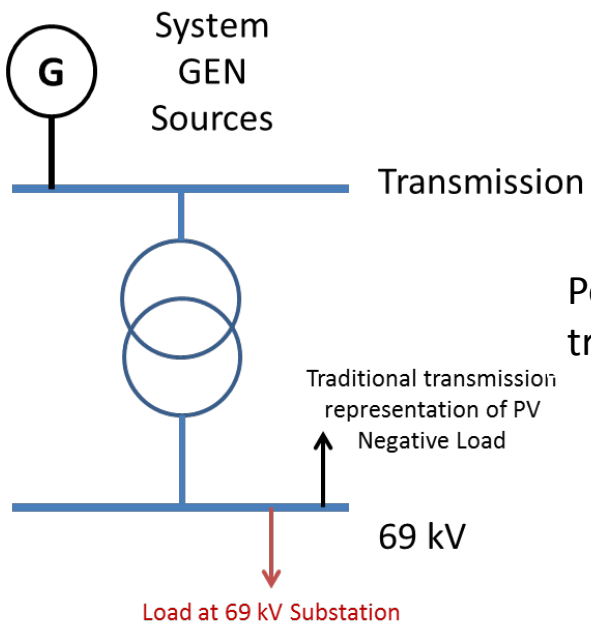
(5) Demand decrease in the evening



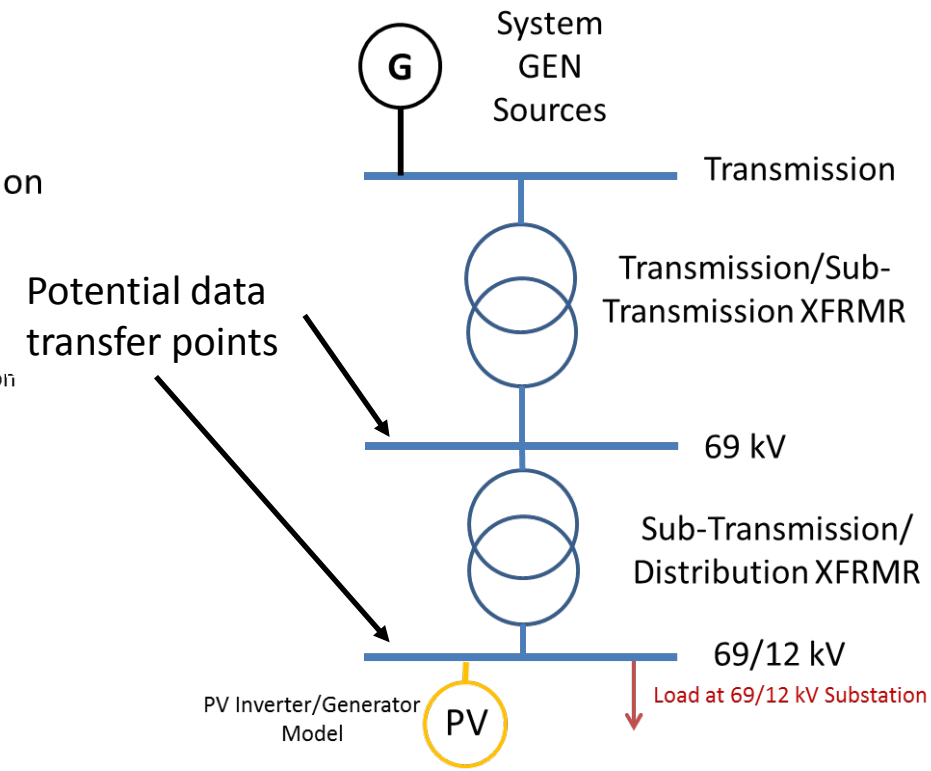
- Significant operational considerations for each time period.
- Minimum load conditions profile is either 40% of peak, with the same form as the peak curve for this example and demonstration
- Or available measured substation load data for a more accurate representation

Two schools of thought for PV penetration impacts studies

Traditional Representation of PV from a transmission POV

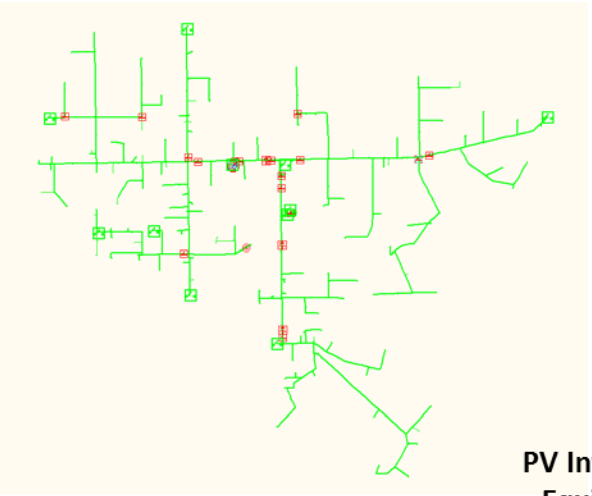


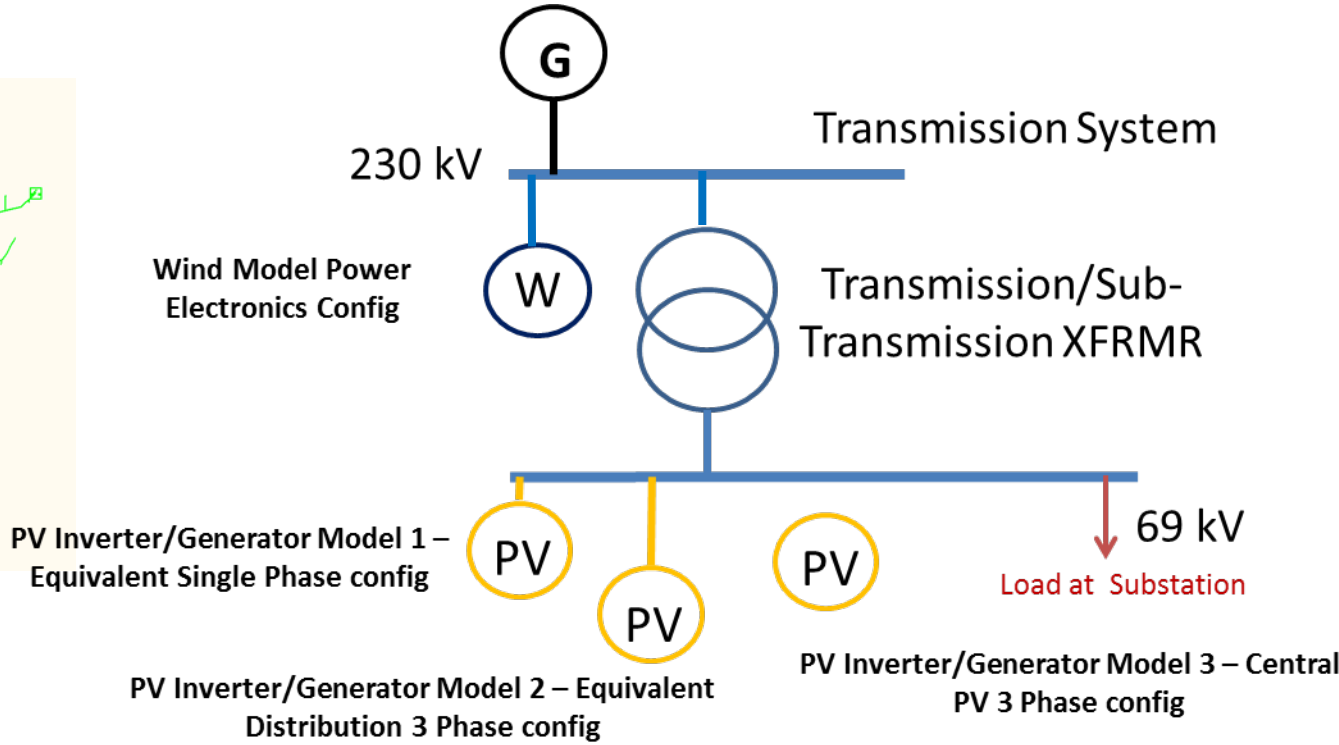
Recommended Representation of PV for a Transmission Analysis



Rural Feeder 1 Nodal Approach

- Large amount of PV being proposed/installed on distribution and sub-transmission levels





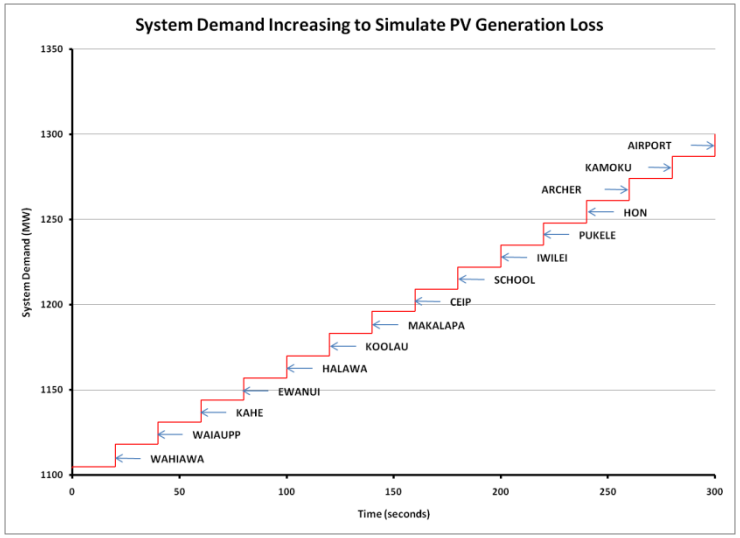
Challenges Encountered with PV Aggregation

- No planning/analysis model can handle very high numbers of PV installations
- After aggregation, certain DG attributes and granularity could be lost
  - Lose differences between single phase inverters without frequency capability
  - Functions with poly-phase
- Accuracy and lost of sensitivity with large aggregation need to be further investigated
- Limited measured PV data to allocate PV generation by zone or feeder

Examining the two approaches and conditions for analysis

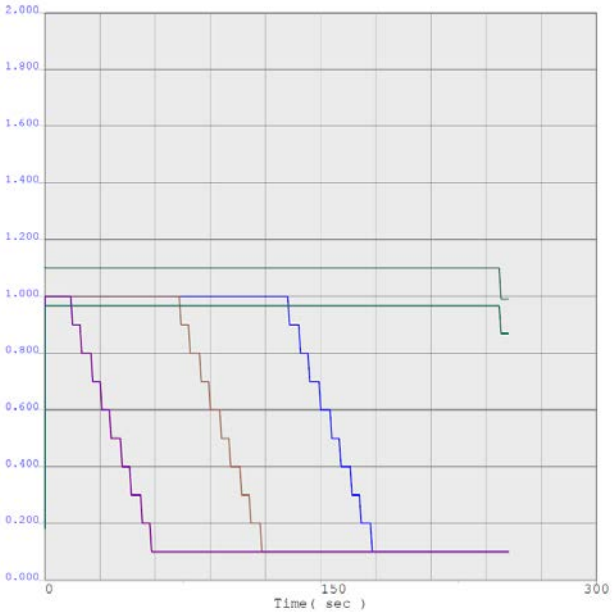
Simple Dynamic Analysis

- PV is treated as a negative load dynamically, therefore losing PV is modeled as a load increase

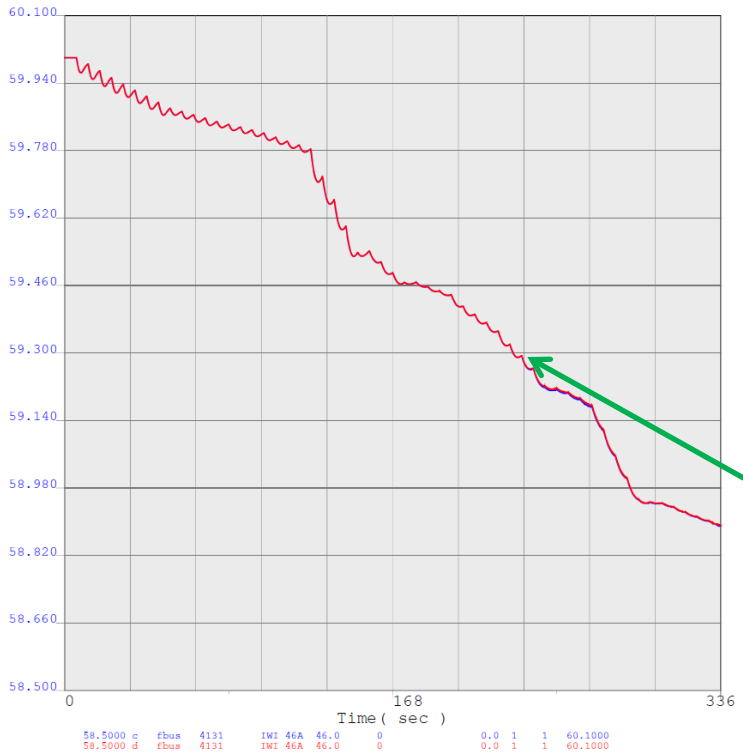


Detailed Dynamic Analysis

- PV is modeled as a dynamic inverter/generator combination
- Dynamic implications of PV tripping is modeled



Example of System Frequency Disturbance During Analysis

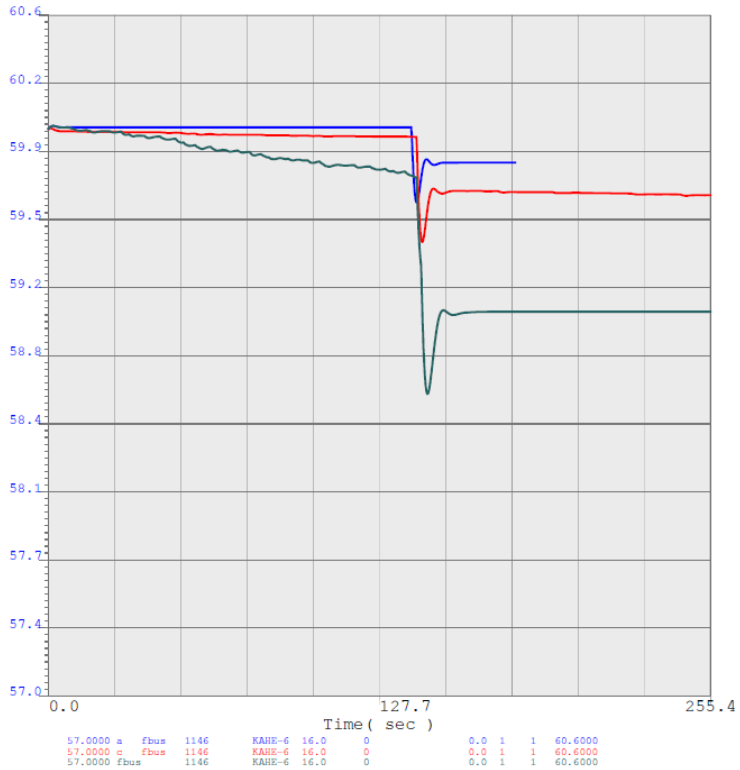


- Load steps up over a 5 minute period
- No cascading effect of multiple inverter trips at once

59.3 Hz
"Normal" inverter trip point

Example System Case: Comparison of PV during Gen Fault

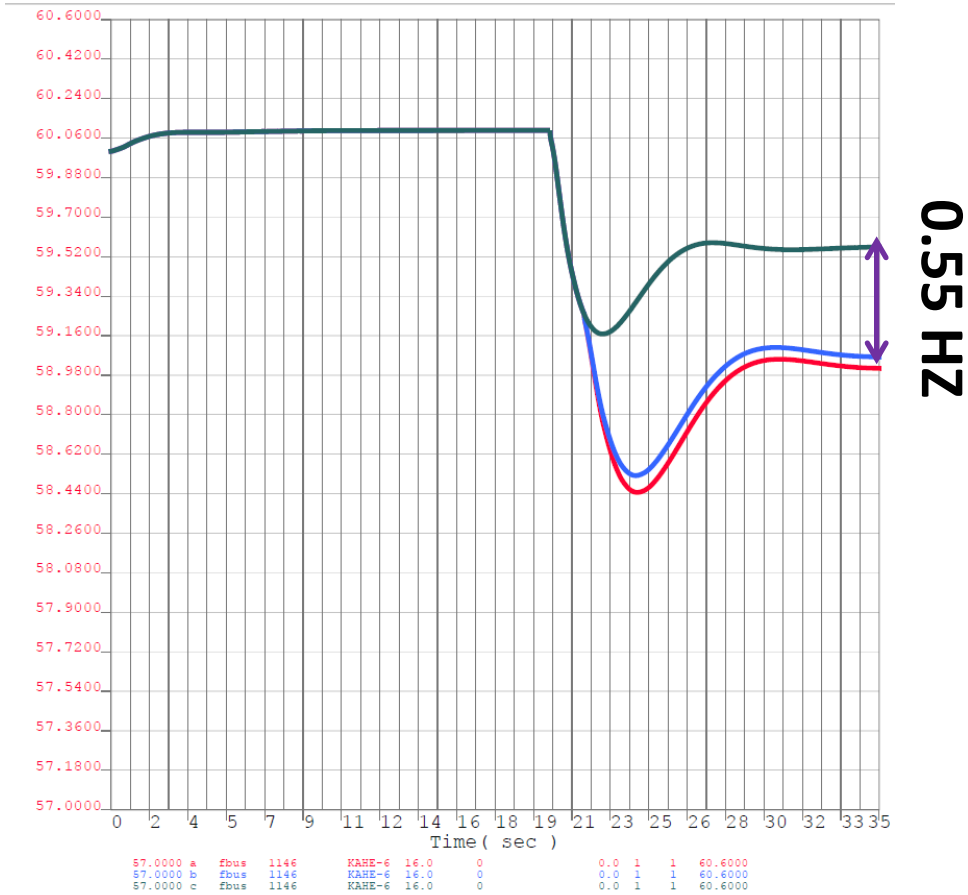
Comparison of System Frequency with 1 conventional gen trip at ~140s
No PV Cloud tripping (Blue)
Existing PV Cloud Tripping in 5 mins (Red)
15% PV Cloud Tripping in 5 mins (Green)



- At generator fault in green case
  - 50% PV cloud tripped
  - All other PV units have an under-frequency trip at this point
  - System frequency recovers low – 58.9 Hz

Example of Dynamic Analysis: Comparison of Inverter Settings

- Generator commitment scenario at HECO
- 1% change in frequency by allowing inverters to ride through the fault at 58 Hz
- At the existing level, little difference in recovery level as very small number of 3 phase generators
- The more that ride through the fault by MW the better the system recovery



Preliminary Feeder Findings

- Fault current rise is significant in high-penetration scenarios going above 40% PV
  - Protection co-ordination studies will be necessary and possibly result in large scale changes
- Detailed PV data is essential to quantify short time scale effects like flicker
- Voltage rise can occur regularly on light load, high penetration feeders
  - Customer impacts (flicker, loss of service, damage to sensitive equipment)
  - Mitigation strategy (regulators, control schemes for cap banks, inverter control strategy)
  - Voltage rise could be due to many things – capacitor banks control system, or fixed on-off settings, line impedances,
- Interaction between capacitor banks/inverters/tap changers could significantly impact reliability

Biggest Challenges & Conclusions

- Availability of measured data is essential for validation and lacking in many cases
- Highly variable PV systems must be analyzed in a detailed dynamic and steady state simulation
- Feeders can be characterized in terms of load type, geo location, voltage, and PV penetration
- Commercially available tools must be integrated and used for different tasks
- As more detailed inverter control schemes become widely available to customers the impact must be justifiable and proven through simulation
- Partnerships between utilities sharing results and funds allow focused and economically viable measurement and analysis to be completed

QUESTIONS?

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