Solar Shading Vs. Fault Conditions from a Utility View

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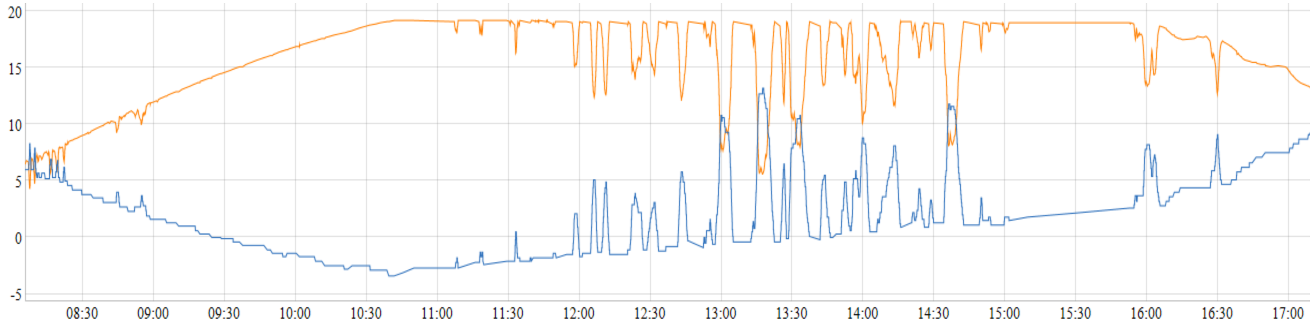
PV Facts

- Utility scale solar installations increased at an average rate of 72% a year from 2010-2016
    - Utility scale is considered any amount above 1 MW
    - Utility scale solar makes up 2% of utility scale generation in USA
        - Over 21.5 GW as of 2016
- Dominion Energy’s distribution system has 930 MW of solar generation in Virginia and North Carolina
- Solar generation is set to increase as states, such as California and New York, develop ambitious goals for renewable energy integration

PV Volatility

- Unlike coal and natural gas, the sun is a variable fuel source
  - Clouds, night time, position of the Earth
- Peak sunlight hours are when this volatility is at its greatest
- The PV output below, orange, fluctuates between a maximum of 18 MW and a minimum of 7 MW
  - The grid is left to make up for the sudden difference



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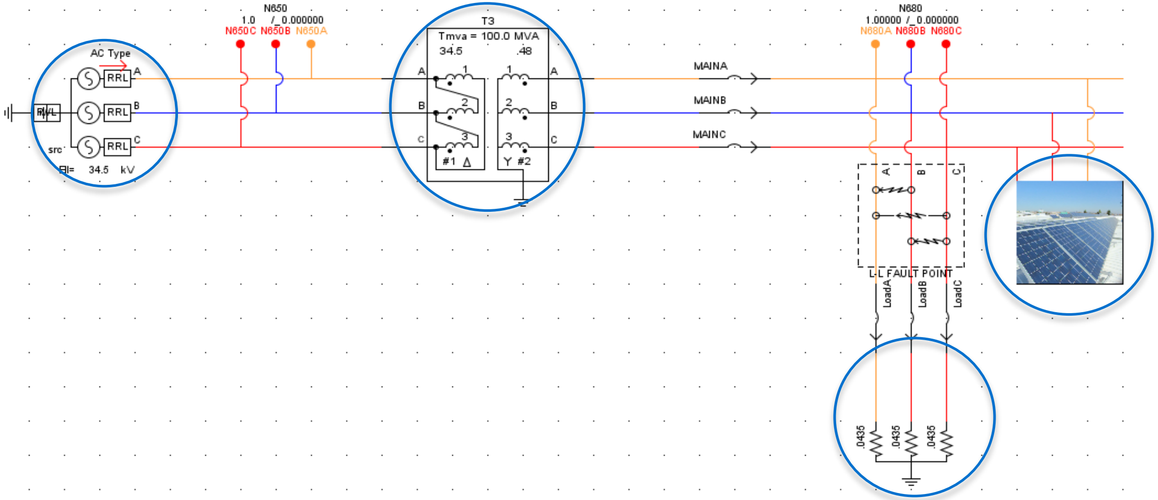
Project Motivation

- Large variation in PV output can be hazardous for the grid
- Grid current will increase to balance load demand
- Loss of power can cause low frequency
- Protection schemes can be compromised
  - Characteristics mimic fault conditions
- As distribution level PV installation increases these effects will worsen
- It is imperative to distinguish between PV shading and fault conditions

Model Outline

- RSCAD software was utilized to develop a distribution model
- A strong RL connected infinite grid is connected to a transformer which leads to a load and the PV generation
- The PV generation is interfaced with the grid via a voltage-sourced converter (VSC) that utilizes PQ control



Simulation Procedure

- Two trials were conducted
  - Sudden PV power output reduction
  - 3-phase fault
    - Each phase is affected equally
- The event is applied to the system and held for the duration of the simulation
- The grid current magnitude and THD are measured at the output of the transformer while voltage magnitude and phase, and system frequency are measured at the load
- Results are compared side by side to determine the nuance differences between instantaneous PV generation decrease and a 3-phase fault

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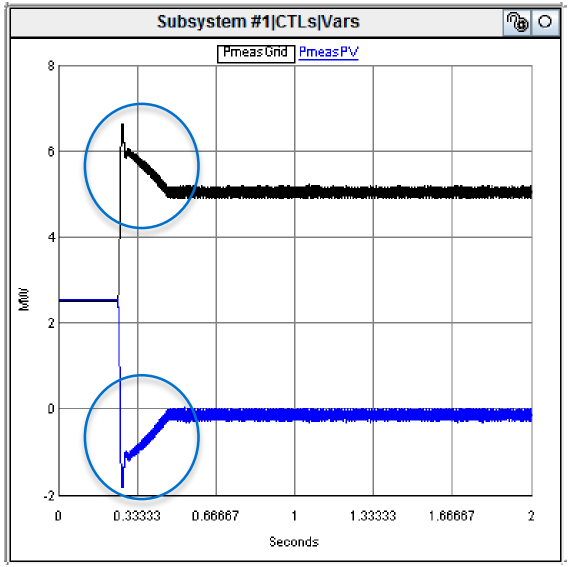
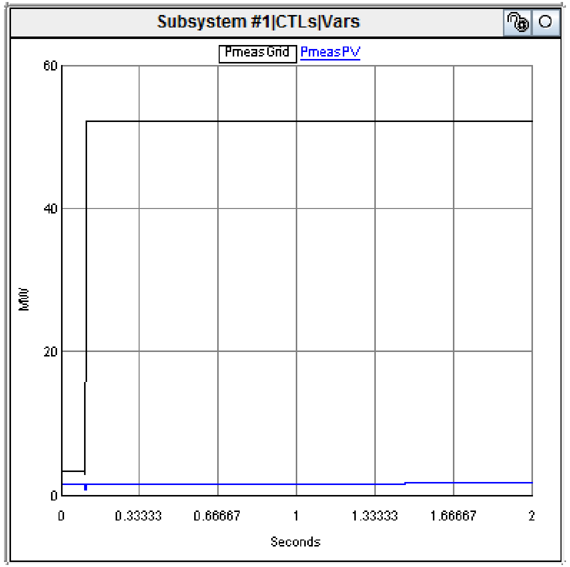
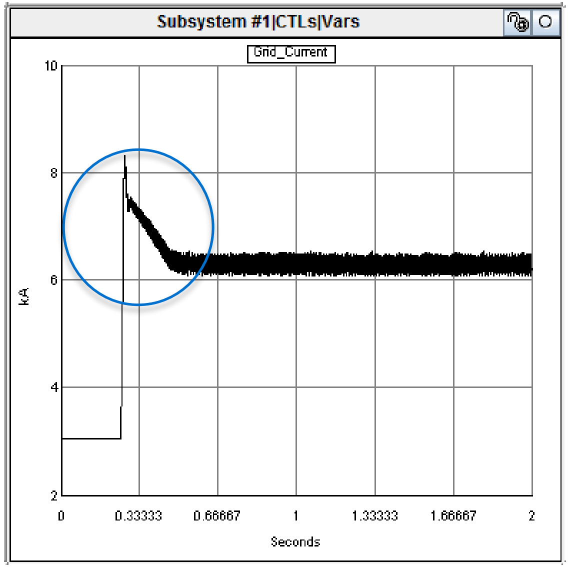
Results – Real Power

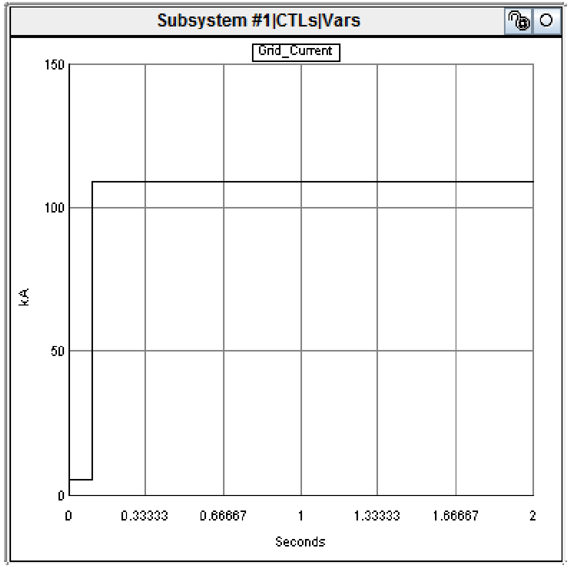




- PV Shading
- 3-Phase Fault

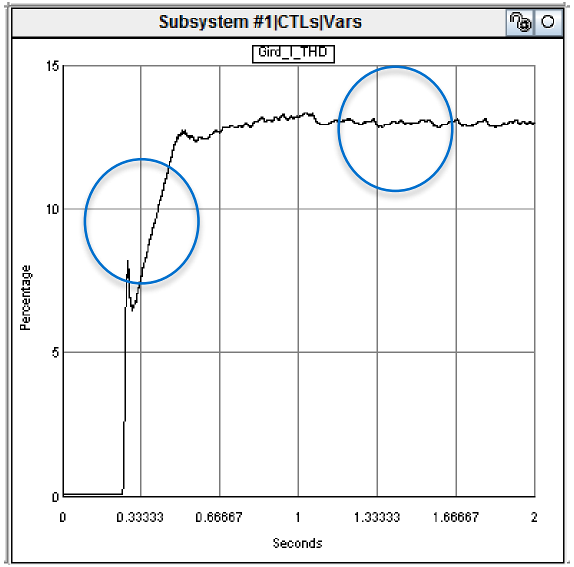
Results – Grid Current Magnitude



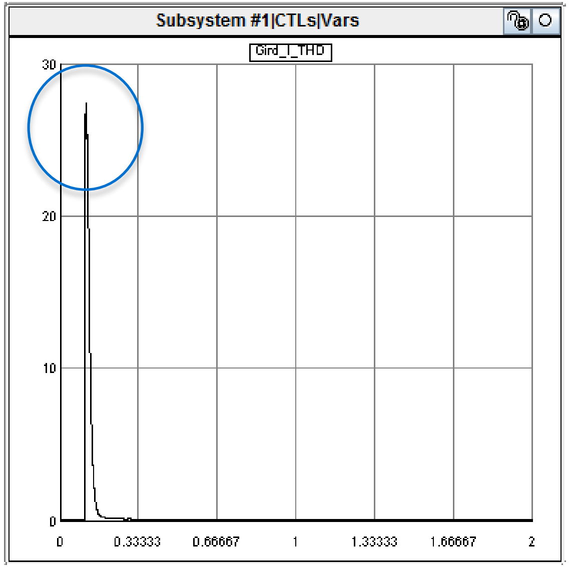


- PV Shading
- 3-Phase Fault

Results – Grid Current THD

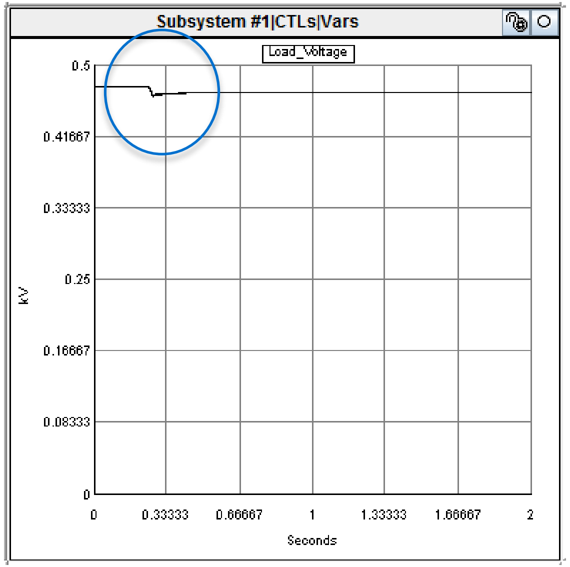


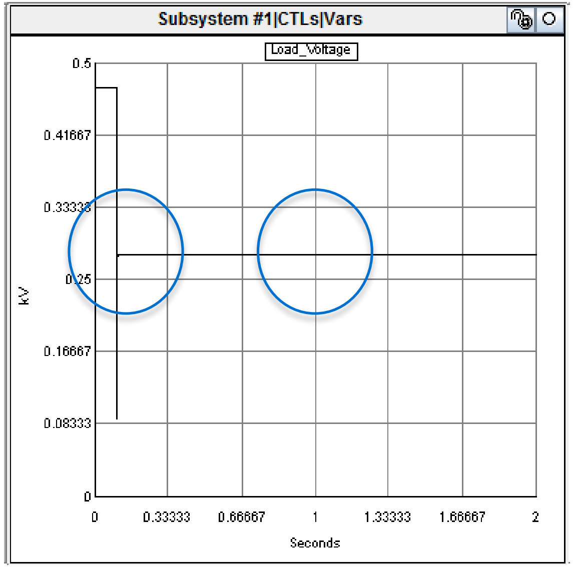
- PV Shading



- 3-Phase Fault

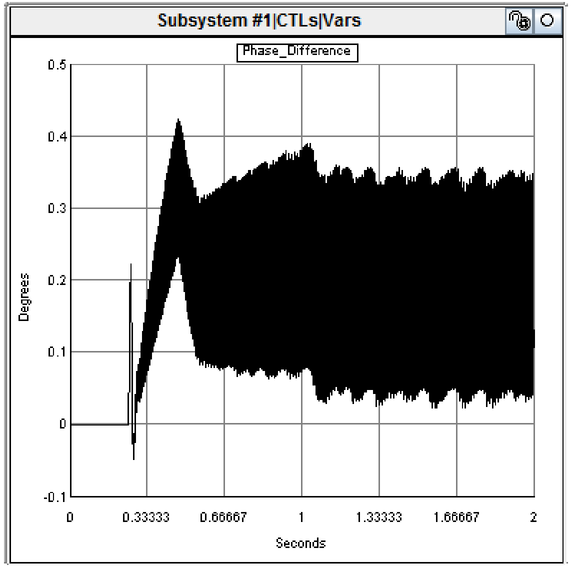
Results – Load Voltage Magnitude

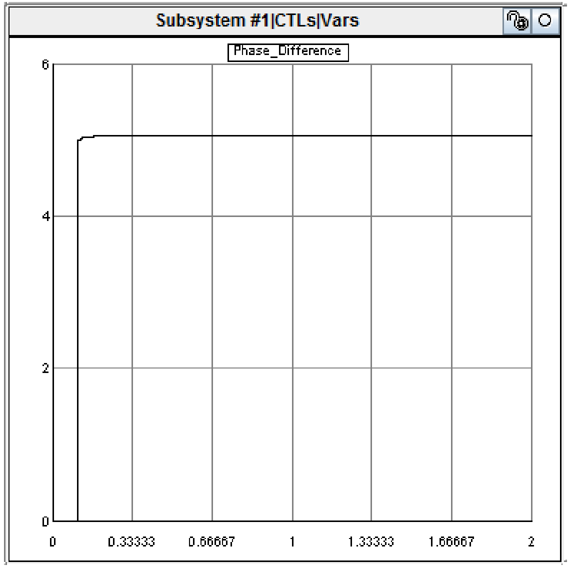




- PV Shading
- 3-Phase Fault

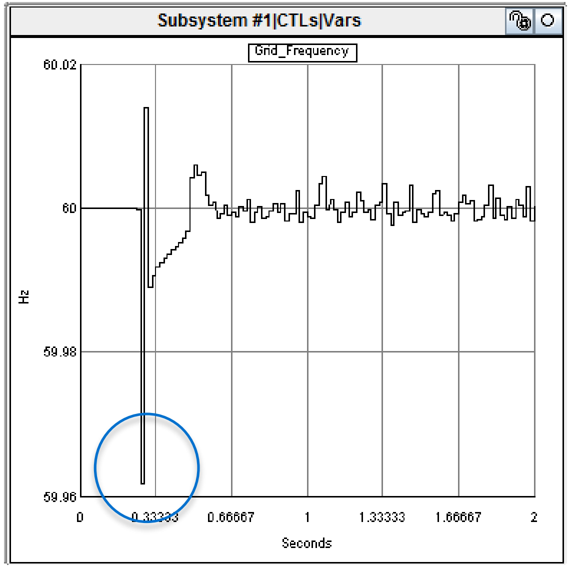
Results – Voltage Phase Shift



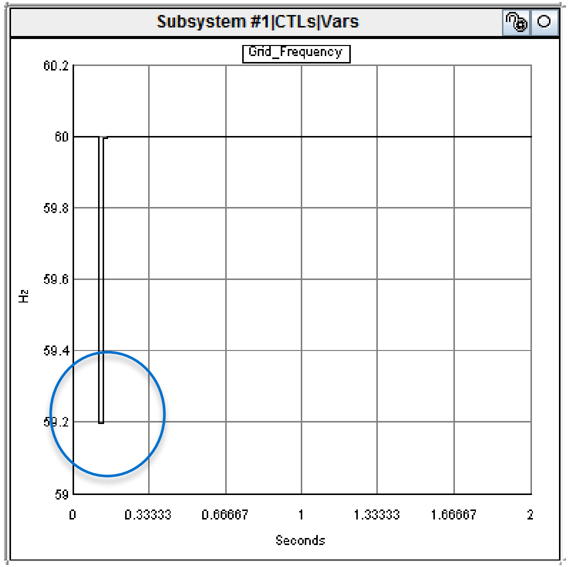


- PV Shading
- 3-Phase Fault

Results – Grid Frequency



- PV Shading



- 3-Phase Fault

Analysis

- Grid Current Magnitude
  - Both scenarios produce a very sharp rise in grid current
  - The fault condition creates a much larger steady state current than that produced by the loss of PV generation
  - The sharp rise in grid current means that protection schemes using dI/dt need to be calibrated properly or the circuit could mistakenly trip for PV shading instead of a fault
- Grid Current THD
  - Grid current THD is the one quantity that has a distinct characteristic for each case
  - When PV shading occurs the THD rises to ~12.5% and stays there but when a fault is placed on the system the THD spikes to ~27% then returns to 0%
  - Possibly due to the VSC's filter, as the output of the VSC compensates for it when active but cannot when PV shading occurs

Analysis Continued

- Voltage Magnitude
  - Significant drop for a 3-phase fault but the reduction in PV output power only causes a voltage drop of 1.25%
  - The grid can compensate for the power lost from the PV generation, stabilizing the voltage at nominal
- Voltage Phase
  - When PV generation is lost the phase shifts ~0.2 degrees, while the fault causes a shift of 5 degrees
  - Phase shift should not false trip for loss of PV generation
  - The phase shift caused by loss of PV is not extremely large, PV shading is a repeatable scenario, potentially causing issues on the grid
- Frequency
  - The frequency dip caused by PV generation loss is 0.05% of the nominal frequency and can therefore be considered negligible

Conclusions

- The growth of PV generation has prompted utility companies to consider PV generation behavior when planning distribution protection
- It is evident that loss of PV generation mirrors the effect of a 3-phase fault, only with lesser consequences
  - Common protection techniques, such as undervoltage, underfrequency, and phase shift will most likely not be in jeopardy of false tripping due to loss of PV generation
- Protection schemes that incorporate dI/dt could be at risk for false tripping due to the rapid increase in grid current in both scenarios
- THD can be used to differentiate between the two scenarios as a fault causes a spike in THD, while PV shading causes a rise in steady state value

Future Work

- Analyze characteristics at the point of DG interconnection
- Leverage this knowledge to develop protection settings for circuits with DG
- Utilize protection settings to lessen reliance on transfer trip
- Investigate protection scheme performance as grid inertia is reduced

Questions?