

Smart Inverter Capabilities for Mitigating Over-Voltages on Distribution Systems with High Penetrations of PV

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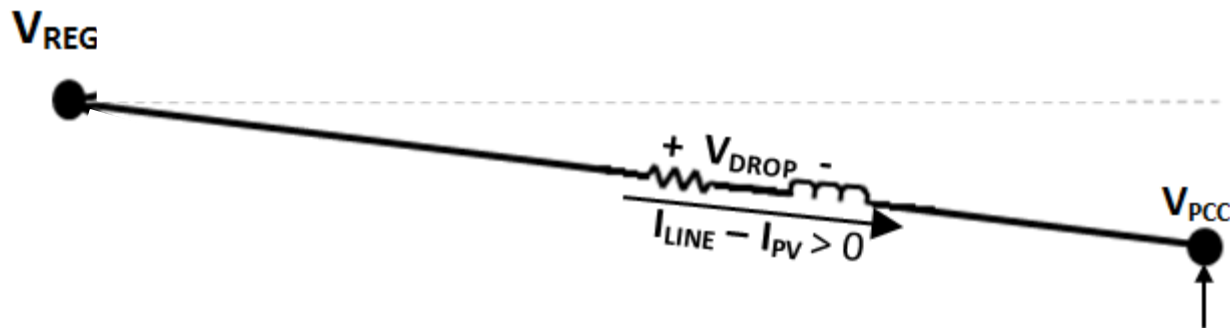


Introduction

- Large amounts of PV on the distribution system can create high voltages, especially when a large PV plant is connected to the end of a feeder
- To allow higher penetrations of PV to be installed on the distribution system, voltage regulation is necessary
 - Voltage regulators can be installed, but solar variability can create significant number of operations and tap changes
- More intelligent smart inverters can be used to support distribution system voltages and regulate its output to mitigate any impact to the grid caused by variability in PV output.
- The reactive power capabilities of the inverter provide voltage regulation
 - Voltage and reactive power are commonly correlated (microgrid droop control, capacitors)

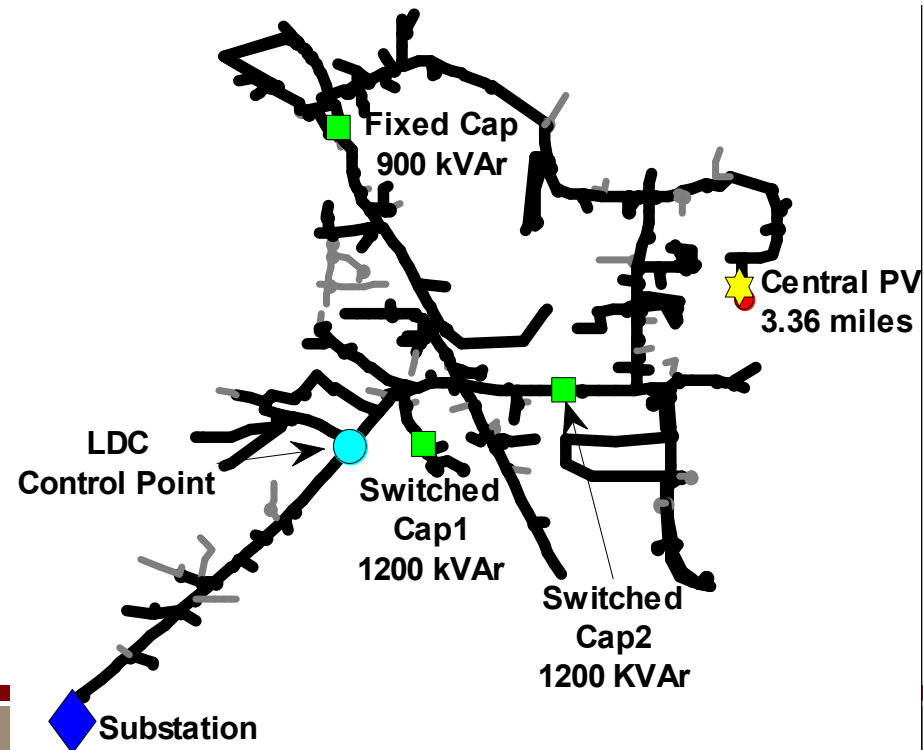
Feeder Voltage Analysis

- Injection of either real or reactive power by the PV inverter changes the PCC and surrounding voltages
- Ohms law – voltage drop from current flowing through the line impedance
- Circuit demonstrates the voltage drop
- The voltage profile can be explained with simple one-line

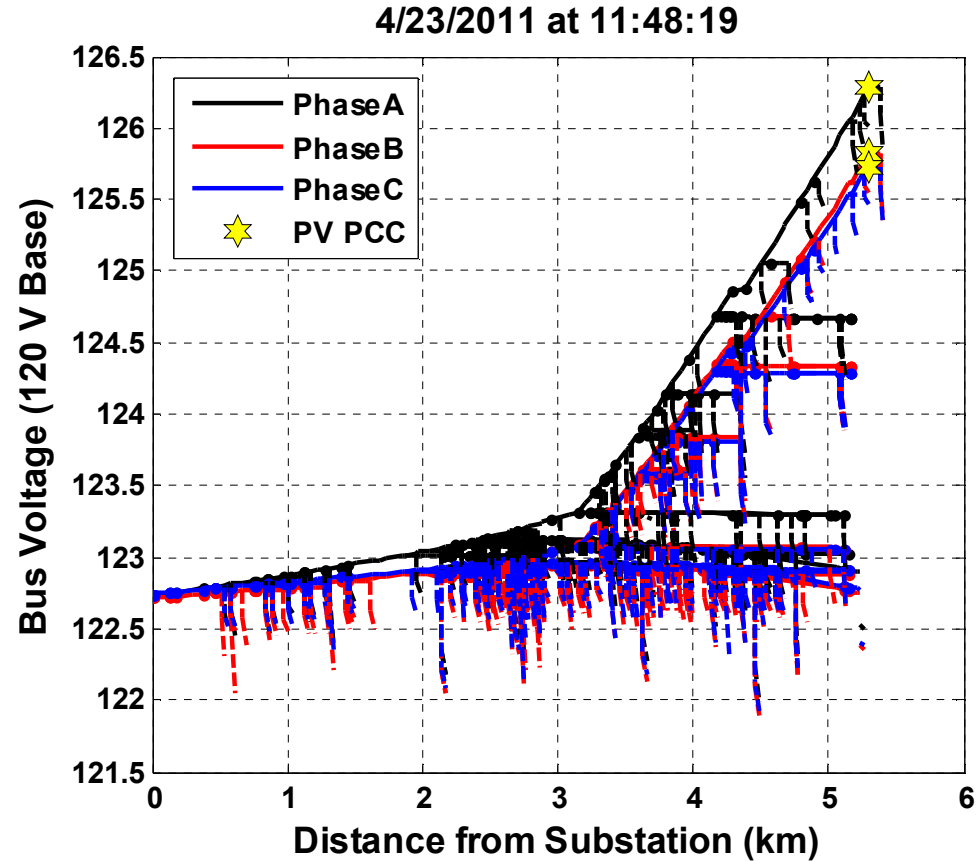
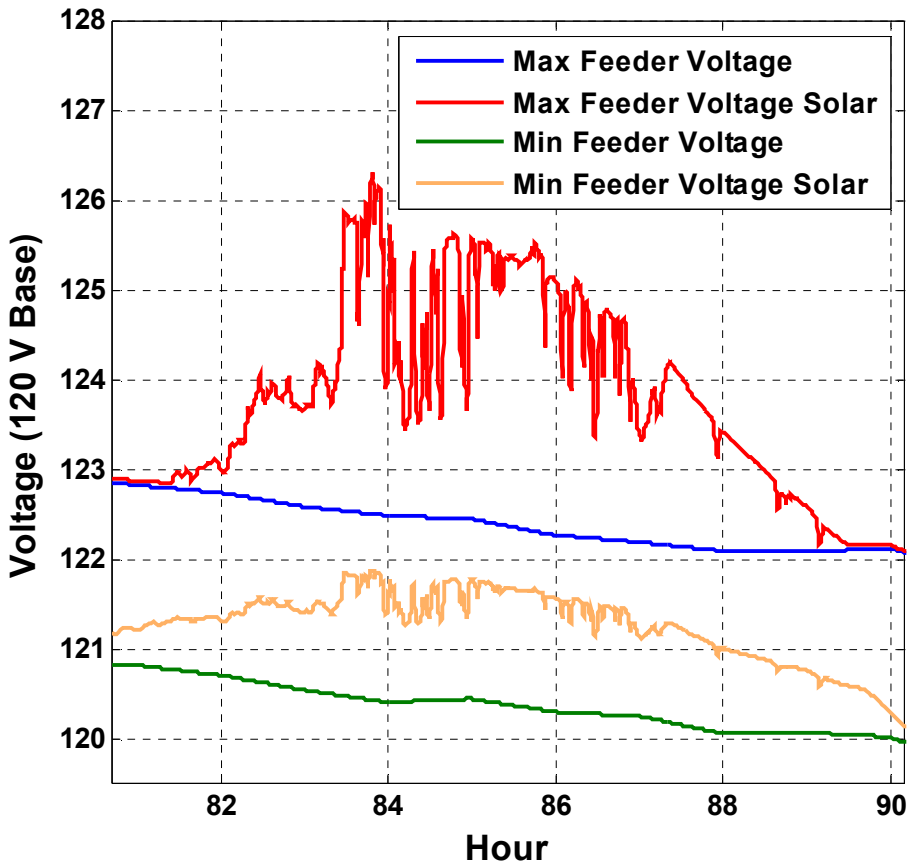


Simulation Setup

- 19.8 kV distribution system, LTC with LDC, four feeders
- Feeder - 7.5 MVA peak load, two switched capacitors
- 7.5 MW PV plant (100% of feeder peak load) modeled using WVM is connected at the end of the feeder
- Simulations performed in OpenDSS, a three-phase distribution system simulation software from EPRI
- Analyzed the peak penetration week of April 20, 2011 to April 26, 2011 with coincident load and local irradiance data



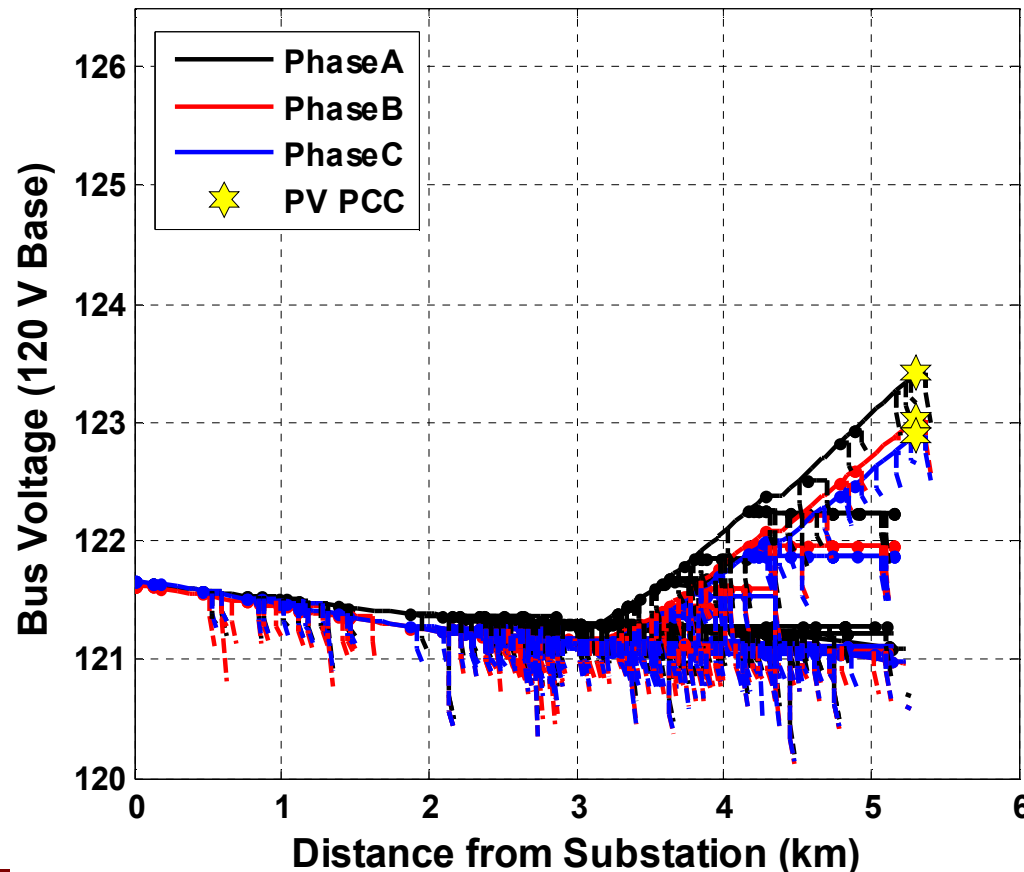
Example of Over-Voltages From PV



Reactive Power Example

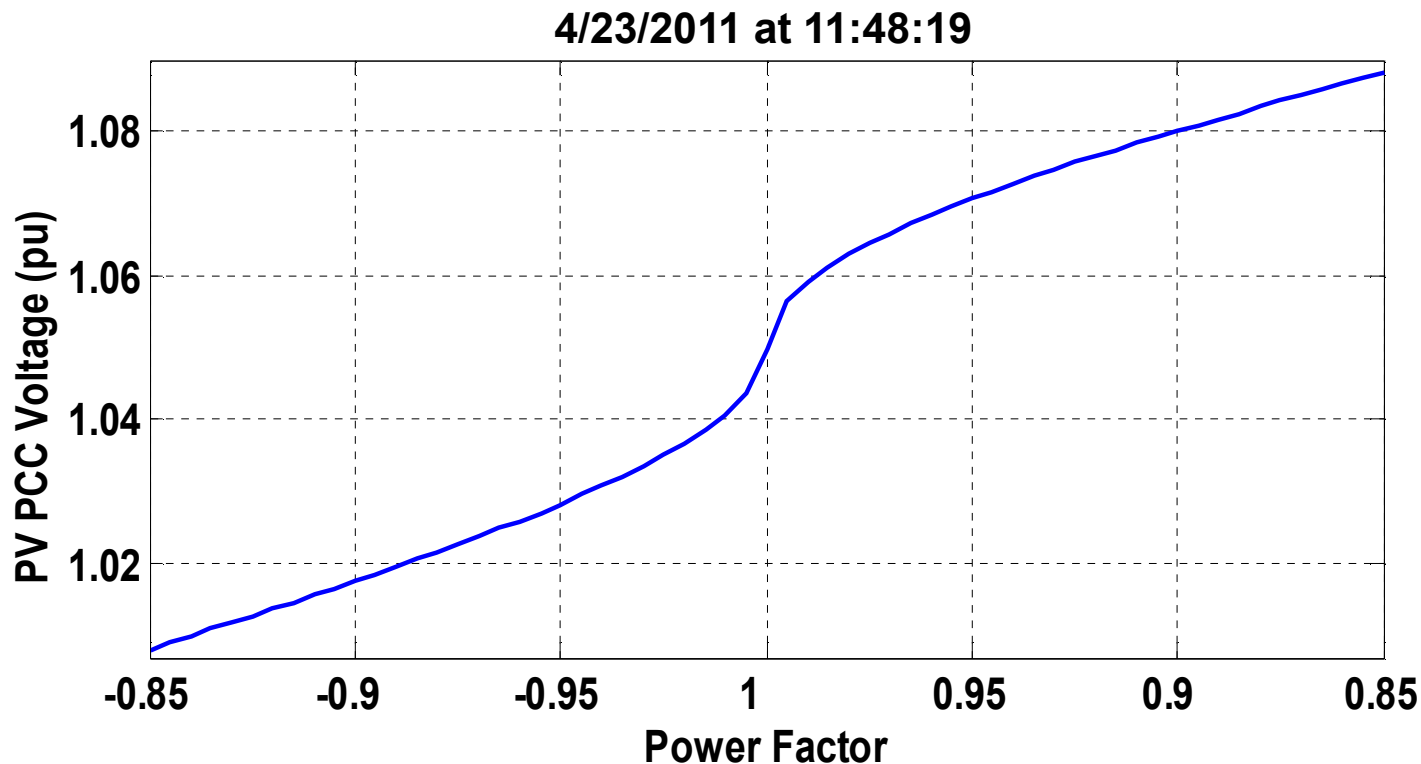
- Even a slight change to the 7.5 MW PV plant producing at 0.95 leading power factor makes a significant difference

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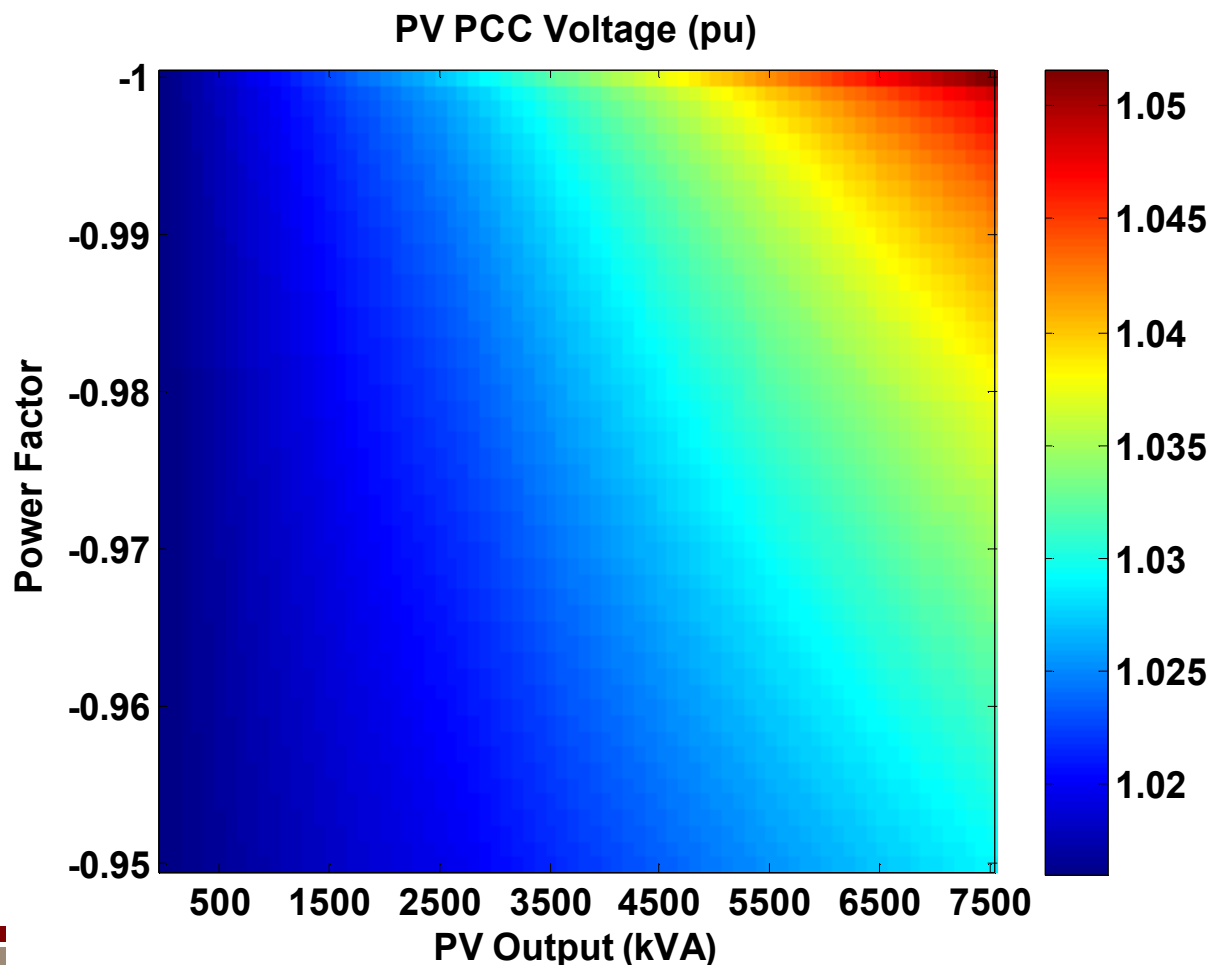
Impact of PV Output Power Factor

- Analyzing the impact of PV output power factor to voltage
- Snapshot analysis for different PV output power factors for the 7.5 MW plant



Impact of PV Output Power Factor

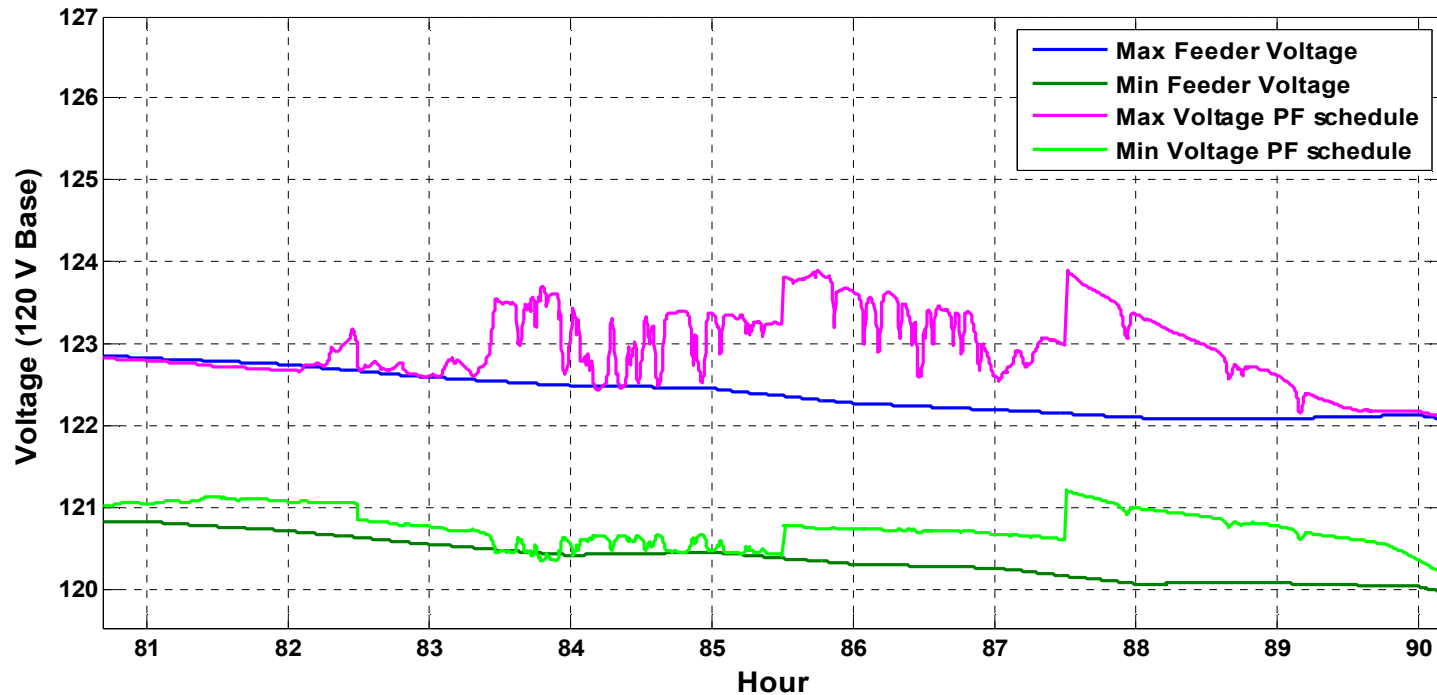
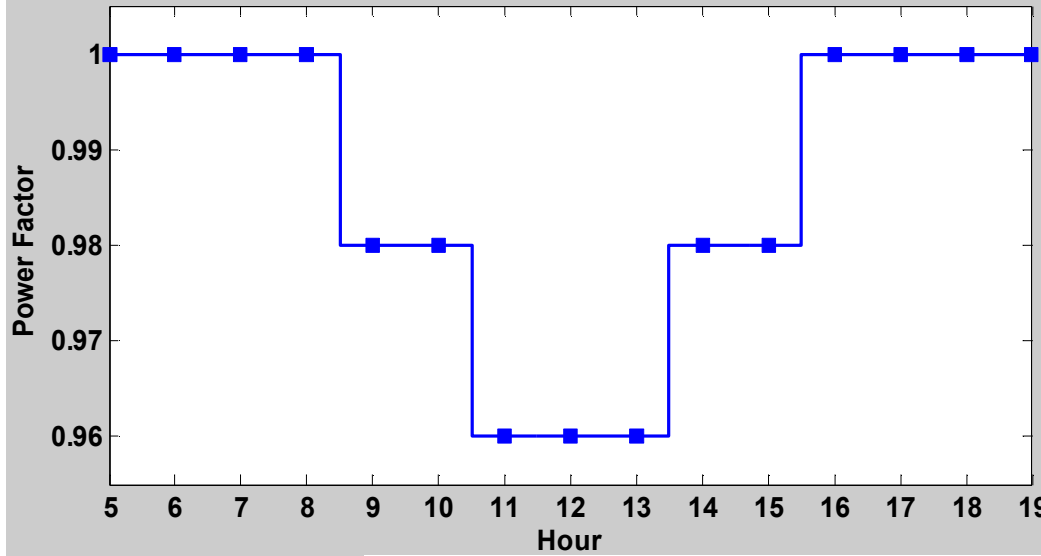
- Snapshot analysis of PCC voltage as a function of PV output power and power factor



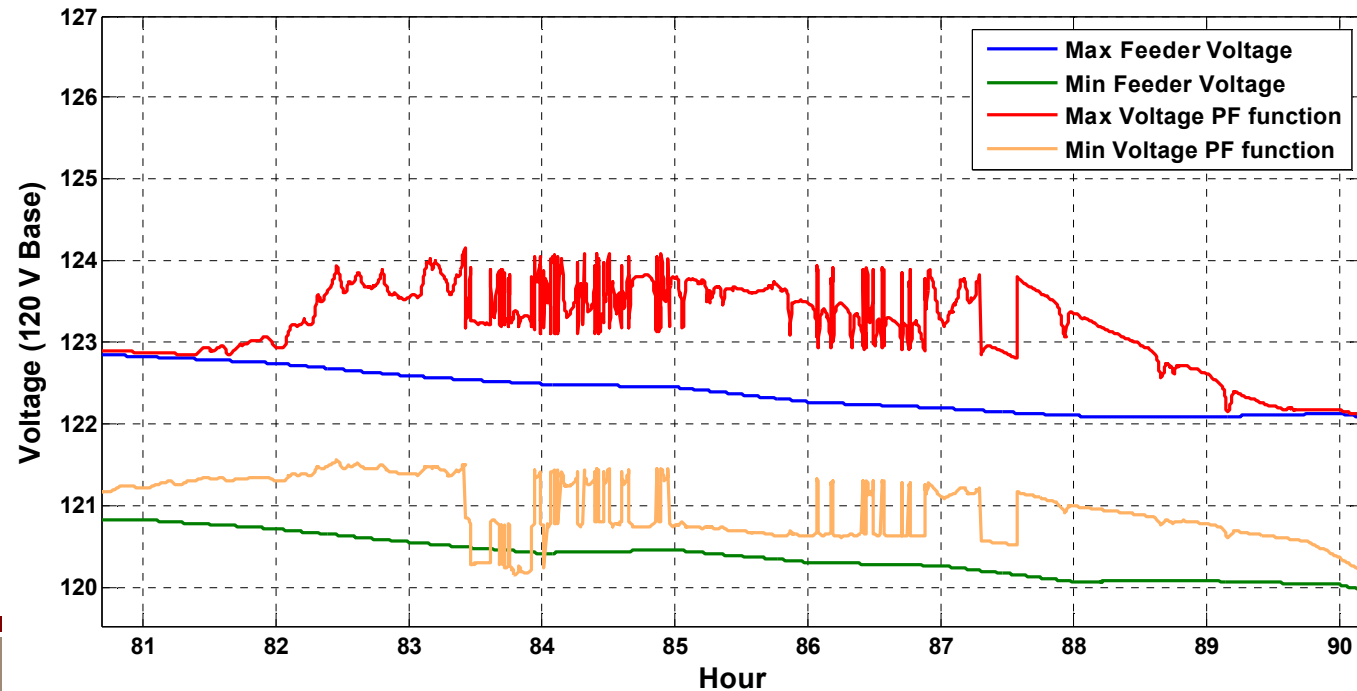
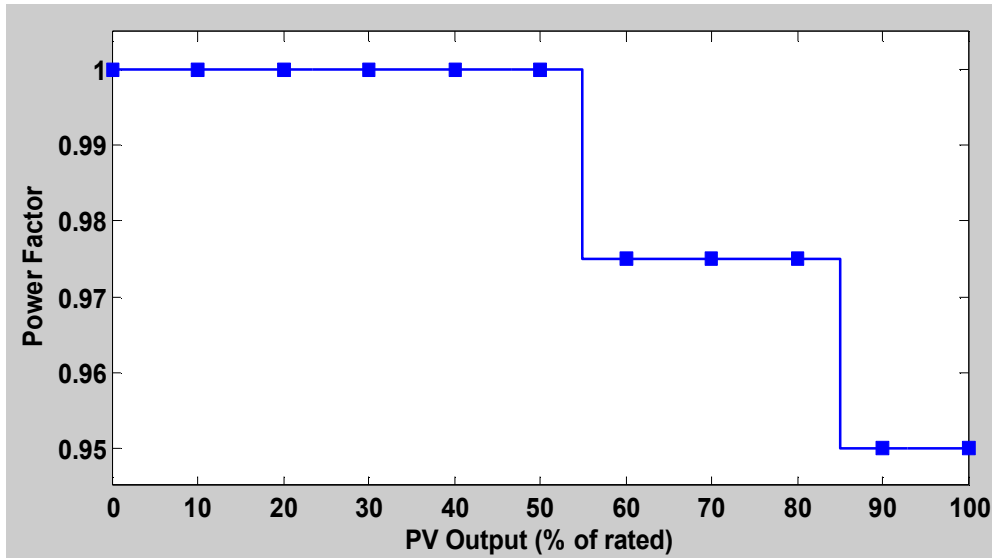
Power Factor Control Strategies

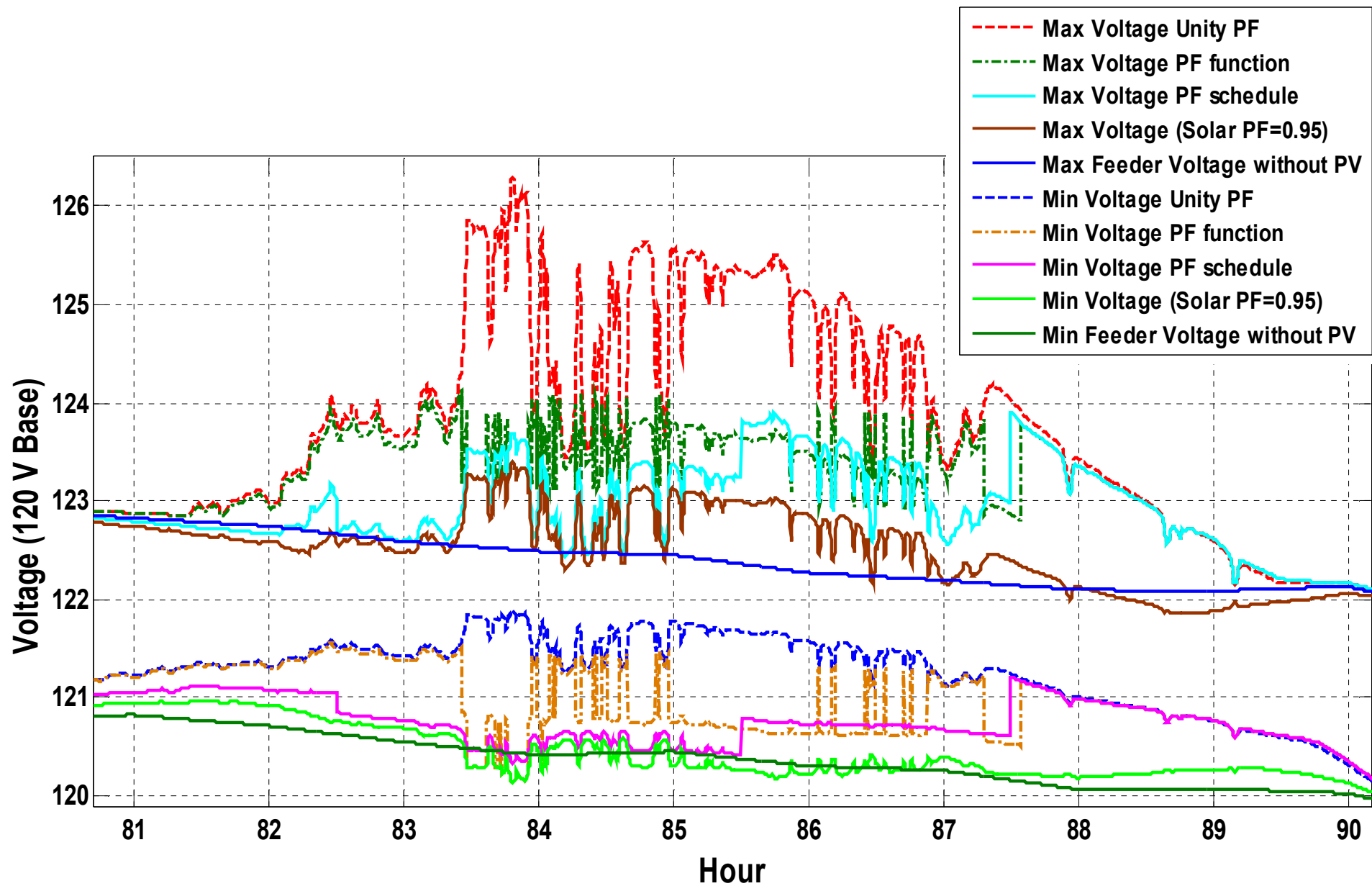
- IEEE 1547 says that inverters “shall not actively regulate the voltage at the PCC”
- Control strategies within current standard
 - Fixed constant-var output
 - Fixed power factor
 - Schedule var output by time of day
 - Var output a function of the PV output

Power Factor Schedule



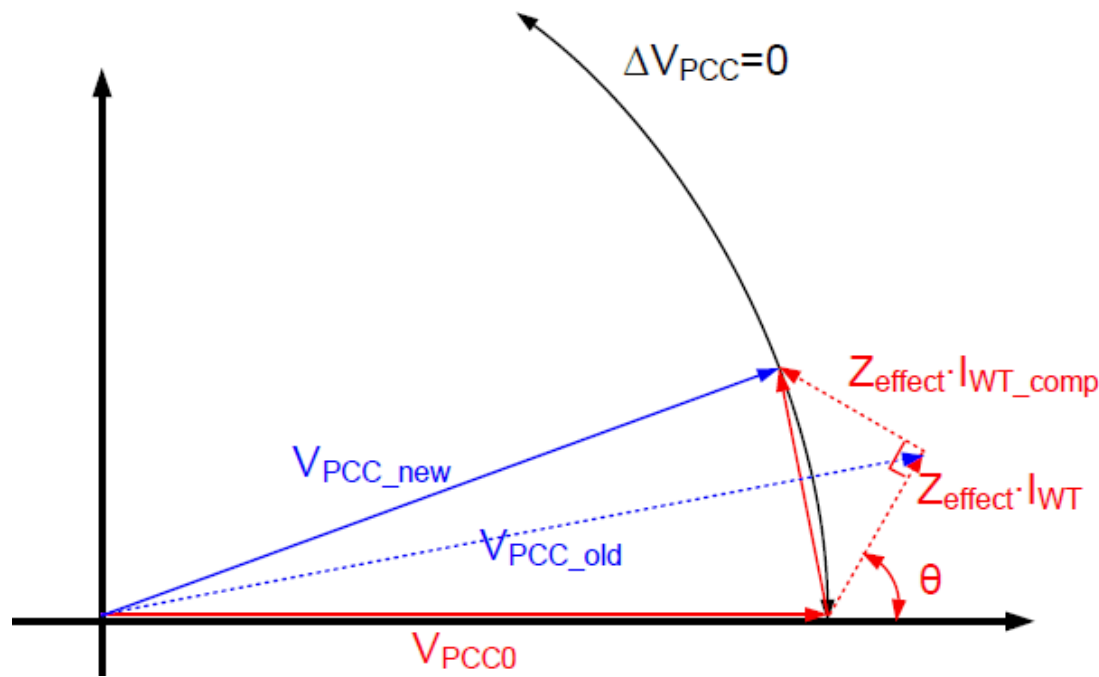
Power Factor as a Function of PV Output





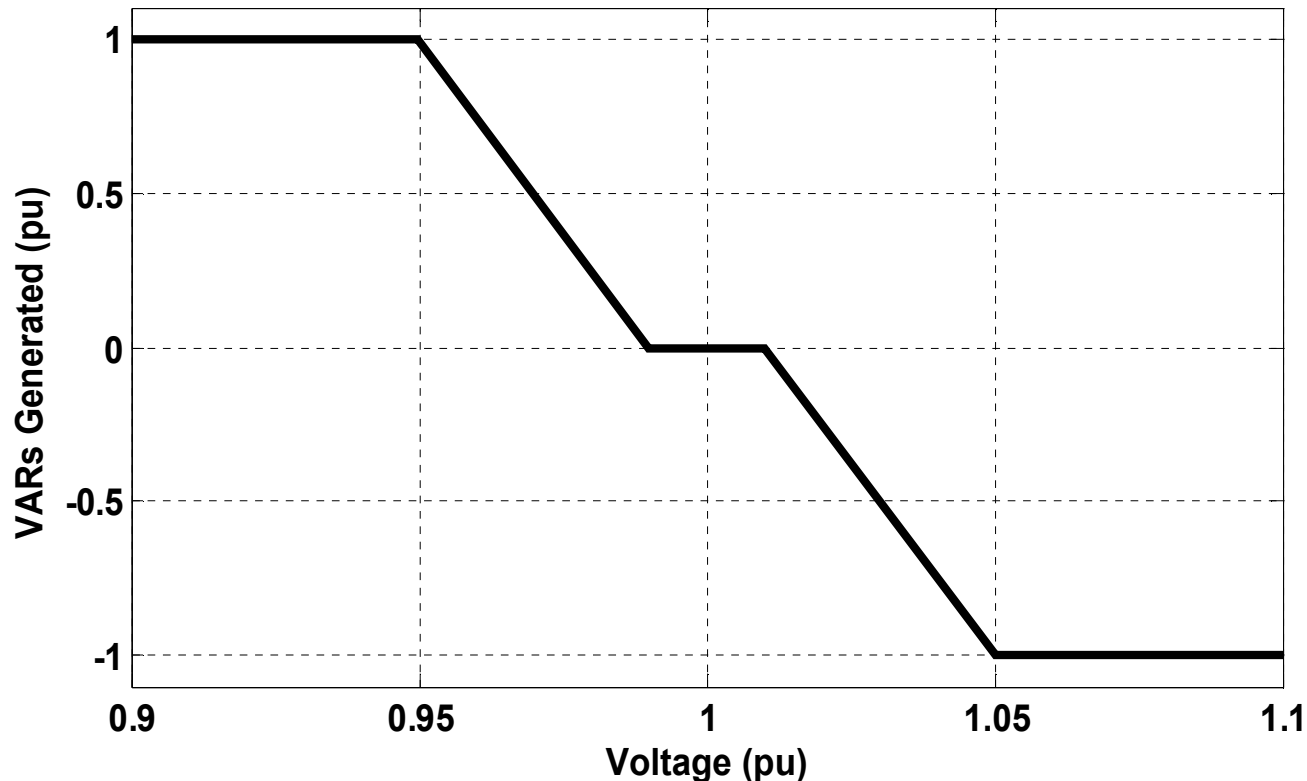
Negate the Change in Voltage

- Using the effective impedance to the nearest voltage regulator, the reactive power can be determined as a function of real power output that is necessary to exactly negate the change in voltage due to real power output

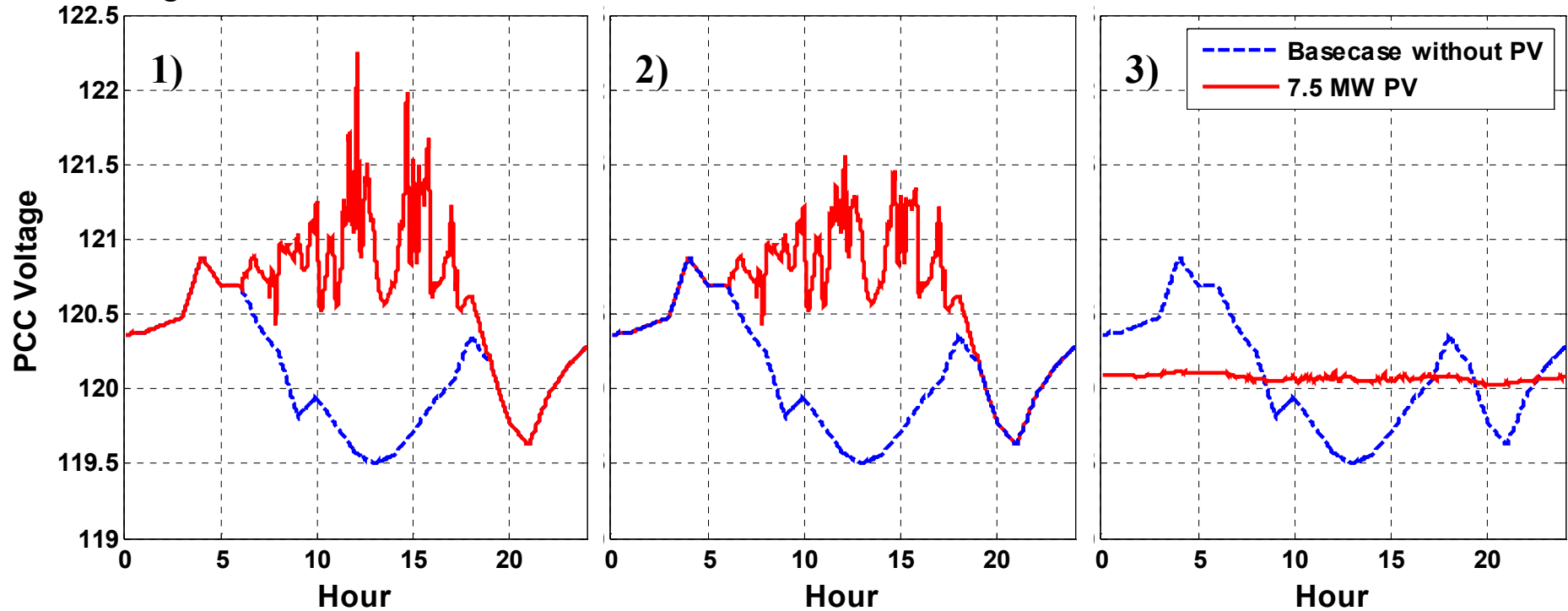


Volt/Var Control

- Standards (IEEE 1547) is set to change soon
- Other countries apply and expect volt/var from PV inverters
- Large plants in the U.S. also commonly do some form of volt/var
- What is Volt/Var Control?



Volt/Var Control Simulation



1) unity power factor, 2) volt/var control with deadband, and 3) voltage regulation

April 20th, 2011

Reactive Power Output

- Voltage regulation can consume large amounts of reactive power. In this case the reactive power consumption was within the inverter rating, because of low solar output on a cloudy day



Inverter Limits

- Inverters have a kVA rating that limits the amount of current that can safely be produced
- Reactive power can be produced or absorbed in the “headroom” between the kVA limit and the real power output of the PV panels
- What happens if you reach the inverter rating?
 - Decrease reactive power output from the expected output, decrease in voltage regulation capabilities
 - Decrease real power output to maintain voltage

Discussion

- Large absorption of reactive power increases line losses
- X/R ratio of the line impedance determines the effectiveness of reactive power to control voltage
- PV reduces the real load (kW) while increasing the reactive load (kVAr), which creates a significant change to power factor
- Reactive power can also create a voltage phase-unbalance

Conclusions

- With increasing penetrations of solar on the distribution system, reactive power capabilities of inverters can be used to support voltage and mitigate any over voltage conditions caused by real power output
- Detailed analysis was shown to demonstrate the exact impact of PV output power factor and reactive power on the distribution system voltage for several different methods
- The expansion of PV and distributed generation to high penetrations on the distribution system requires intelligent and well controlled devices to ensure reliable service and minimal impact to the existing customers.

Questions?