Solar Photovoltaic Modeling Impacts on Distribution Systems – Case Study

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OUTLINE

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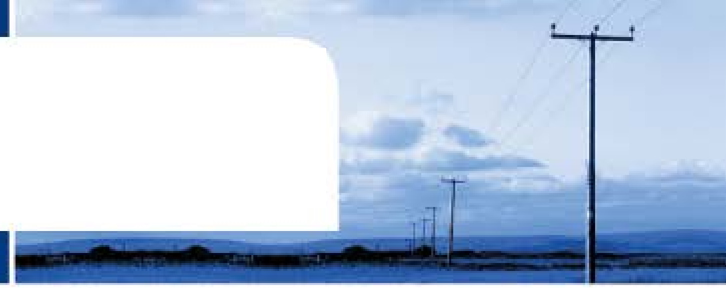
- **PV Plant Modeling**
  - PV Arrays
    - Tilt, angle and ratings
    - Insolation Curves
  - Inverters and Operating Modes
- **Line Voltage Regulator Operating Modes**
- **Loads**
  - Local Feeder Load Review
  - Coincidence with Solar Plant generation profiles
- **Case Study with 2 MW PV Plant**
  - Voltage Issues with Step Voltage Regulators
  - Inverter Operating Mode Effects

1547 Interconnection Series



SCC21 Standards Coordinating Committee on Fuel Cells, PV, DG, and Energy Storage

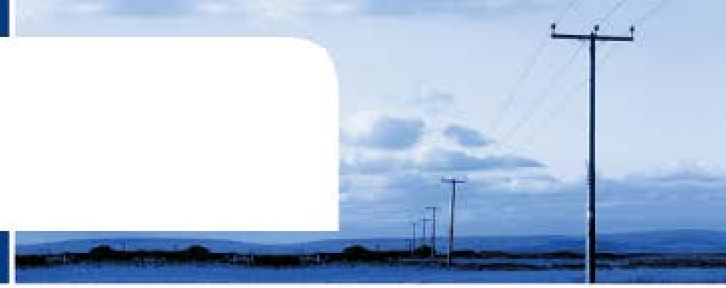
1547 Interconnection Series

1547 (2008)	Standard for Interconnecting Distributed Resources with Electric Power Systems
1547-1 (2005)	2005 Standard for Conformance Tests Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems
1547-2 (2008)	Application Guide for IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems
1547-3 (2007)	Guide For Monitoring, Information Exchange, and Control of Distributed Resources Interconnected with Electric Power Systems
1547-4 (2011)	Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems
1547-6 (2011)	Draft Recommended Practice For Interconnecting Distributed Resources With Electric Power Systems Distribution Secondary Networks
1547-7 (Draft)	Draft Guide to Conducting Distribution Impact Studies for Distributed Resource Interconnection
1547-8 (Draft)	Recommended Practice for Establishing Methods and Procedures that Provide Supplemental Support for Implementation Strategies for Expanded Use of IEEE Standard 1547

Solar PV Plant Components

- Panels – DC Ratings in Watts
- Panels create collectors
- Collectors mounted on tracking system
- Inverters
- Interconnect Step-Up Transformer

Inverter Operating Modes



- Fixed Power Factor (Unity, Q=0)
- Fixed Power Factor (Q≠0)
  - Maintain a Fixed PF at the POI, e.g. maintain between 0.98 lag and unity
- Voltage Droop
  - Increase/Decrease Q linearly based on Voltage at POI within limits. Inverters rating based on voltage, so voltage decrease means can increase Q, and vice versa.
- Voltage Control
  - Regulate a set point voltage at the POI by allowing inductive or capacitive Q within the limits of the inverter

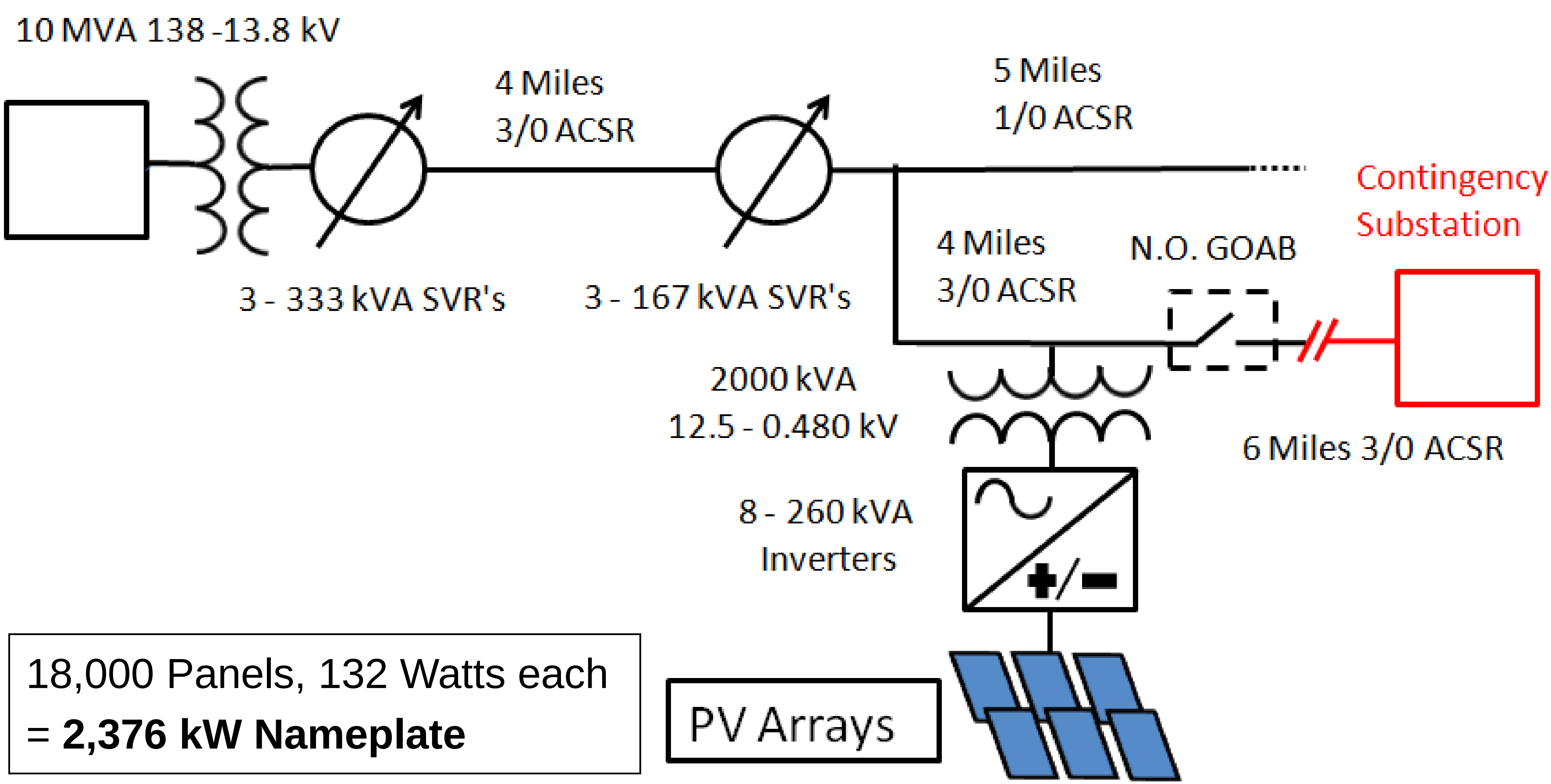
Traditional deployment is to size inverters for PV Array de-rated AC kW due to IEEE 1547 standard, and operate in Unity PF mode.

…..Why not oversize the inverter to gain reactive power potential?….

Case Study

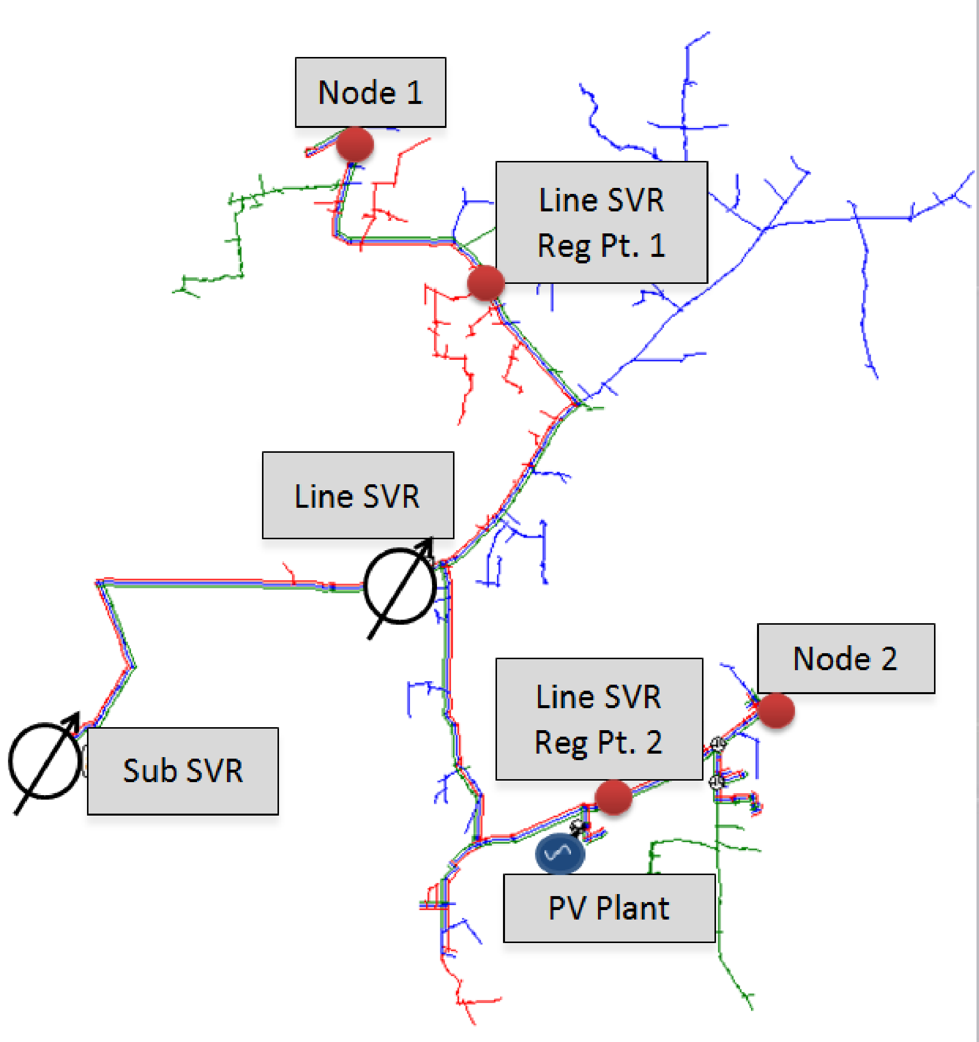
- 2 MW PV Plant integration with electric cooperative system in southern U.S.
- Use fully detailed, field verified Milsoft WindMil engineering model including secondary services (transformers, triplex, etc)
- System Impact Study in preliminary data gathering stage
- Analyze situation for possible adverse operating conditions due to PV

Case Study Feeder – One-Line



18,000 Panels, 132 Watts each
= **2,376 kW Nameplate**

Case Study Feeder Layout



Line SVR Reg Pt. 1 and Reg Pt. 2 reflect summer load profiles/load shapes

Accumulated X/R of 1.3 at Line SVR Reg Points

Existing Regulator Settings

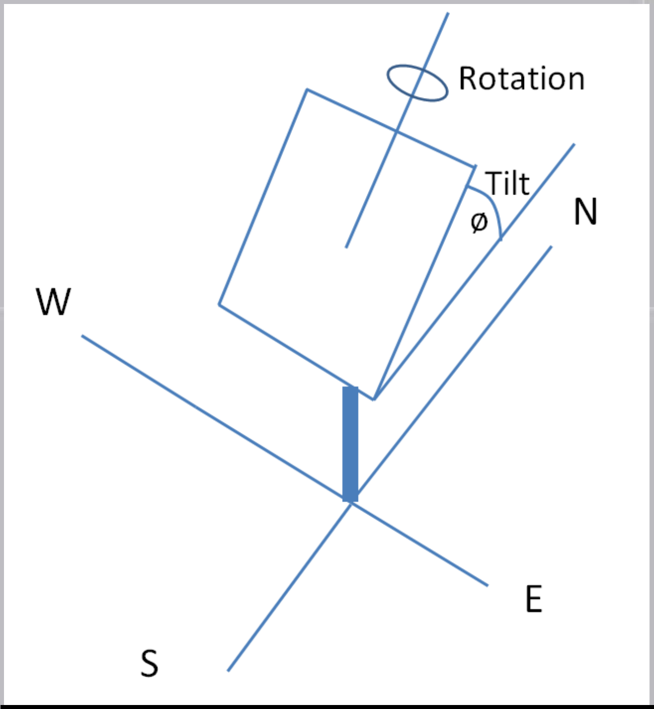
	Sub SVR	Line SVR	Line SVR Reverse
Voltage	122	119	126
LDC R	0	5.7	0
LDC X	0	7.1	0
Time Delay	30	45	45
Bandwidth	2	2	2

PV Plant Component Derating

Item	Factor
Module nameplate DC rating	0.95
AC and DC wiring	0.97
Inverter Mismatch	0.98
Inverter Efficiency	0.965
Transformer Losses	0.95
Dirt and Debris	0.95
Total Derating	**0.79**
Total DC kW Rating of Panels	**2,376**
Net Rating	***1,877 kW***

Reference : NREL PVWatts Grid Calculator

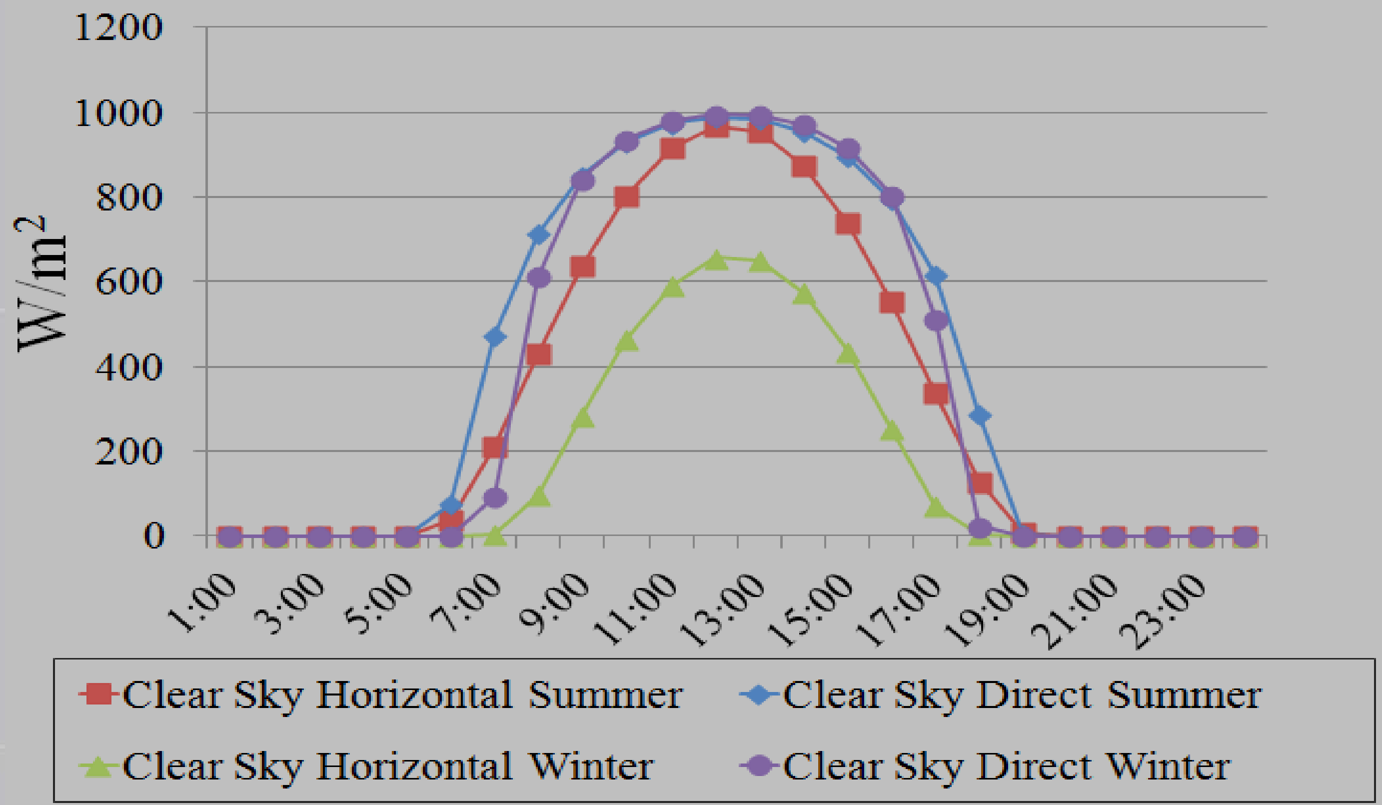
Array Types



Fixed Tilt, one axis rotation

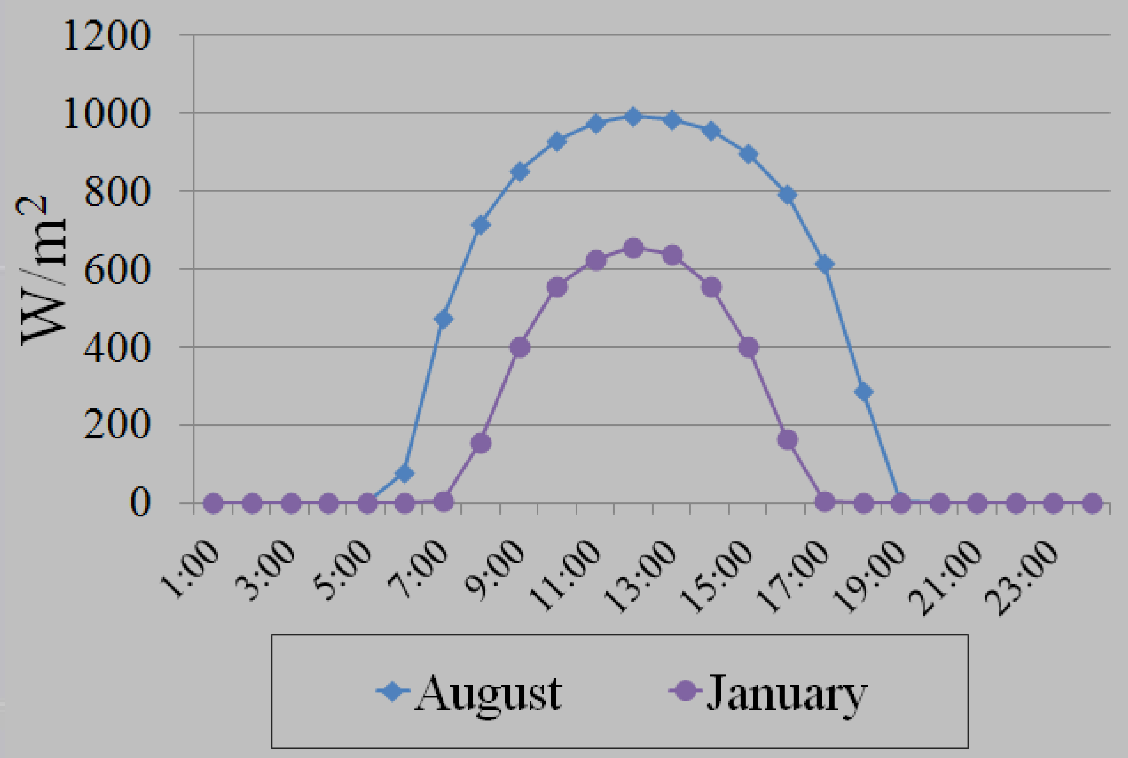
Case Study Collectors are horizontal (no tilt), but rotate +/- 55 degrees east/west (110 degrees total) for sun tracking capability

Clear Sky Insolation Profiles at Site



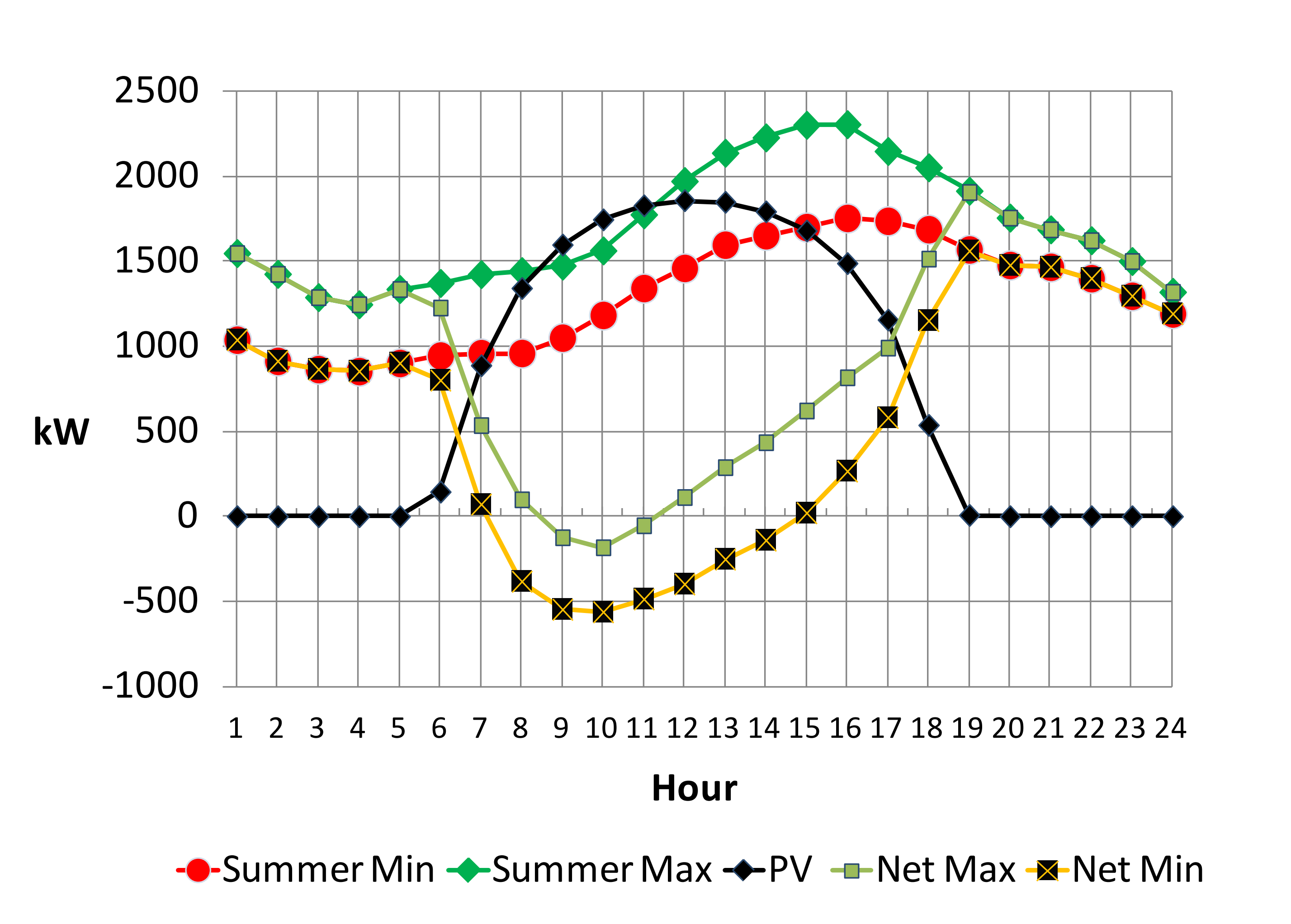
Source: National Renewable Energy Laboratory (NREL) METSTAT (Meteorological/Statistical) solar radiation model. Developed to support production of the NSRDB (National Solar Radiation Database. Estimates hourly values of direct normal, diffuse horizontal, and global horizontal radiation.

Insolation Profile – Case Study Location

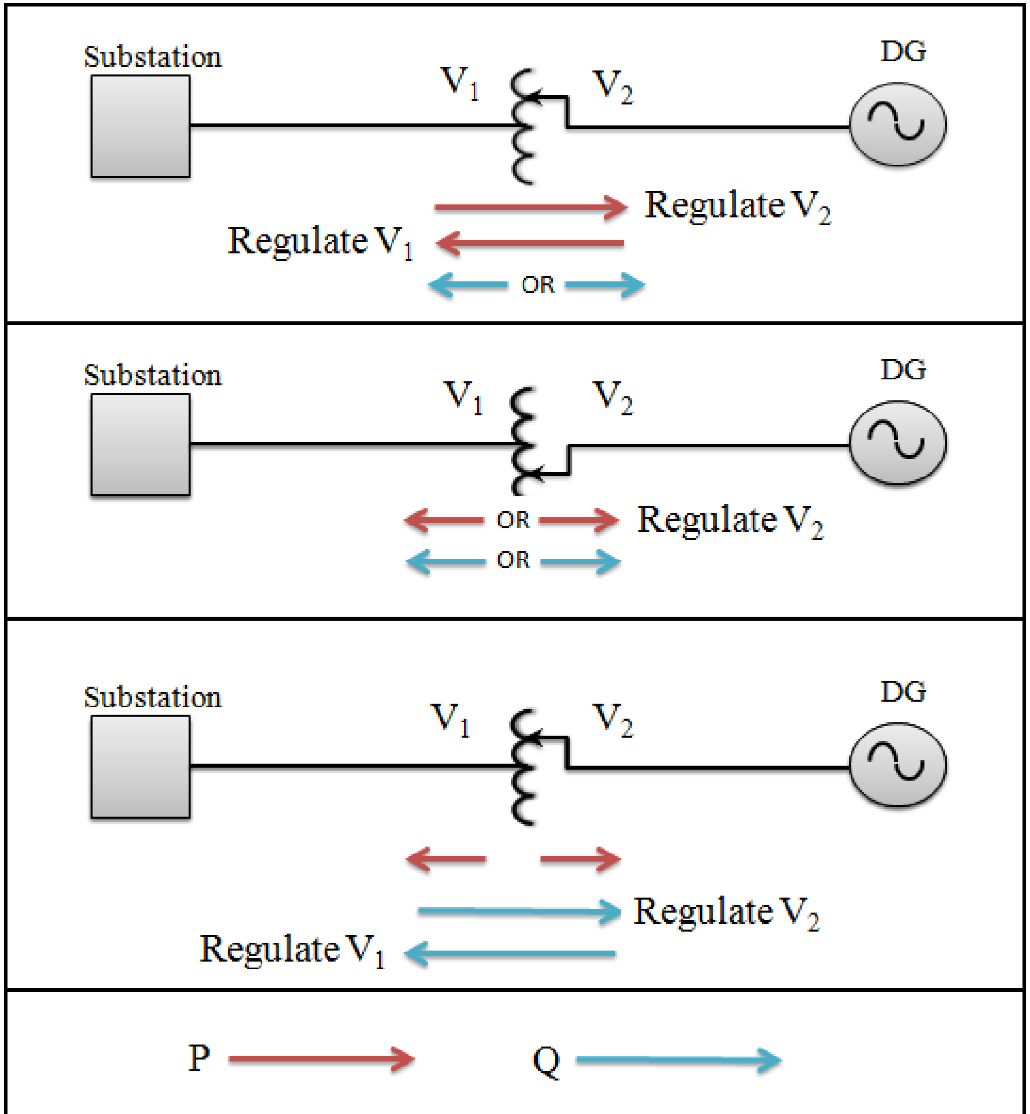


Insolation Profiles multiplied by de-rated kW (1877 KW) of PV Plant used to develop kW insolation curves for case study.

Summer Load Profiles With and Without PV



Voltage Regulator Operating Modes



Bi-Directional --
V_1 or V_2 controlled based on real current component direction

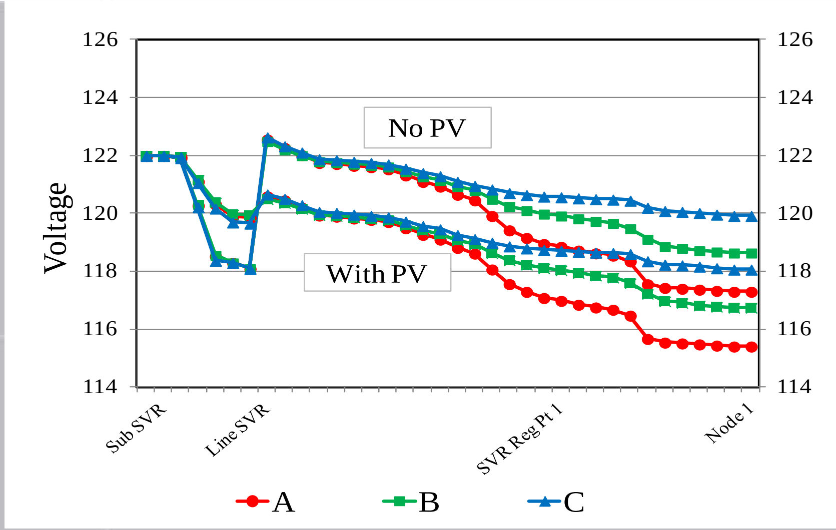
Co-Generation –
V_2 controlled during forward and reverse active current flow

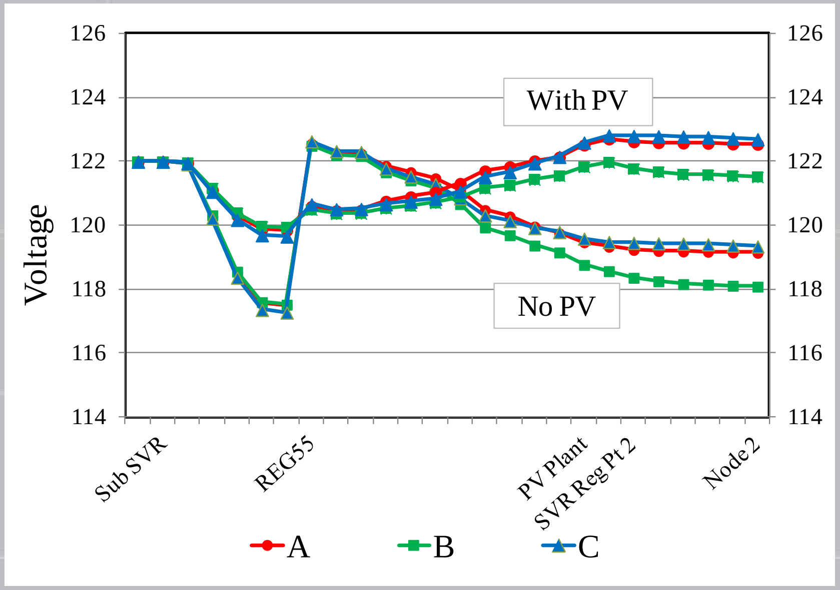
Reactive Bi-Directional --
V_1 or V_2 controlled based on reactive current direction

Case Studies

- Case 1: Affects on Line Drop Compensation
- Case 2: Reverse Power Flow with **Bi-Directional** Mode on Line Regulator
- Case 3: Reverse Power Flow with **Co-Generation** Mode on Line Regulator and Inverters in Unity Power Factor Mode (voltage following)
- Case 4: Reverse Power Flow with **Co-Generation** Mode on Line Regulator and Inverters in Active Voltage Regulating Mode
- Case 5: Ramping/Intermittency

Case 1: Voltage Profiles





Summer 3 p.m.,2300 kW local load, 1600 kW PV generation (700 kW net)

Node 1

- Prior to PV, ANSI Range A met
- With PV, Phase A voltage violation

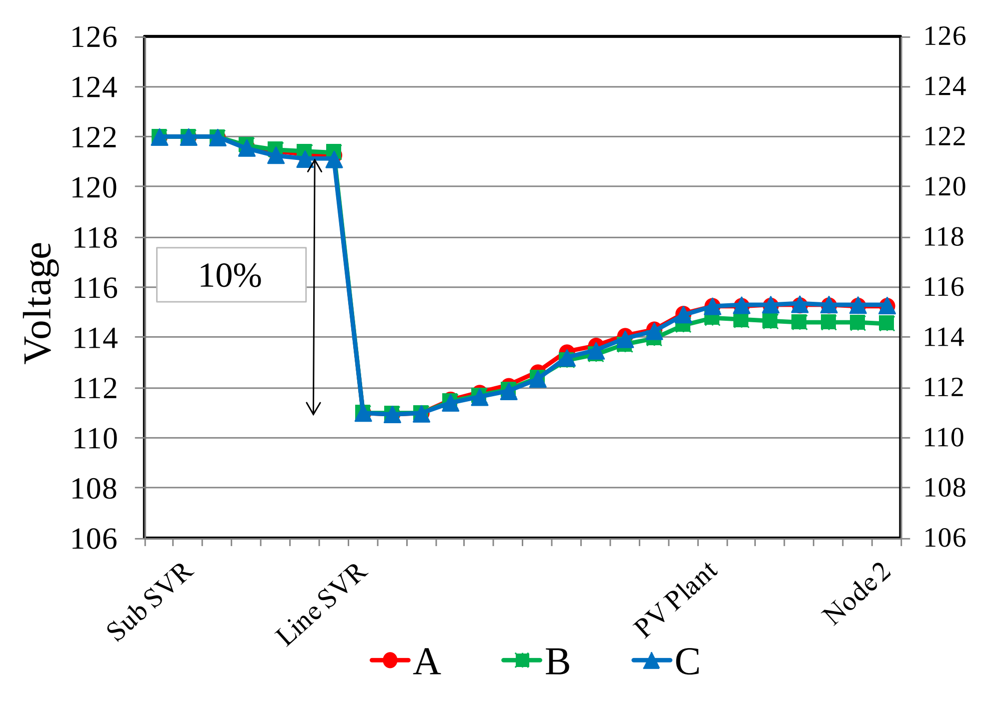
Node 2

- ANSI Range A met before and after PV contribution.
- Note V rise from Line SVR to PV due to reverse power flow

Note Line SVR LDC voltage boost reduced from ~5 V to ~2V

Case 2: Reverse Power Flow Through Line SVR

Node 2 Voltage Profile



Line SVR ratchets until it taps to maximum creating 10% voltage change across SVR

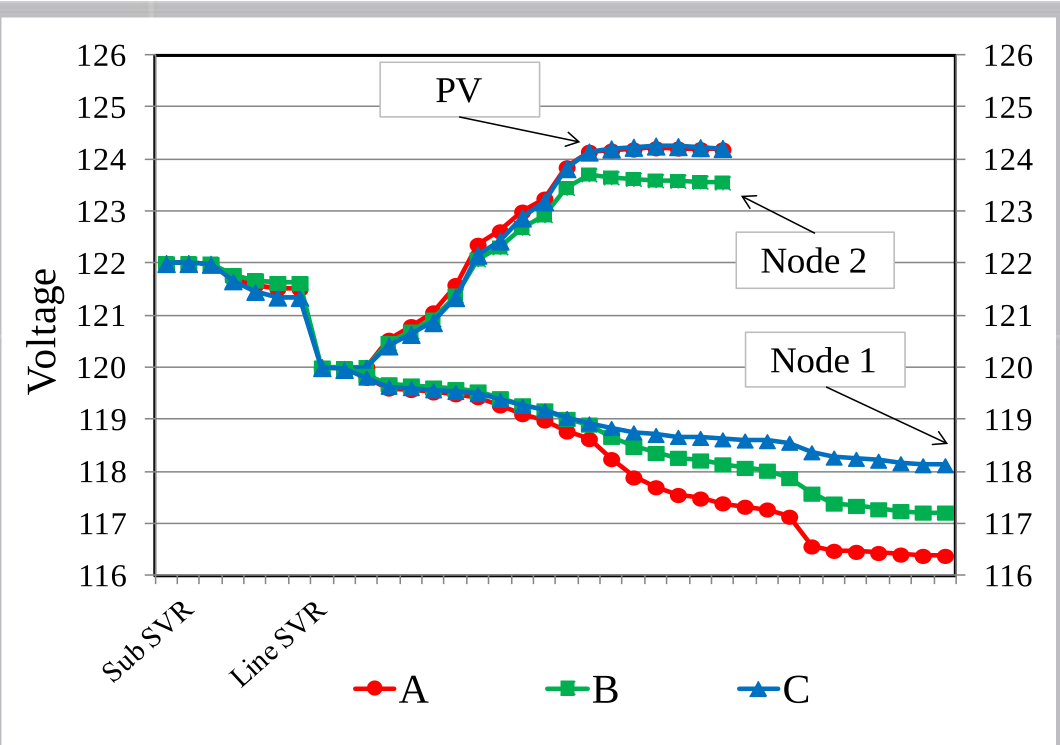
- Substation SVR set to 122 V
- Line SVR reverse mode set to 126 V
- Substation side of Line SVR < 126 Volts, thus Line SVR will ratchet until reaching max tap.

Potential to occur whenever active current is reversed (PV > Load),

9 a.m. – 3 p.m. winter

7 a.m. – 3 p.m. summer

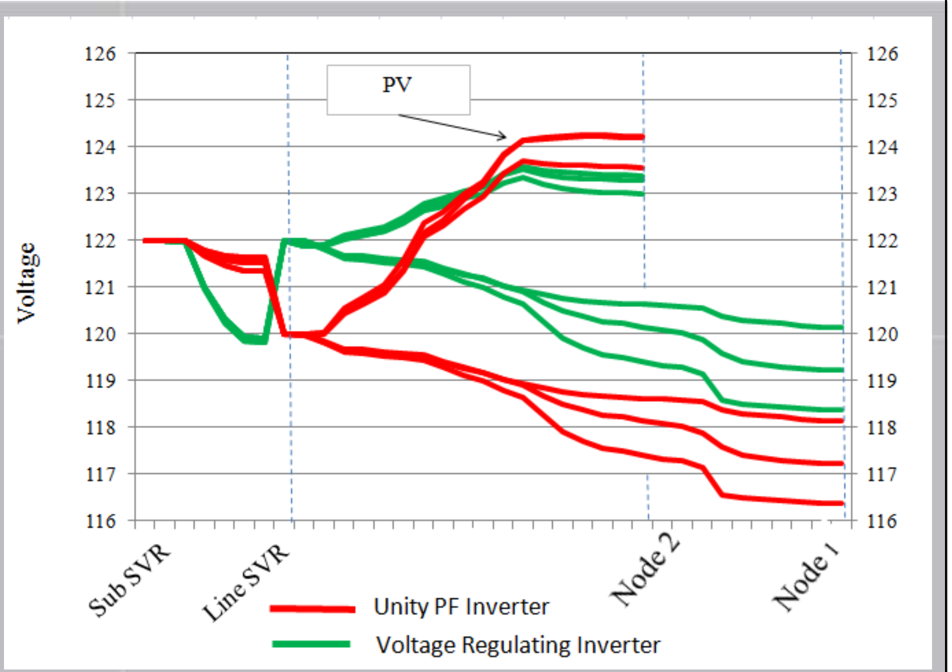
Case 3: Reverse Power Flow with SVR Co-Gen Mode and Unity PF Inverter

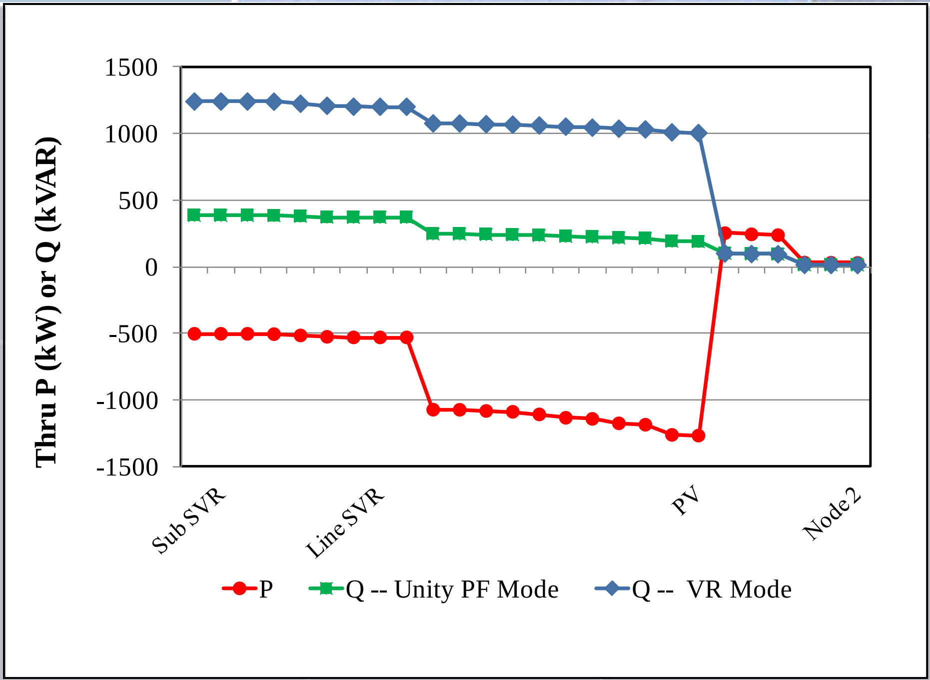


- Co-Gen Mode set to 120 Volts
- Note 8 Volt difference on Phase A between nodes 1 and 2

How can this voltage band be tightened?

Case 4: Reverse Power Flow with SVR Co-Gen Mode and Inverter Holding Voltage





- Increase Line SVR Co-Gen Voltage to 122 V to improve voltage at Node 1
- Inverter set to hold 123.5 V at POI.

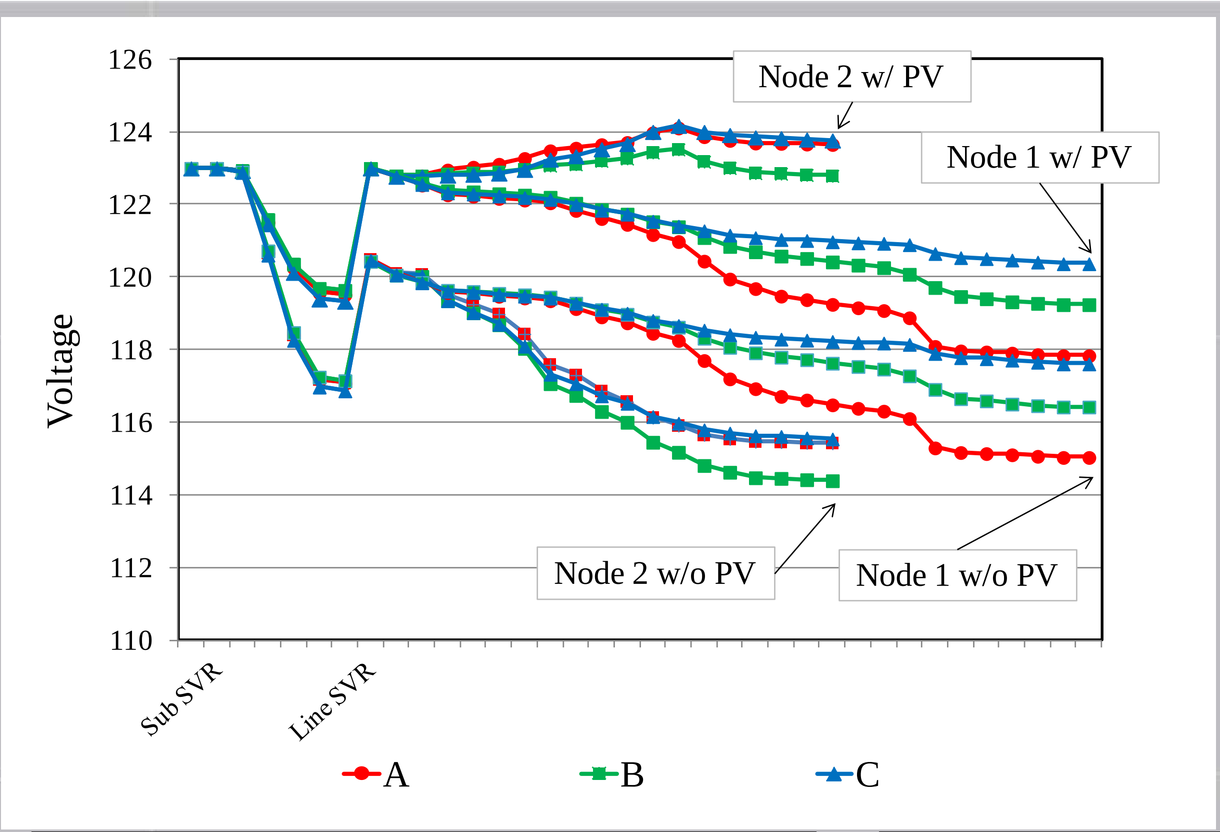
- Allow Inverter to absorb kVAR to increase voltage drop from SVR to Node 2
- PV absorbs ~1000 kVAR

Case 5: Ramping due to Clouding

- Calculated reasonable ramp rate of ~30 seconds from peak generation to no generation
- Simulation --» conduct load flows for each of the following to find SVR tap positions with generator in unity power factor mode:
  1. Peak load w/ maximum coincidental PV kW
  2. Minimum load w/ maximum coincidental PV kW
  3. Peak PV at 12 p.m. with maximum coincidental circuit load
- --» Eliminate PV generation to find ΔV

Similar to PV disconnecting from EPS fault requiring PV to disconnect per IEEE 1547

Case 5: Worst Case Voltage Change



- Summer Case:
  → 2300 kW load
  → 1700 kW PV
- Sub SVR = 123 volts
- Co-Gen = 123 volts

<u>With Generation</u>

Regulators on Tap 5 →

4 volt boost

<u>Without Generation</u>

5 Volt Drop from Line SVR to PV

Δ ***V* = 9 volts, phase B, Node 2 or ~ 7%**

Summary

- IEEE 1547 Series are Key Resources
- Make sure to model step voltage regulators and inverters correctly in engineering analysis software
- PV Plant Modeling and Load Review must cover:
  - Insolation Profiles
  - Coincidence of PV Output Availability Coincident with local Load
  - Operating Modes of Inverters
  - Operating Modes of Regulators
- Case Studies presented existing system loads and regulator settings to show voltage issues with PV contribution and unity PF Inverter modes
- Possible remediation’s using SVR Co-Generation Modes and non-unity PF inverter modes were presented.
- Worst case voltage profiles due to intermittency and/or generation disconnect were presented
- Continue to keep an eye on IEEE 1547-8 progress

Thanks for your attention

Questions/Comments?

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