PV System and Load Models for Power Flow Analysis

Distribution System Modeling for PV Integration Workshop
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Milsoft's WindMil Engineering Analysis

- *Full Transmission/Distribution/Secondary Service Analysis*
- *Unbalanced By-Phase Analysis*
  - *Line Spacing*
  - *Full Transposition*
  - *3x3 "Phase-Frame" unbalanced impedance matrix rather than sequence impedances used in balanced, transmission flows*
- *Full secondary service modeling including center tapped transformers and triplex/quadriplex cable*
- *Model entire power system down to the customer meter*

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Solar PV Models

- *Two Options for Load Flow*
  - *Negative PQ load*
    - *Unity PF inverters such as residential rooftop*
    - *Larger inverters set with fixed PF*
    - *Simple current source with fixed P and Q injections*
  - *"Swing kVAR" –*
    - *Fixed P, Variable Q (defined by nameplate limits of inverter)*
    - *Represent inverters with inherent Q capability for voltage control*
    - *Power Flow iterates until level of reactive current (inductive or capacitive) is found that is required to hold specified voltage given fixed kW*
- *Fault Flow – Voltage source behind an impedance*

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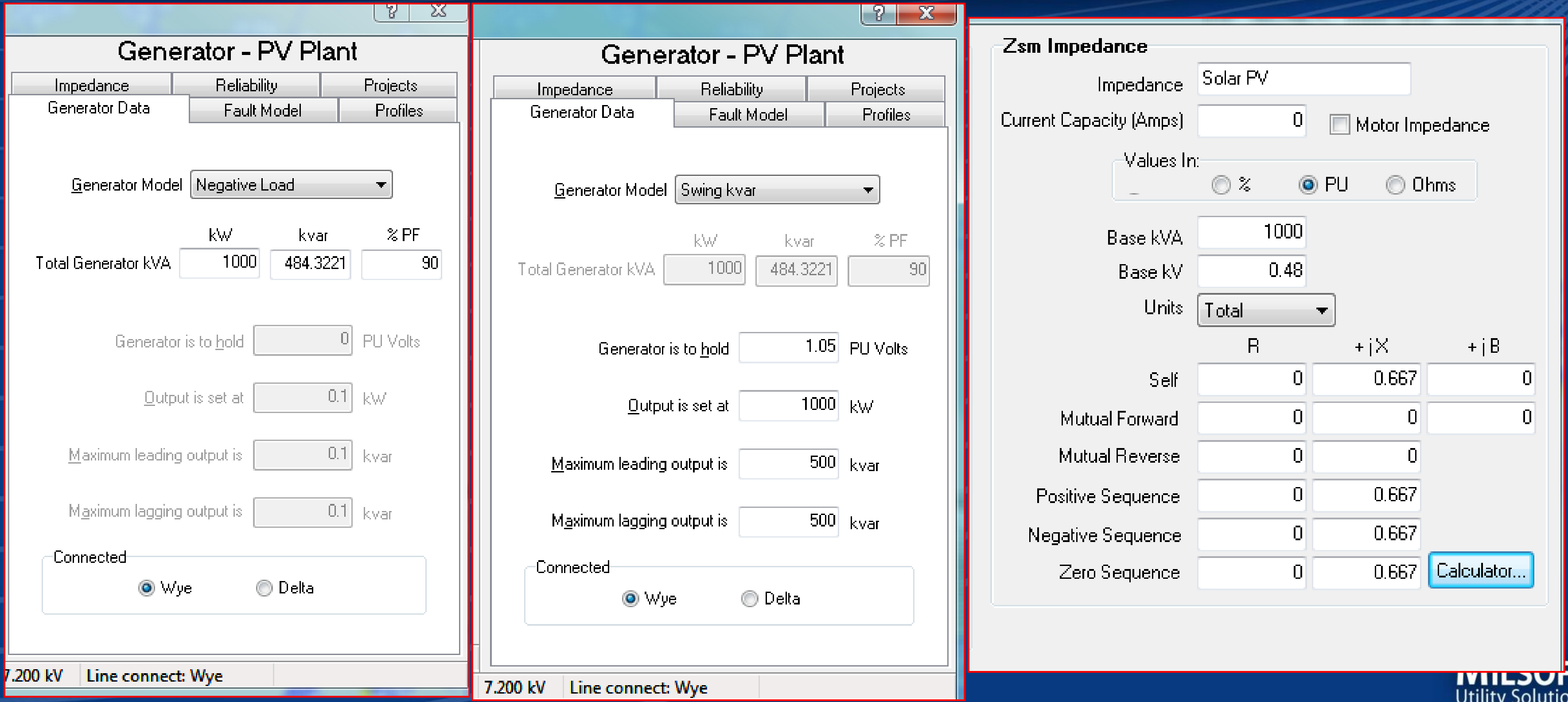
Solar PV Generator Model



Distributed Load Models – Allocation Methods

Good

Transformer kVA	REA Allocated	Seasonal Allocated

↓

Better

kWh Allocated	kW Diversity Fixed	kW Diversity Allocated

↓

Best

Coincidental kW (logged AMI readings)

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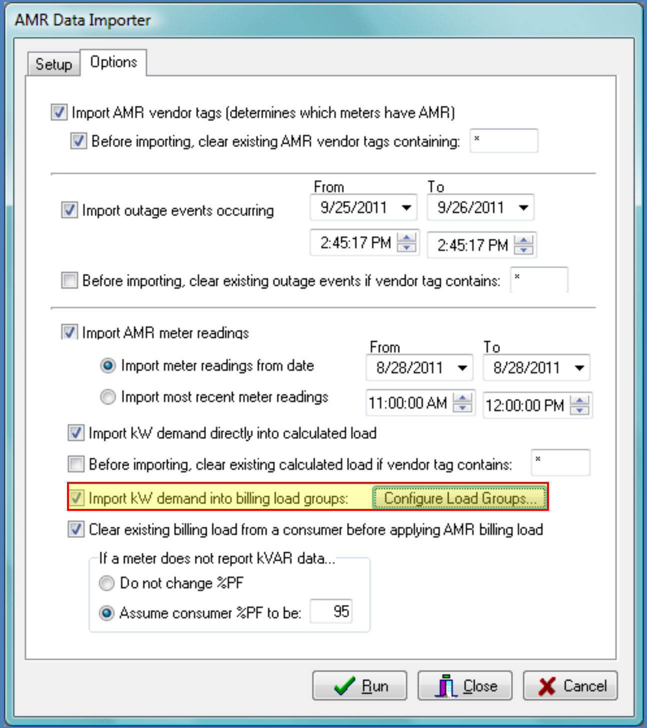
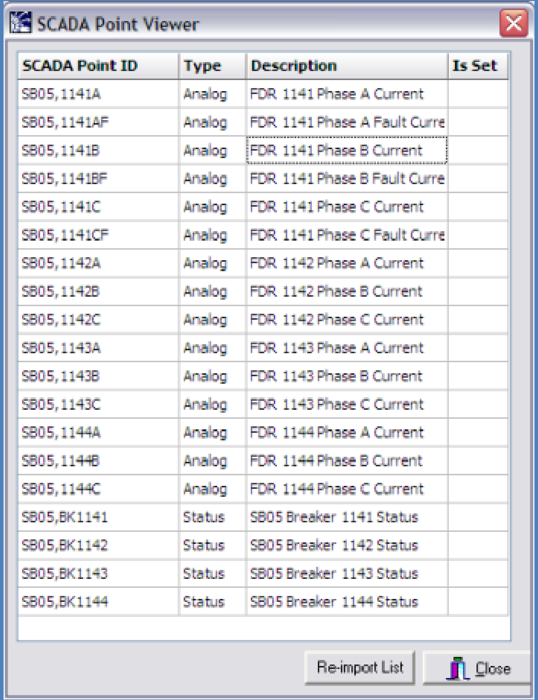
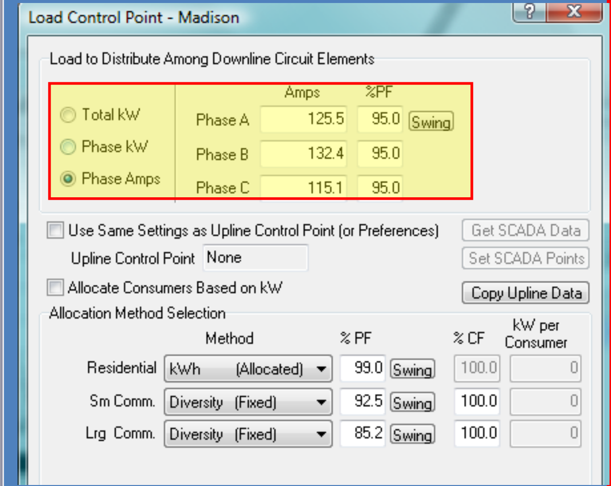
Data Retrieval Interfaces – AMR & SCADA



AMR





SCADA Load (kW, kVAR, Amps, PF)

WindMil's Project Management System

- *Uses a Project Management system to log loading levels and dynamic system states*
  - *Keeps system model accurate and updated "as built"*
- *Allows analysis at user specified time/load interval and/or system condition*
- *Analyze "what if" or "sensitivity" scenarios*
  - *regulator/capacitor settings*
  - *PV inverter modes or generation levels*
  - *new lines or upgrades*
  - *load growth*
  - *customer ZIP models*

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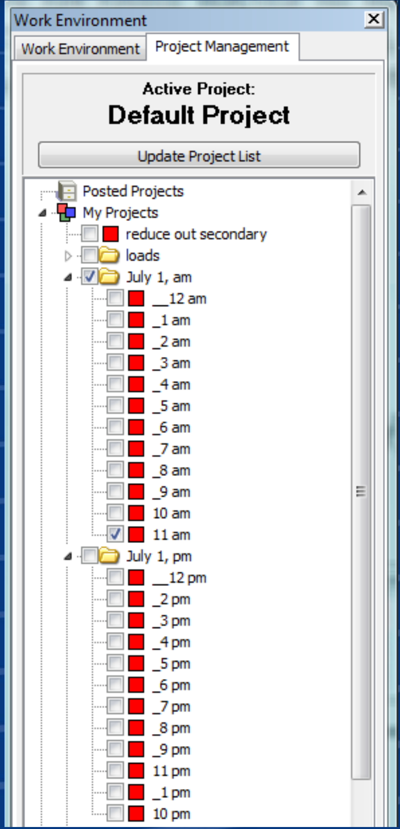
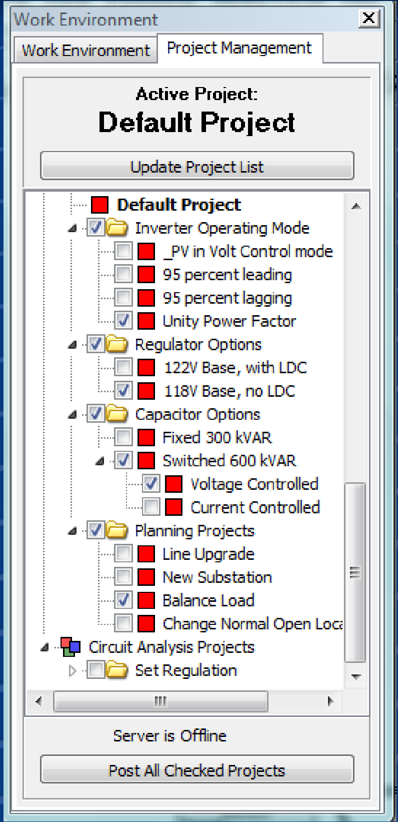
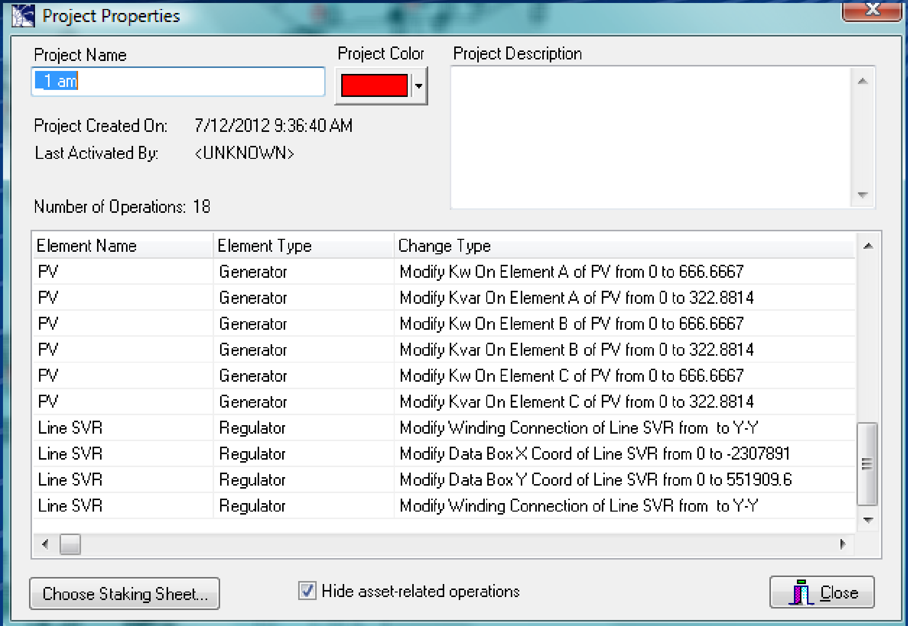
Project Management GUI’s







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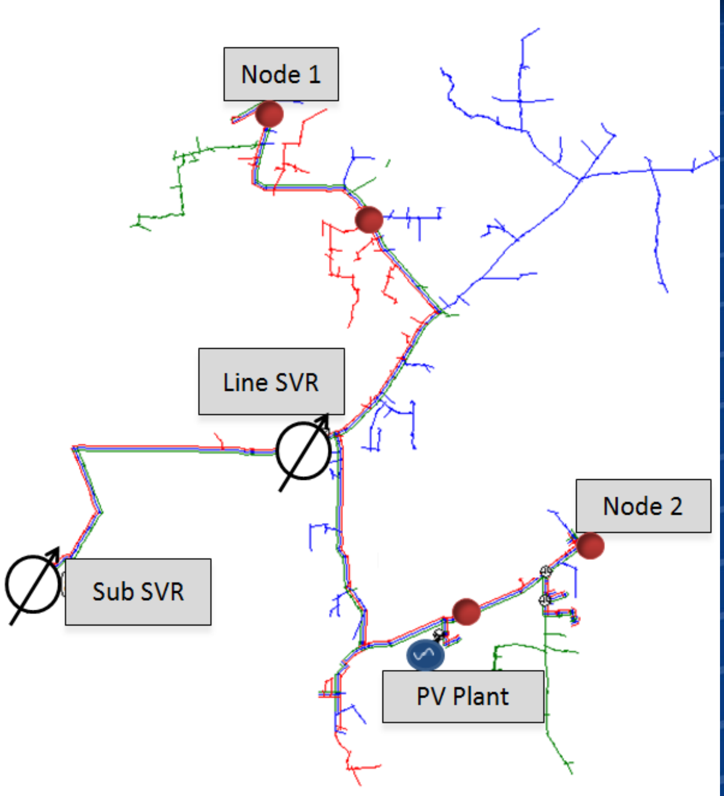
Power Flow Impacts - Case Study Examples



Type	Value
Primary Voltage (kV)	12.47
Peak Summer Load (kW)	2,300
Min. Summer Load (kW)	900
Peak Winter Load (kW)	3,000
Min. Winter Load (kW)	600
PV Max Summer (MW)	2.0
Substation SVR	122 V, No LDC 30 second delay, +/- 1V BW
Line SVR	119 V, LDC, R=6, X=7 60 second delay, +/- 1V BW Prior to PV, Reverse Power Mode (no Co-gen Mode)
Capacitors	1 – 300 kVAR, Fixed
Distance to Extremities	8 miles

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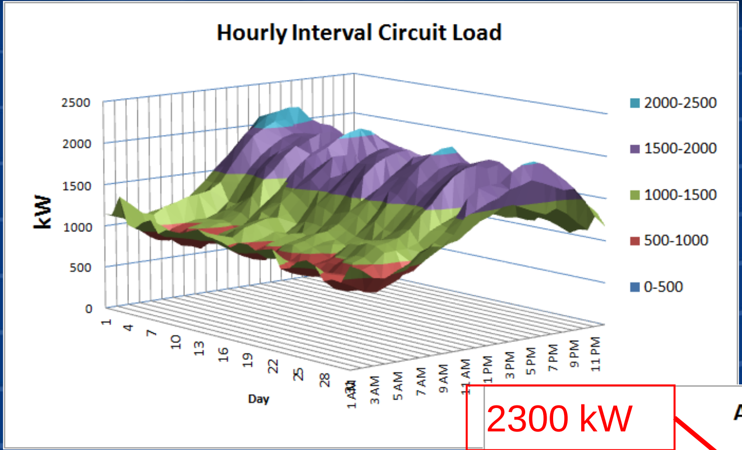
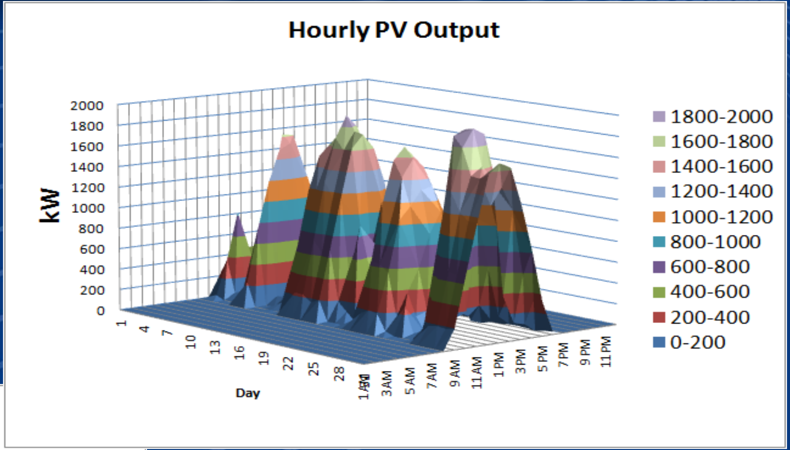
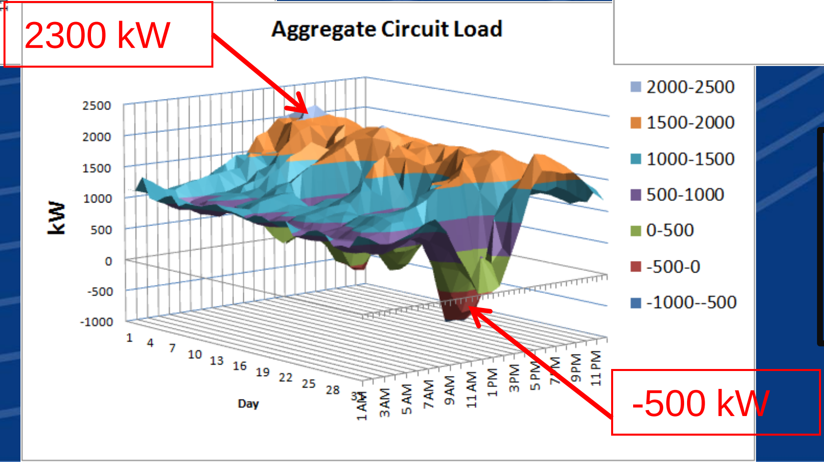
Power Flow Impacts - Circuit Loads



Circuit Load – PV Gen =
Aggregate Circuit Load





NREL /TMY Proxy Data. Interpolate points between direct and horizontal collector data for actual planned tracking system (horizontal arrays with +/- 55 degree azimuth tracking)

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Power Flow Impacts - Procedure

- *Load Allocation for Min and Max kW*
  - *Partial AMI deployment*
  - *Allocate AMI meter data first*
  - *Allocate remainder of feeder demand from SCADA system using kWh allocated method*
- *For PV Generation, use proxy insolation data. Interpolate for flat horizontal arrays tracking on the azimuth +/- 55 degrees*
- *Create projects with test case loads in Project Management System*

Power Flow Impacts - Test Cases

1. *Affects on line regulator LDC*
2. *Reverse Power Flow with bi-directional reverse settings on line regulator (no Co-Gen)*
3. *Reverse Power Flow with Co-Gen Mode on line regulator*
4. *Inverter Regulating/Holding Voltage*
5. *Intermittency/Ramping Affects*

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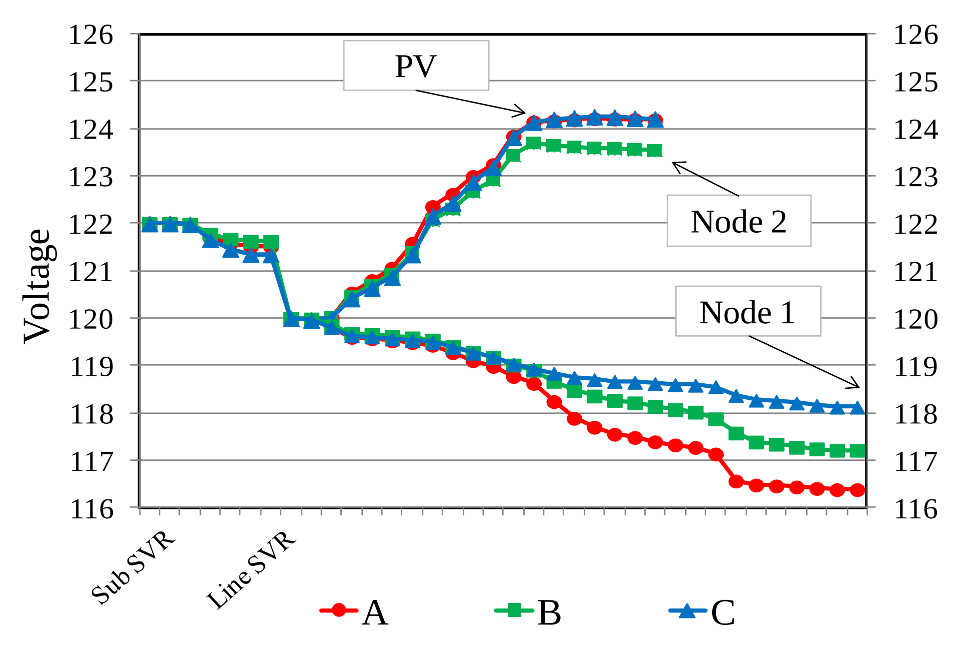
Case 3 - Reverse Power Flow with SVR Co-Gen Mode and Unity PF Inverter



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

How to tighten band?

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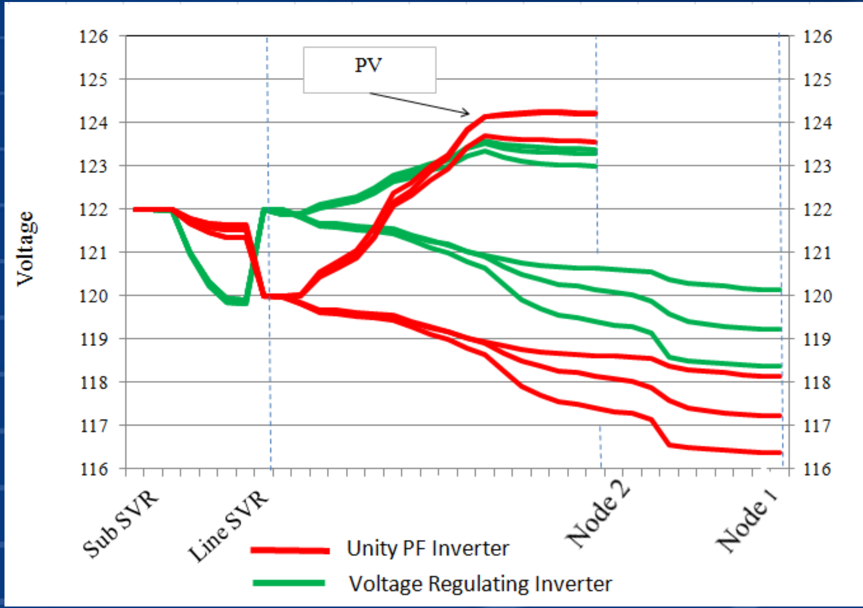
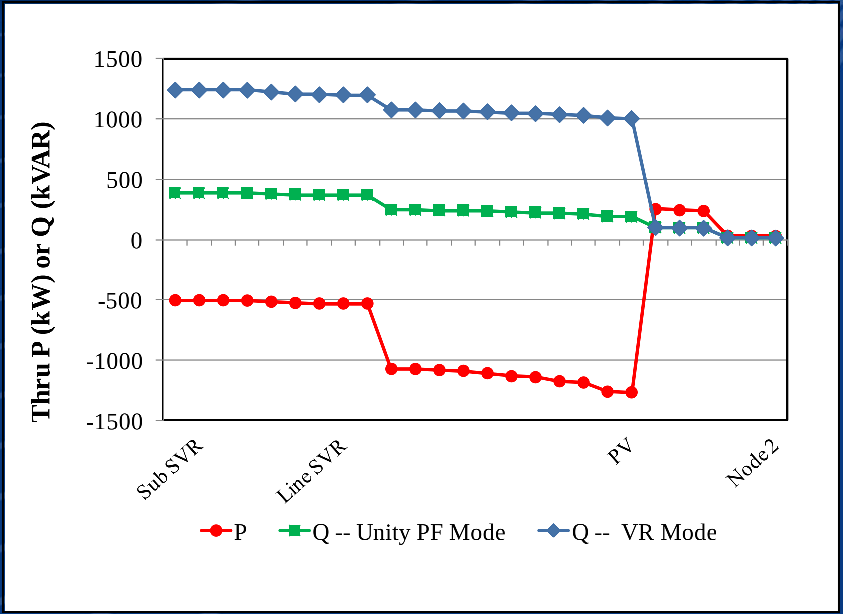
Case 4 - Reverse Power Flow with SVR Co-Gen Mode and Inverter Holding Voltage





- 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

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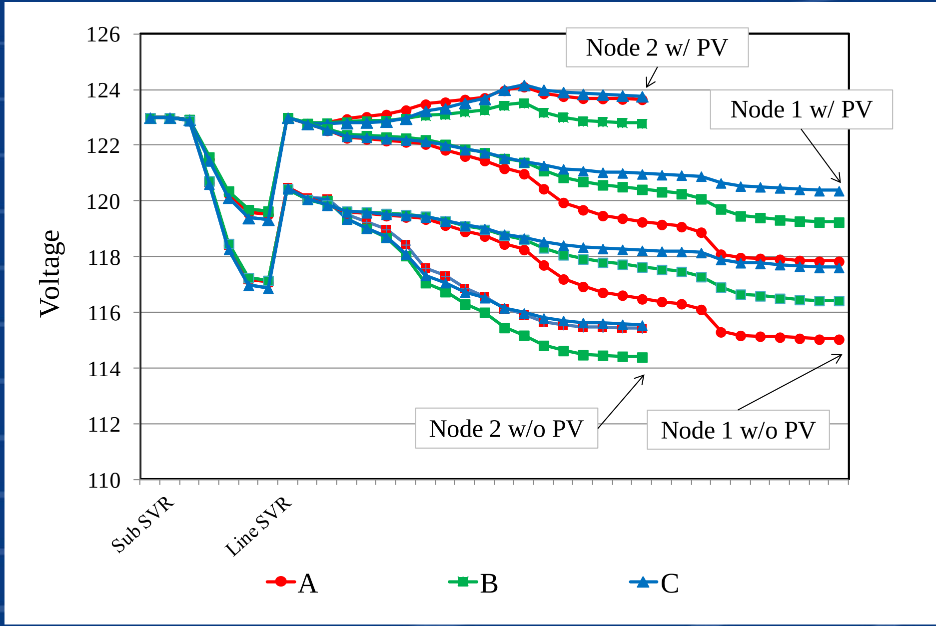
Case 5 – PV Ramping Faster than SVR Time Delay



With Generation

Regulators on Tap 5 → 4 volt boost

Without Generation

5 Volt Drop from Line SVR to PV

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

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Summary

- *Generation levels and inverter operating modes represented by Negative Load (PQ) and Swing kVAR (PV) generator models*
- *Distributed Load Models*
  - *Variety of allocation methods based upon data availability*
  - *Interfaces with AMI/SCADA to ease allocation unknowns*
- *Power Flow Impact Studies leverage Project Management System to activate and investigate:*
  - *"Worst Case" load/generation states*
  - *Line voltage regulator operating modes*
  - *Inverter operating modes*
  - *PV affects on any system change*

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Thanks for your attention

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