

PV System and Load Models for Power Flow Analysis

Distribution System Modeling for PV Integration Workshop

La Jolla, CA

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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*

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*

Solar PV Generator Model

Generator - PV Plant

Impedance Reliability Projects
Generator Data Fault Model Profiles

Generator Model: **Negative Load**

	kW	kvar	% PF
Total Generator kVA	1000	484.3221	90

Generator is to hold: PU Volts

Output is set at: kW

Maximum leading output is: kvar

Maximum lagging output is: kvar

Connected: ☒ Wye ☐ Delta

7.200 kV Line connect: Wye

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Zsm Impedance

Impedance: **Solar PV**

Current Capacity (Amps): ☐ Motor Impedance

Values In: ☐ % ☒ PU ☐ Ohms

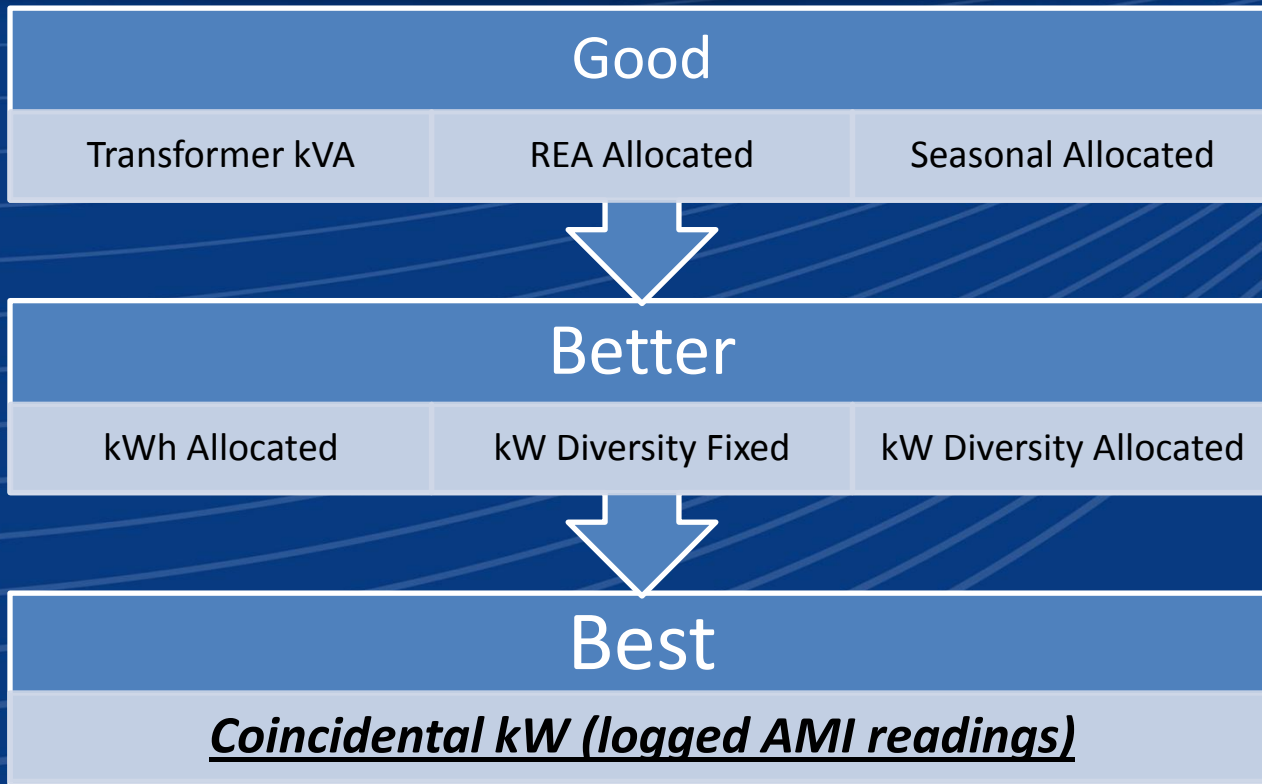
Base kVA:

Base kV:

Units: **Total**

	R	+jX	+jB
Self	<input type="text" value="0"/>	<input type="text" value="0.667"/>	<input type="text" value="0"/>
Mutual Forward	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0"/>
Mutual Reverse	<input type="text" value="0"/>	<input type="text" value="0"/>	
Positive Sequence	<input type="text" value="0"/>	<input type="text" value="0.667"/>	
Negative Sequence	<input type="text" value="0"/>	<input type="text" value="0.667"/>	
Zero Sequence	<input type="text" value="0"/>	<input type="text" value="0.667"/>	<input type="button" value="Calculator..."/>

Distributed Load Models – Allocation Methods



Data Retrieval Interfaces – AMR & SCADA

AMR Data Importer

Setup Options

☒ Import AMR vendor tags (determines which meters have AMR)

☒ Before importing, clear existing AMR vendor tags containing: *

☒ Import outage events occurring

From: 9/25/2011 To: 9/26/2011

2:45:17 PM 2:45:17 PM

☐ Before importing, clear existing outage events if vendor tag contains: *

☒ Import AMR meter readings

☒ Import meter readings from date: 8/28/2011 To: 8/28/2011

☐ Import most recent meter readings: 11:00:00 AM To: 12:00:00 PM

☒ Import kW demand directly into calculated load

☐ Before importing, clear existing calculated load if vendor tag contains: *

☒ Import kW demand into billing load groups: [Configure Load Groups...](#)

☒ Clear existing billing load from a consumer before applying AMR billing load

If a meter does not report kVAR data...

☐ Do not change %PF

☒ Assume consumer %PF to be: 95

Run Close Cancel

AMR

SCADA Point Viewer

SCADA Point ID	Type	Description	Is Set
SB05,1141A	Analog	FDR 1141 Phase A Current	
SB05,1141AF	Analog	FDR 1141 Phase A Fault Current	
SB05,1141B	Analog	FDR 1141 Phase B Current	
SB05,1141BF	Analog	FDR 1141 Phase B Fault Current	
SB05,1141C	Analog	FDR 1141 Phase C Current	
SB05,1141CF	Analog	FDR 1141 Phase C Fault Current	
SB05,1142A	Analog	FDR 1142 Phase A Current	
SB05,1142B	Analog	FDR 1142 Phase B Current	
SB05,1142C	Analog	FDR 1142 Phase C Current	
SB05,1143A	Analog	FDR 1143 Phase A Current	
SB05,1143B	Analog	FDR 1143 Phase B Current	
SB05,1143C	Analog	FDR 1143 Phase C Current	
SB05,1144A	Analog	FDR 1144 Phase A Current	
SB05,1144B	Analog	FDR 1144 Phase B Current	
SB05,1144C	Analog	FDR 1144 Phase C Current	
SB05,BK1141	Status	SB05 Breaker 1141 Status	
SB05,BK1142	Status	SB05 Breaker 1142 Status	
SB05,BK1143	Status	SB05 Breaker 1143 Status	
SB05,BK1144	Status	SB05 Breaker 1144 Status	

Re-import List Close

SCADA Load (kW, kVAR, Amps, PF)

Load Control Point - Madison

Load to Distribute Among Downline Circuit Elements

		Amps	%PF
<input type="radio"/> Total kW	Phase A	125.5	95.0 Swing
<input type="radio"/> Phase kW	Phase B	132.4	95.0
<input checked="" type="radio"/> Phase Amps	Phase C	115.1	95.0

☐ Use Same Settings as Upline Control Point (or Preferences)

[Get SCADA Data](#)

Upline Control Point: None

[Set SCADA Points](#)

☐ Allocate Consumers Based on kW

[Copy Upline Data](#)

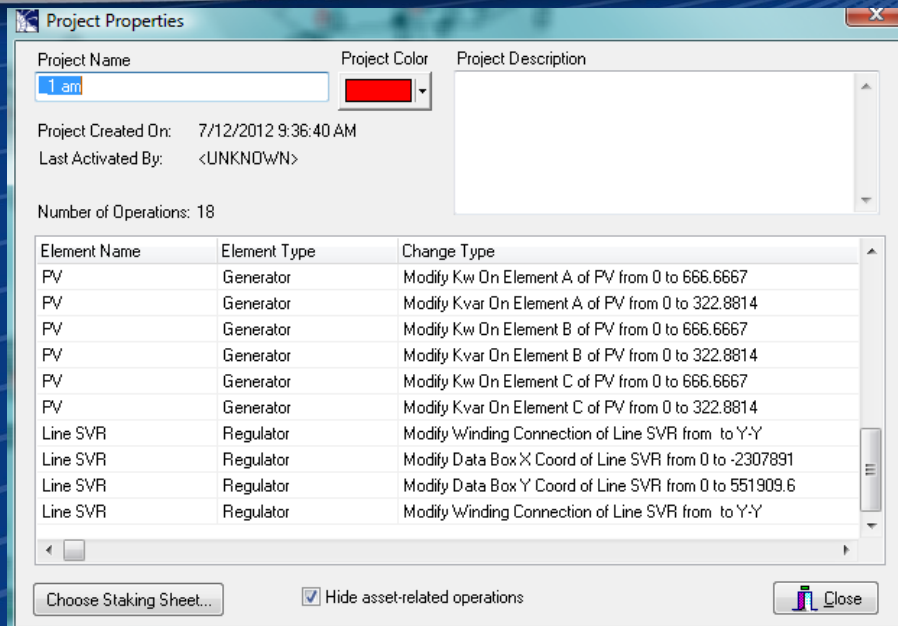
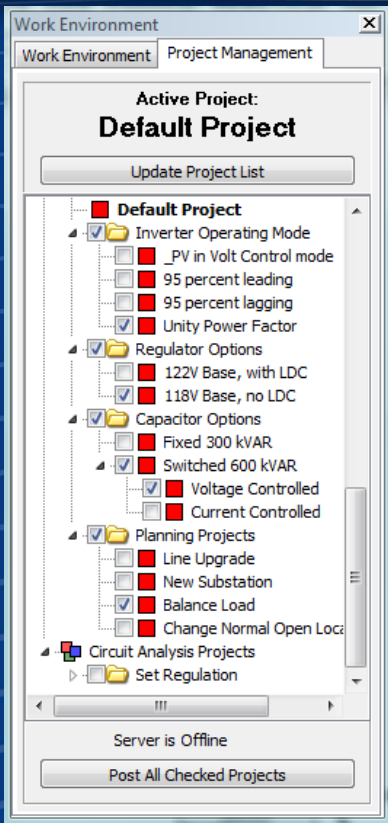
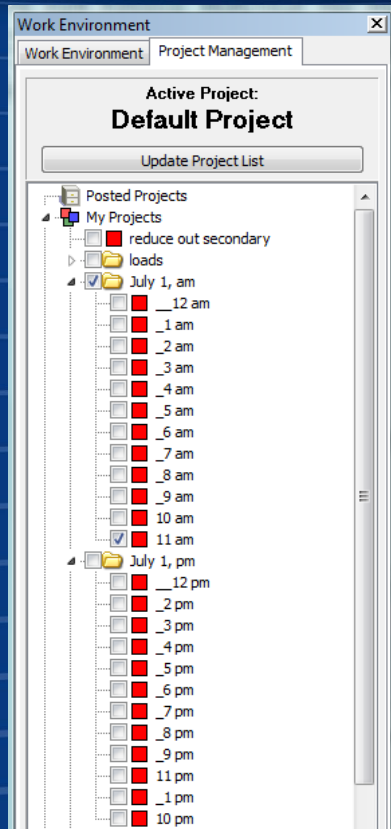
Allocation Method Selection

	Method	% PF	% CF	kW per Consumer
Residential	kWh (Allocated)	99.0 Swing	100.0	0
Sm Comm.	Diversity (Fixed)	92.5 Swing	100.0	0
Lrg Comm.	Diversity (Fixed)	85.2 Swing	100.0	0

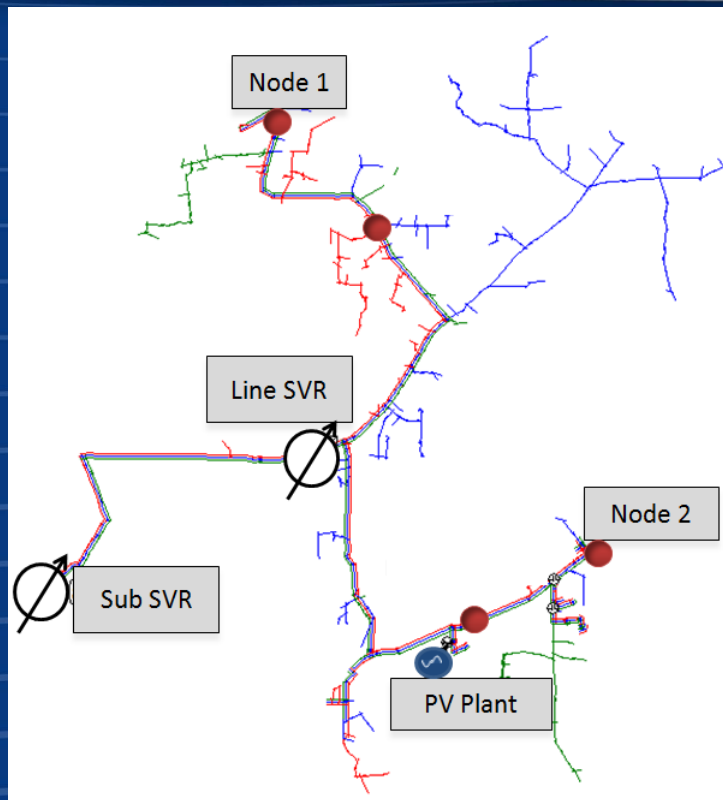
WindMil's Project Management System

- *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*

Project Management GUI's



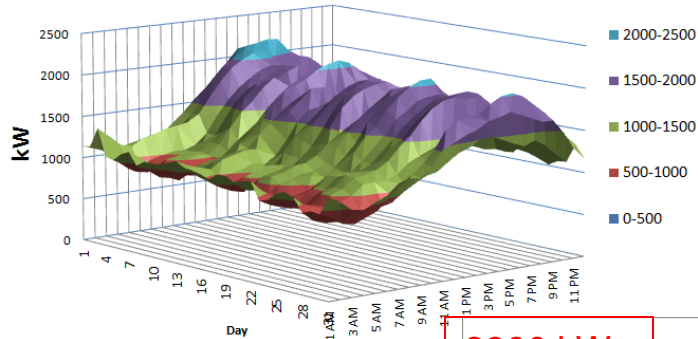
Power Flow Impacts - Case Study Examples



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

Power Flow Impacts - Circuit Loads

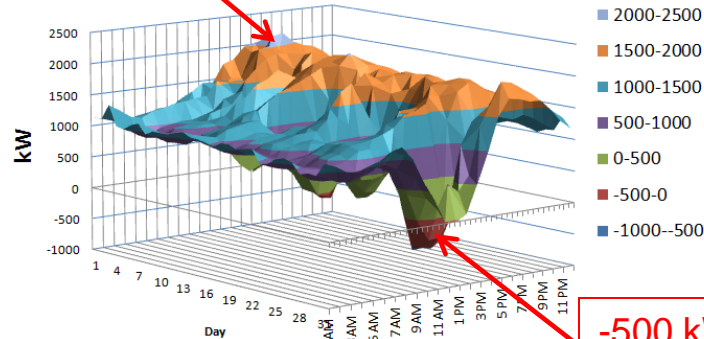
Hourly Interval Circuit Load



Circuit Load – PV Gen =
Aggregate Circuit Load

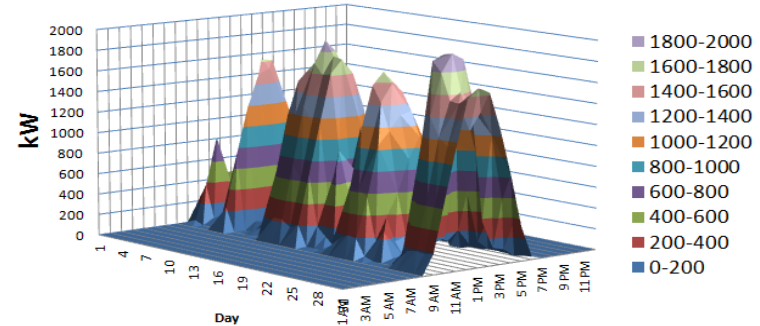
2300 kW

Aggregate Circuit Load



-500 kW

Hourly PV Output



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

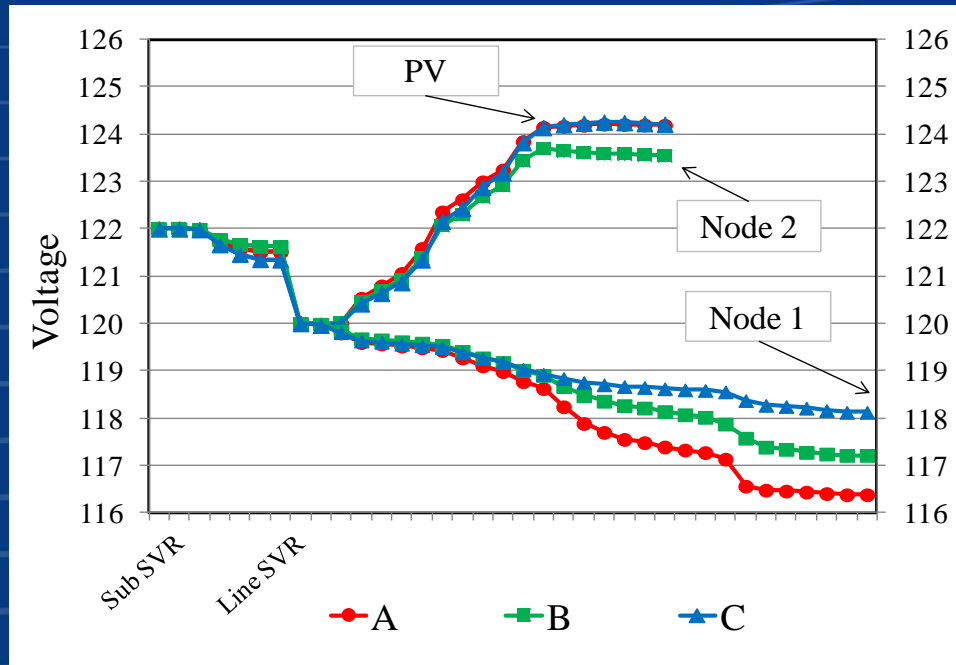
Power Flow Impacts - Procedure

- *Load Allocation for Min and Max kW*
 - *Partial AML deployment*
 - *Allocate AML 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*

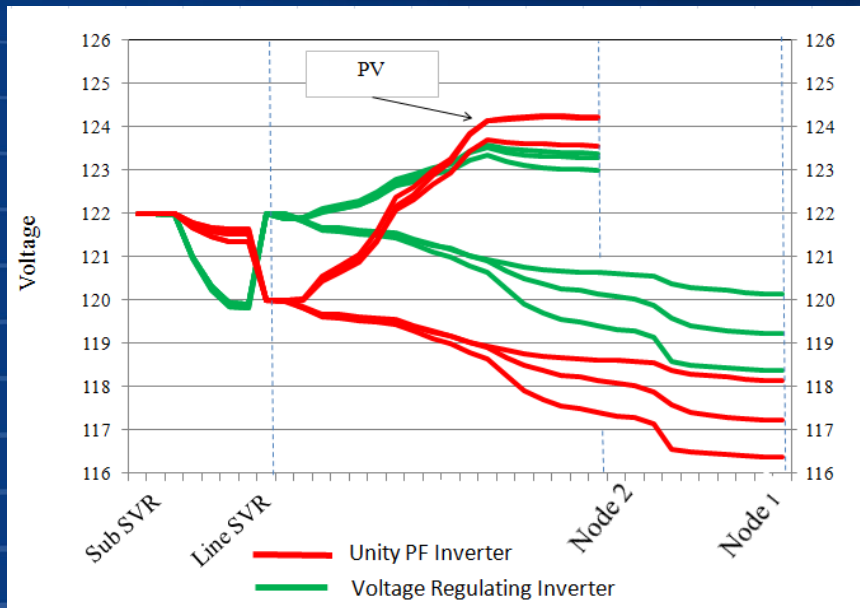
Case 3 - Reverse Power Flow with SVR Co-Gen Mode and Unity PF Inverter



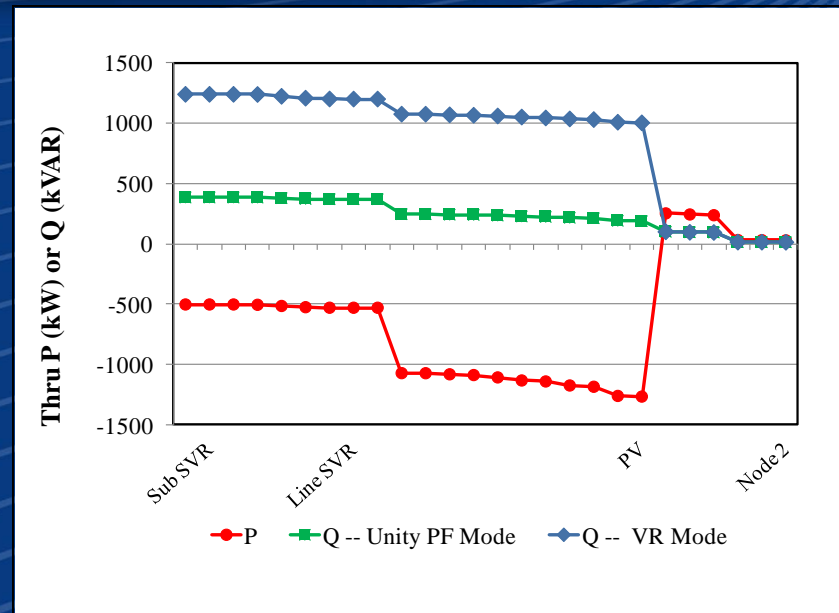
- Co-Gen Mode set to 120 Volts
- Note 8 Volt difference on Phase A between nodes 1 and 2

How to tighten band?

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

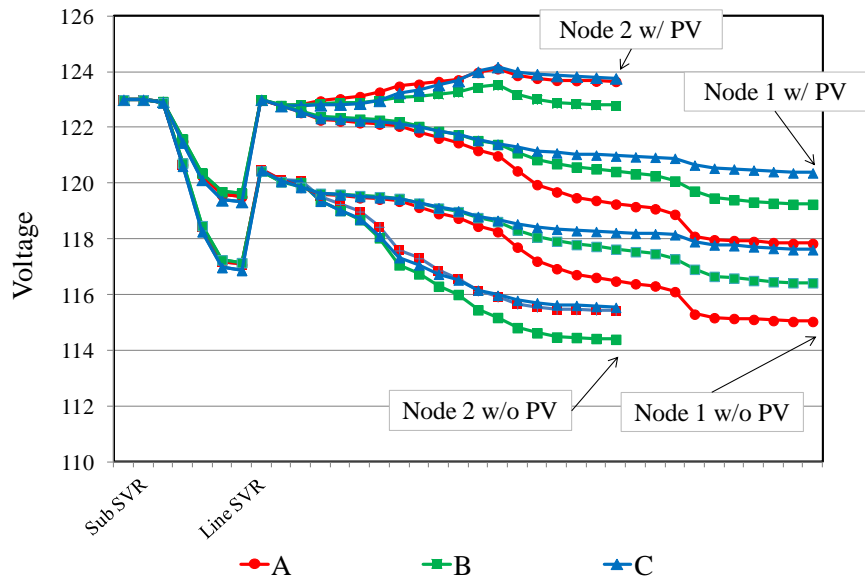


- Increase Line SVR Co-Gen Voltage to 122 V to improve voltage at Node 1
- Inverter set to hold 123.5 V at POI.



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

Case 5 – 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

$\Delta V = 9$ volts, phase B, Node 2 or ~ 7%

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*

Thanks for your attention

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