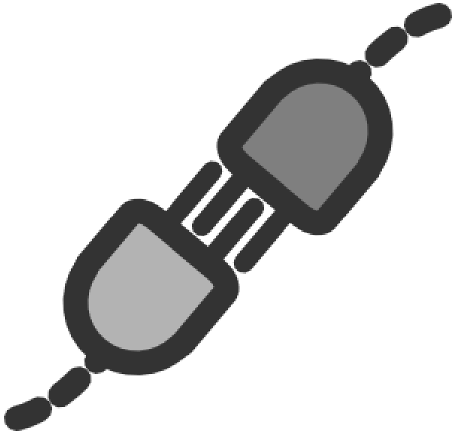
Electric Grid Impact of PV and Mitigation Strategies

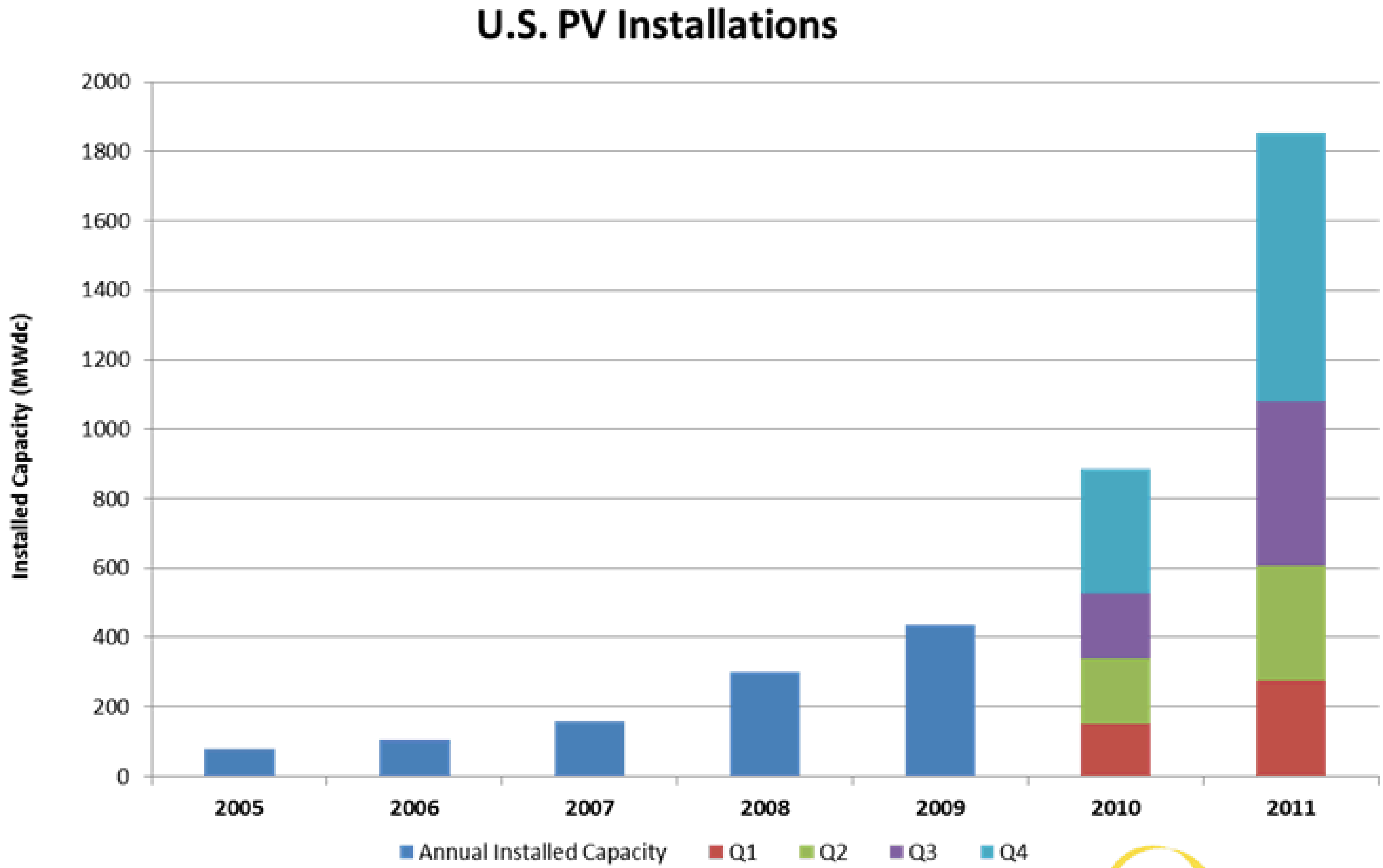


December 4, 2012
United States Energy Assoc.

Pepco Holdings, Inc

Overview

- Intro to Pepco Holdings, Inc & Renewable Activity
- Three Critical Areas for Creating Smart Energy
- Assessing the Impact of PV
- PV Issues with Different Size Systems, Case
  - Large PV (Greater than 3 MWs)
  - Medium PV (250 kW – 3 MW)
  - Small PV (less than 250 kW)
- Hosting Capacity Study (EPRI)
- Voltage Regulation Strategy
- Utility Collaboration Efforts to Develop Advanced Solutions



Source: SEIA/GTM Research Solar Market Insight, "2011 Year In Review"

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3 states and Washington DC in mid-Atlantic US

pepco – A PHI Company

648 sq mi (*575 in MD)*

782,000 cust (*528,000 in MD)*

4 and 13kV distribution

delmarva power – A PHI Company

5,400 sq mi (*3,500 in MD)*

498,000 cust (*199,000 in MD)*

4, 12, 25 and 34kV distribution

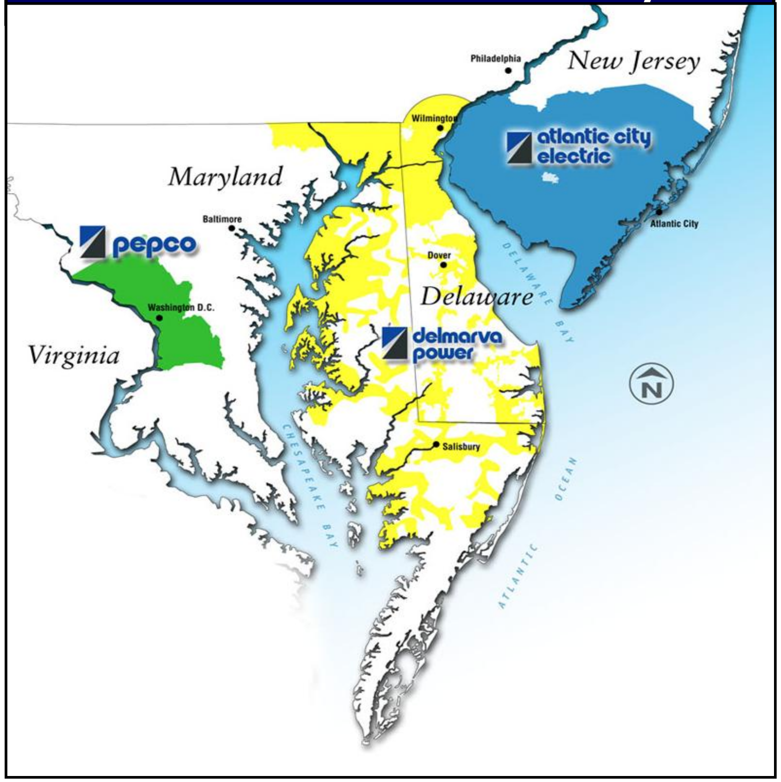
atlantic city electric – A PHI Company

2,700 sq mi

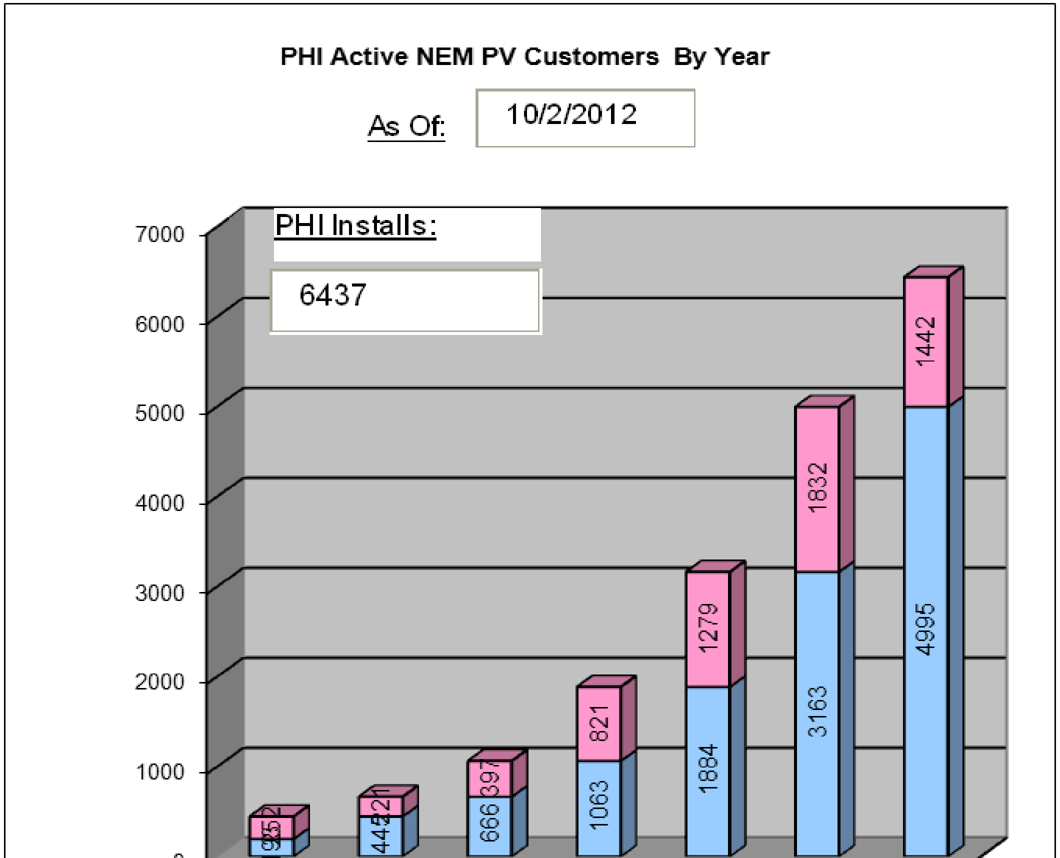
546,000 cust

4, 12, 23, and 34kV distribution

Combined Service Territory



Active NEM PV Systems By Year



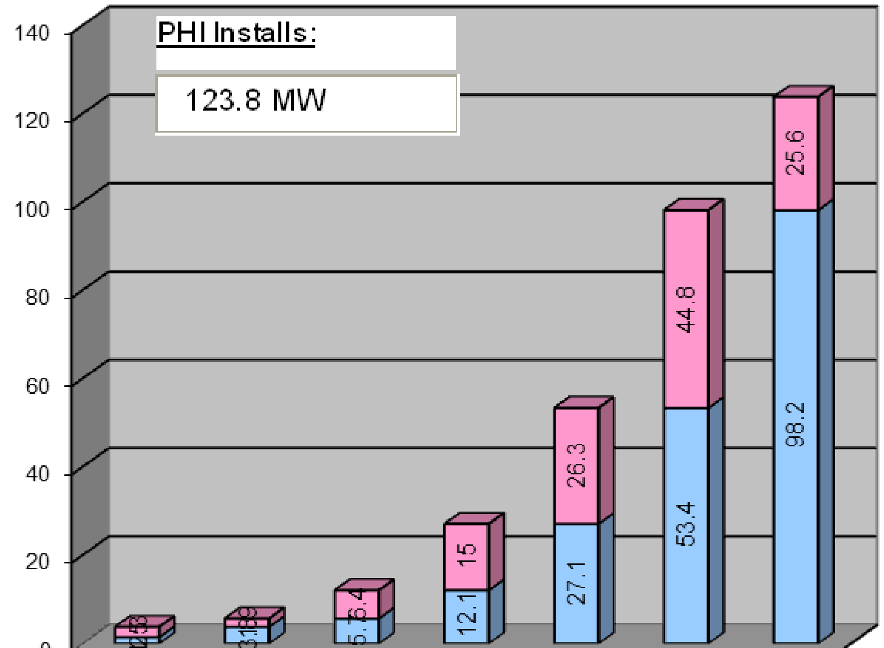
	2006	2007	2008	2009	2010	2011	2012
PV-New	252	221	397	821	1279	1832	1442
PV-Existing	193	445	666	1063	1884	3163	4995

Pepco Holdings, Inc

Active NEM PV MWS By Year

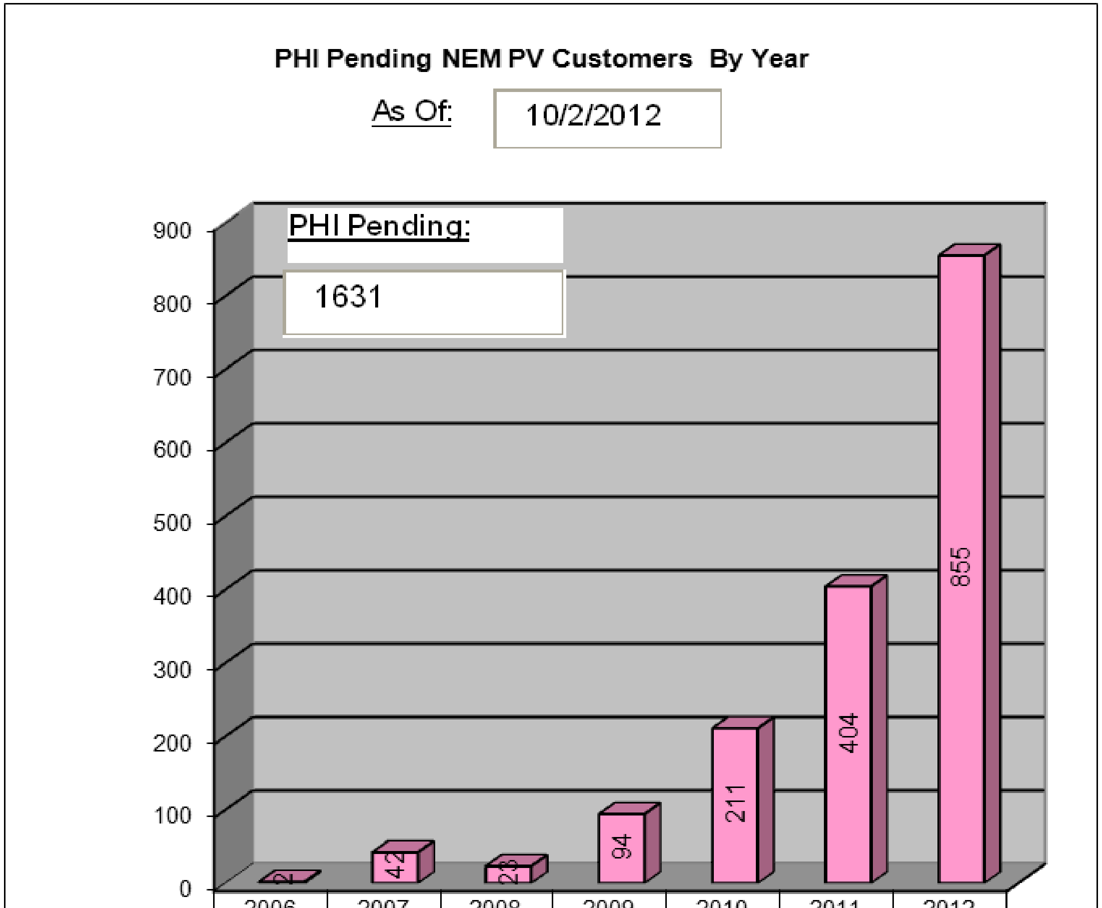
PHI Active NEM PV Generation (MW) By Year

As Of: 10/2/2012



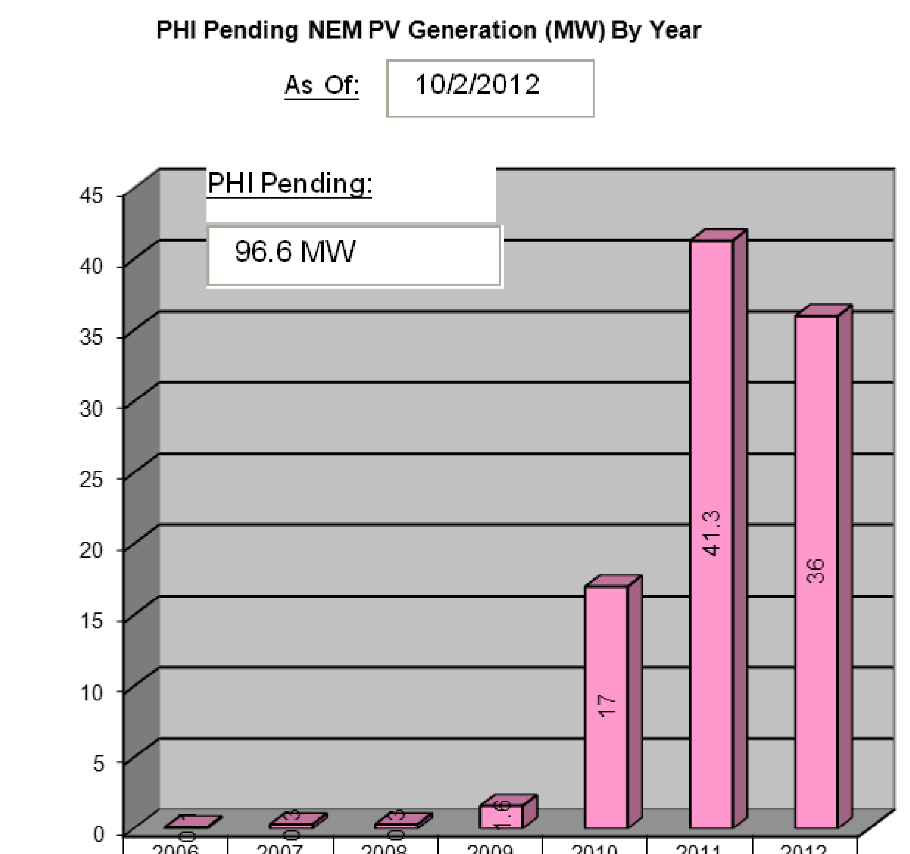
	2006	2007	2008	2009	2010	2011	2012
PV-New	2.3	1.9	6.4	15	26.3	44.8	25.6
PV-Existing	1.5	3.8	5.7	12.1	27.1	53.4	98.2

Pending Solar PV NEM



	2006	2007	2008	2009	2010	2011	2012
PV-New	2	42	23	94	211	404	855

Pending Solar PV NEM (MWs)



	2006	2007	2008	2009	2010	2011	2012
PV-New	0.1	0.3	0.3	1.6	17	41.3	36

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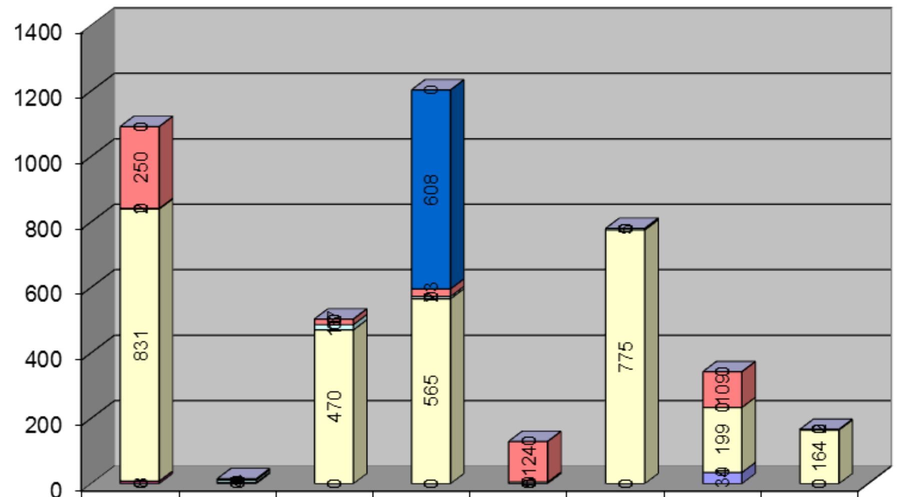
Wholesale Facilities

PHI: PJM Projects MW By IS Year And Fuel Type

As Of: 10/2/2012



	2005	2006	2007	2008	2009	2010	2011	2012
Biomass	0	4	0	0	0	0	0	0
Coal	0	0	0	608	0	0	0	0
Oil	250	0	17	23	124	0	109	0
Diesel	0	0	0	0	0	0	0	0
Methane	2	7	16	7	5	5	0	2
Natural Gas	831	4	470	565	0	775	199	164
Wind	8	0	0	0	0	0	0	0
Solar	0	0	0	0	0	0	34	0

Paradigm Changes in the US

- Edison, Tesla, Westinghouse -- AC wins out over DC
- Small Systems band together to make a large grid structure
- Power Plants got larger – Power flow one way – from central plants to end use customers
- Deregulation of Commodity while Delivery remained regulated
- Interest in Distributed Generation picks up – we see Land Fill gas, Wind, PV and other CHP applications
- Carbon reduction goals and government incentives bolster renewables – PV becoming the most popular
- People expect the grid to be a 2 way street

atlantic city electric
A PHI Company

Smart Energy

SMART GRID

- ISO (Independent Sys.Operator)
  - Bulk Generation
  - Bulk Transmission
    - Synchrophasors
  - Bulk Load Control
- LDC (Local Distribution Co.)
  - Transmission
  - Substation
    - Power Transformers
  - Feeders
    - Distributed Automation
    - Conductors, ALE
    - Line Transformers
    - DMS, Advanced Fdr Mgmt
  - DSM, DR
- AMI
  - Outage Mgmt
  - Real Time Pricing
  - Load Profile Info
  - HAN (Home Area Network)
    - Price and other comm.

SMART INVERTER

- Voltage/Freq Ride Thru
- Ramp Rate Control
- Autonomous & Centralized Control
  - -- VAR/PF Control
    - Fixed/Dynamic
    - Algorithm based
  - Curtailment
  - Remote Trip
- WITH BATTERY
  - Premium Power
  - Voltage Control
  - Frequency Regulation
  - Spinning Reserve
  - Arbitrage (TOU or Real Time Pricing)
  - Demand Side Mgmt.
  - Peak Demand Mgmt.

SMART PREMISE

- HEMS (Home Energy Mgmt System)
  - Pricing Signal Response
  - Peak Load Control
- DER (Distributed Energy Resource)
- Renewables, CHP, etc.
- Smart Thermostat
- Smart Appliances
- Smart HVAC
  - Thermal Storage
- EV
  - Controllable Charging, V2G
- Remote Access and Control
- Energy Efficiency & Controls
  - Turn off Phantom Loads
  - Vacant space mgmt.
- Direct Use of DC

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High Level System Impact Evaluation

- Pre-Screen: 50kW – 250kW
- Screen: 250kW and up   (static load flow)
- Detailed Study: Time Series Study for projects
  - With unresolved criteria violations (steady state or voltage fluctuations)
  - Significant other generation
  - Reverse Flow at Automatic Line Equipment, Feeder Terminal, or Substation Power Transformer

Large Solar – 3 MW to 20 MW

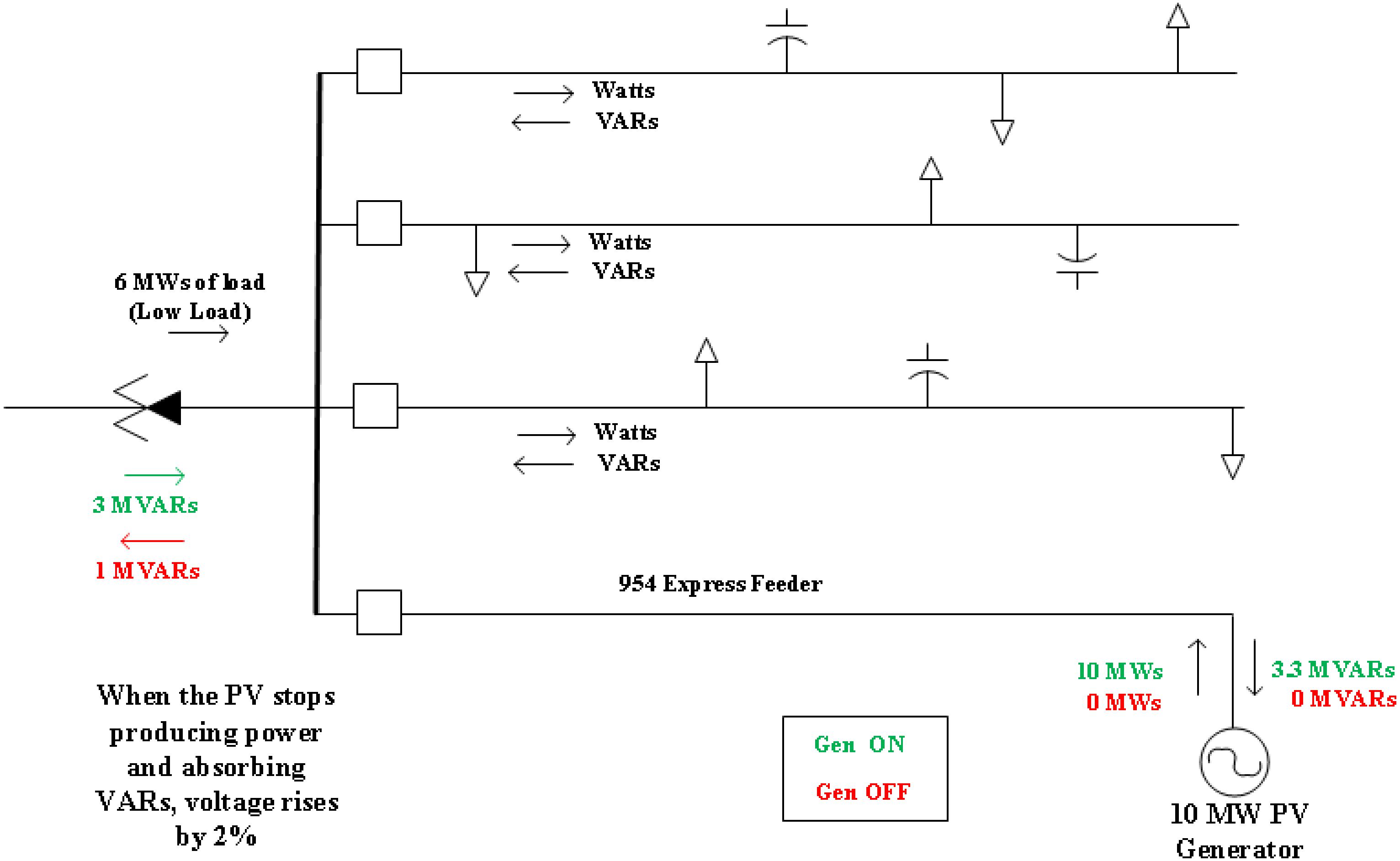
Potential Voltage Rise and Fluctuations

- Simulated Voltage Levels for 18 MW PV System (on 120V base)
  - System Off 124.0
  - 0.97 Leading PF 125.9 ← setting
  - Unity PF 126.8
  - 0.97 Lagging PF 127.4
- State Reqt: 115.2 – 124.8 V (+/- 4%)
- Feeder Voltage: 12,470 V phase to phase
- Injection to Substation: 9MWs each on 2 express feeders
- Substation has 2 other load carrying feeders

How Does an Absorbing PF help?

- Delta V = (Delta P/V1) R + (Delta Q/V1) x
- If the inverter maintains a constant absorbing PF, as the real (active) power export increases, the reactive power absorption also increases.
- For a sudden decrease in solar irradiance, the active power will drop as well as the Vars being absorbed.
- Benefits –
  - Reduces steady state voltage rise
  - Reduces voltage fluctuation significantly
  - Helps prevent voltage sag or collapse if large amounts of solar are tripped off line at one time

Low Load VAR Fluctuation Impact



When the PV stops producing power and absorbing VARs, voltage rises by 2%

Harmonic Issue – Inverter Tripping

- 10 MW Solar System
- Voltage Rise causes the nominal voltage to be up to 1.05 pu
- Resonant with utility system - asymmetric 1.3 kHz harmonic oscillations superimposed on the inverter's fundamental
- A number of times per day it caused some over voltages and unexpected tripping
- Capacitance was added to the inverters to resolve the situation

Figure 7. Adding Capacitance to the Inverter LC Output

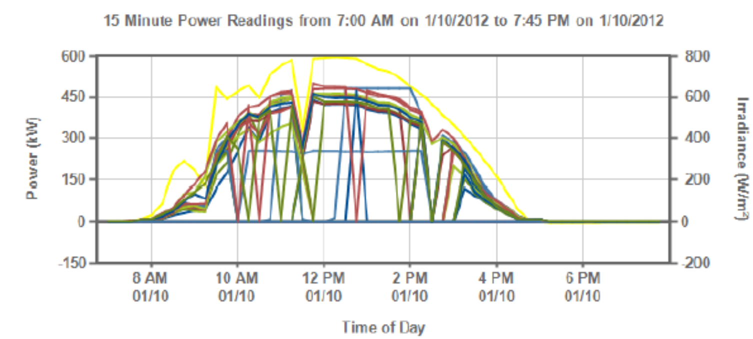


Figure 1. ArgusON monitoring reveals power cycling

Reverse Flow on Substation Transformer

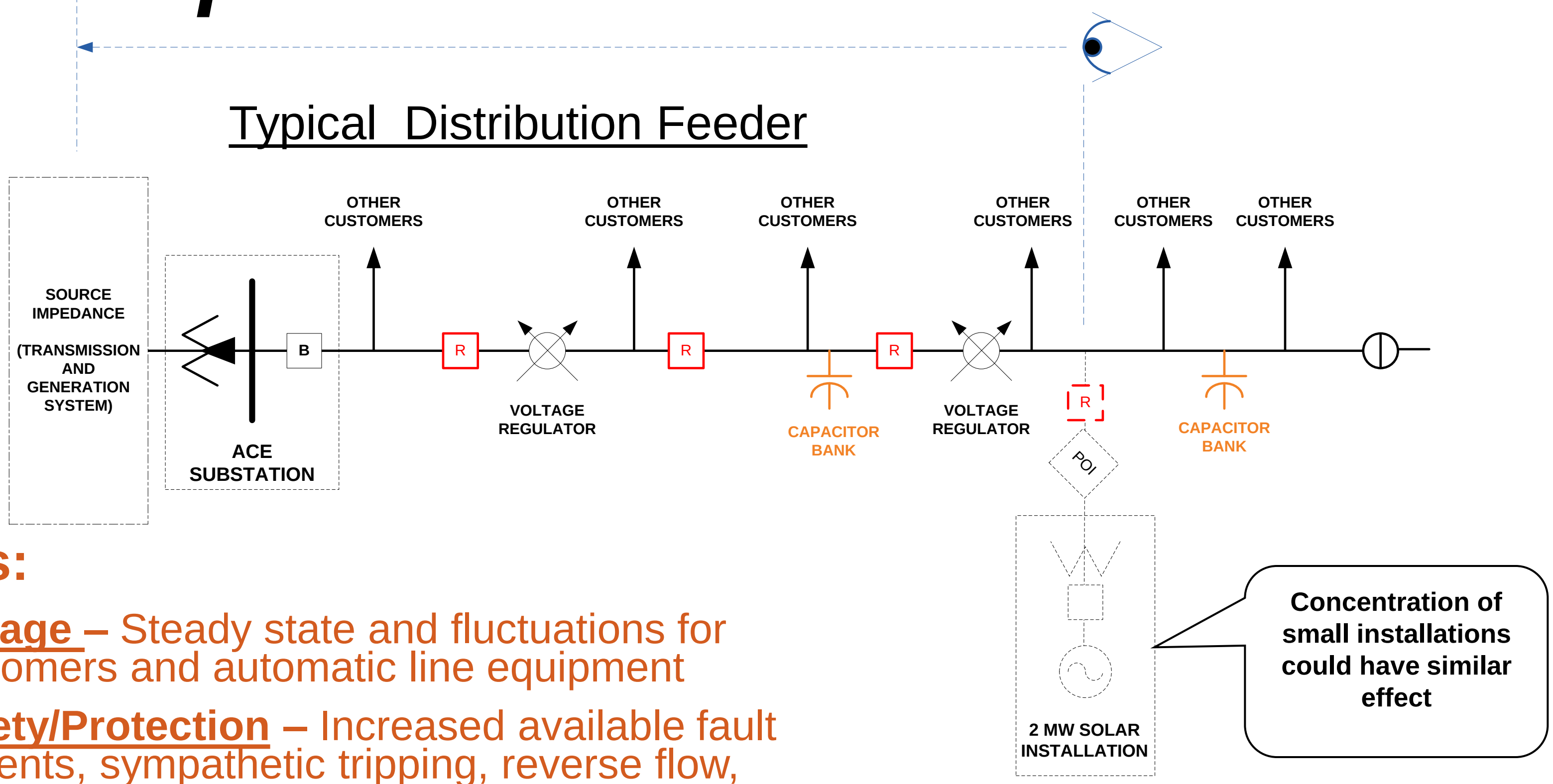
- Many Substation Power Transformers are Delta – Wye connected.
- When solar, wind, gas or other type of generation feeds into a fault on the high side of a delta winding the potential for creating an over voltage condition exists. If output was causing reverse flow at the critical time, it would then be back feeding through an ungrounded high side delta winding. Without the ground reference the voltages can "float“.
- The solution is a transfer trip package from the substation (sensing high side voltages) to the generator that will trip it for abnormal voltages.

Issues and Solutions for Large Solar

- Voltage Rise or Fluctuation on express feeder - Move interconnection to higher voltage level, lower the substation secondary bus voltage (if possible), set PF, future use of dynamic var control, limit ramp rate, curtailment, SCADA
- Voltage regulation for other feeders – smart LTC controls
- Losses – Move to higher voltage level, larger conductor and/or connect load to circuits
- System Stability – Low Voltage/Frequency Ride Through
- Getting Settings Correct – Insist on output readings. It can have a big impact

Medium Solar – 250 kW - 3 MW

DER Impacts to a Distribution Feeder

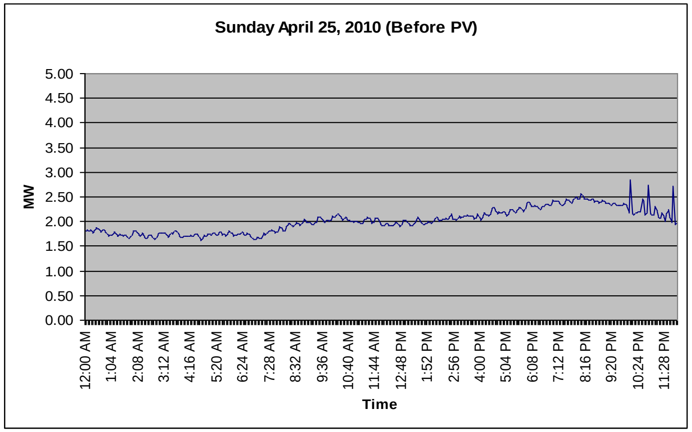


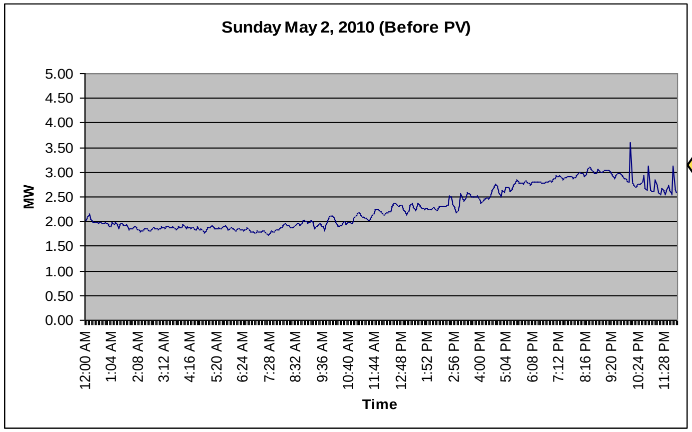
Impacts:

- **Voltage –** Steady state and fluctuations for customers and automatic line equipment
- **Safety/Protection –** Increased available fault currents, sympathetic tripping, reverse flow, reduction of protective reach
- **Loading –** Increases in unbalance, masking of demand, capacity overloads
- **Control Equipment –** potential for increased operations for voltage regulators, capacitors and under load tap changers
- **Power Quality –** potential for harmonic issues

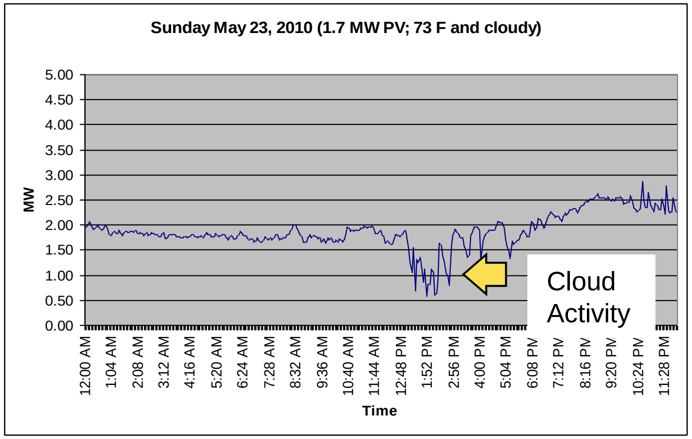
Distribution System Impacts (cont.)

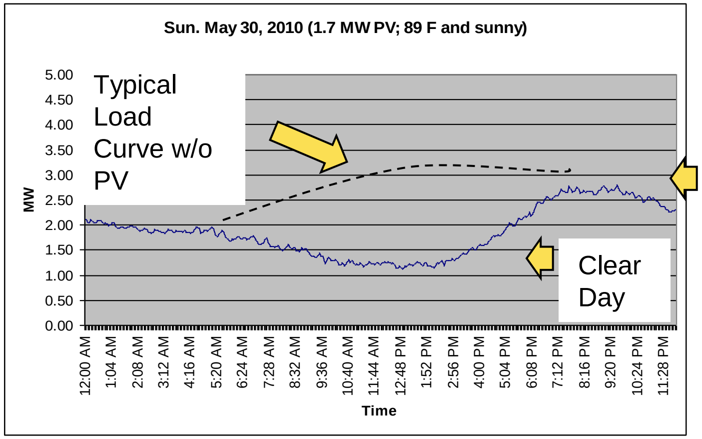
Sunday Load Profile Before and After 1.7 MW PV Installation as seen at Feeder Terminal





Industrial Load Startup



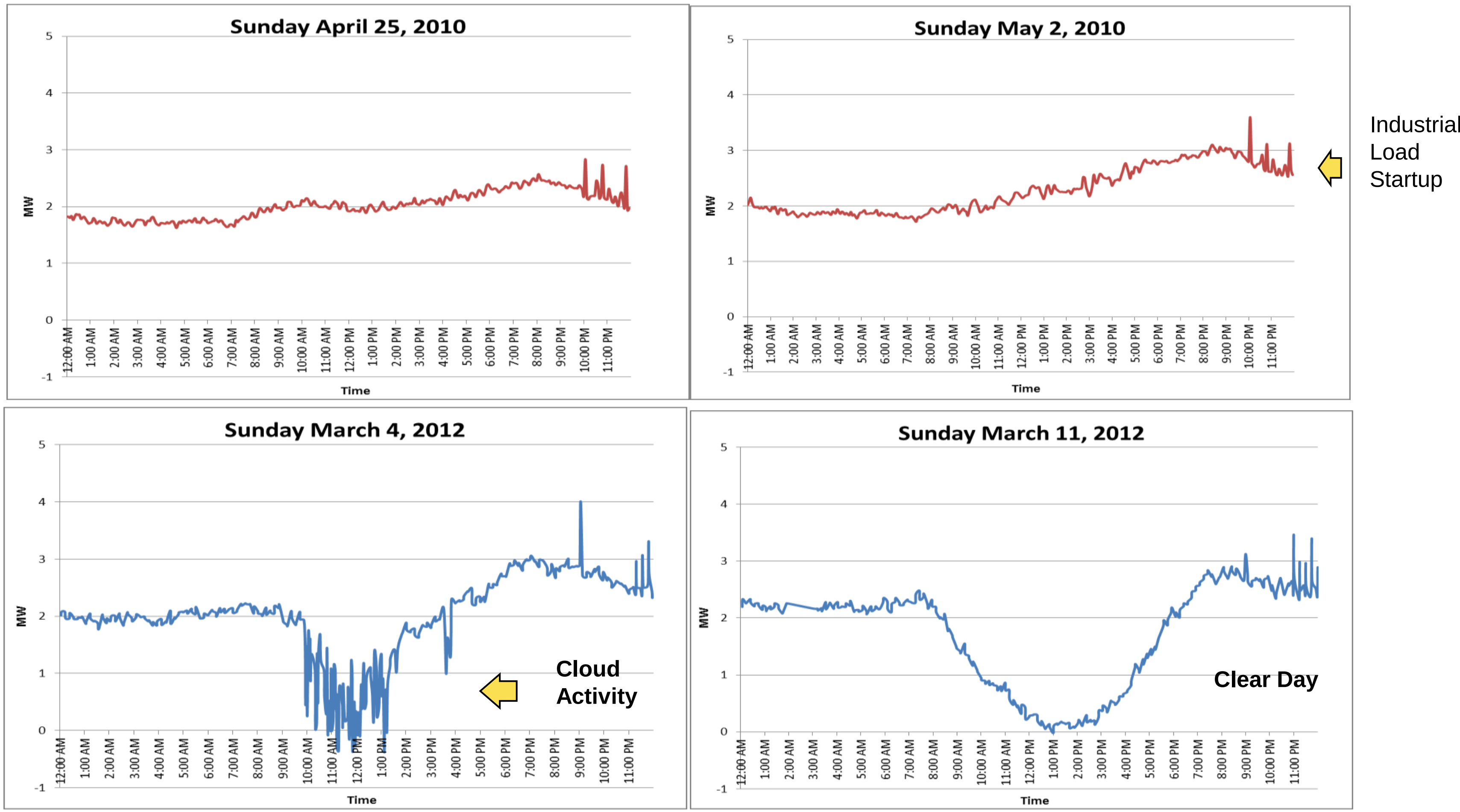


Monday Holiday

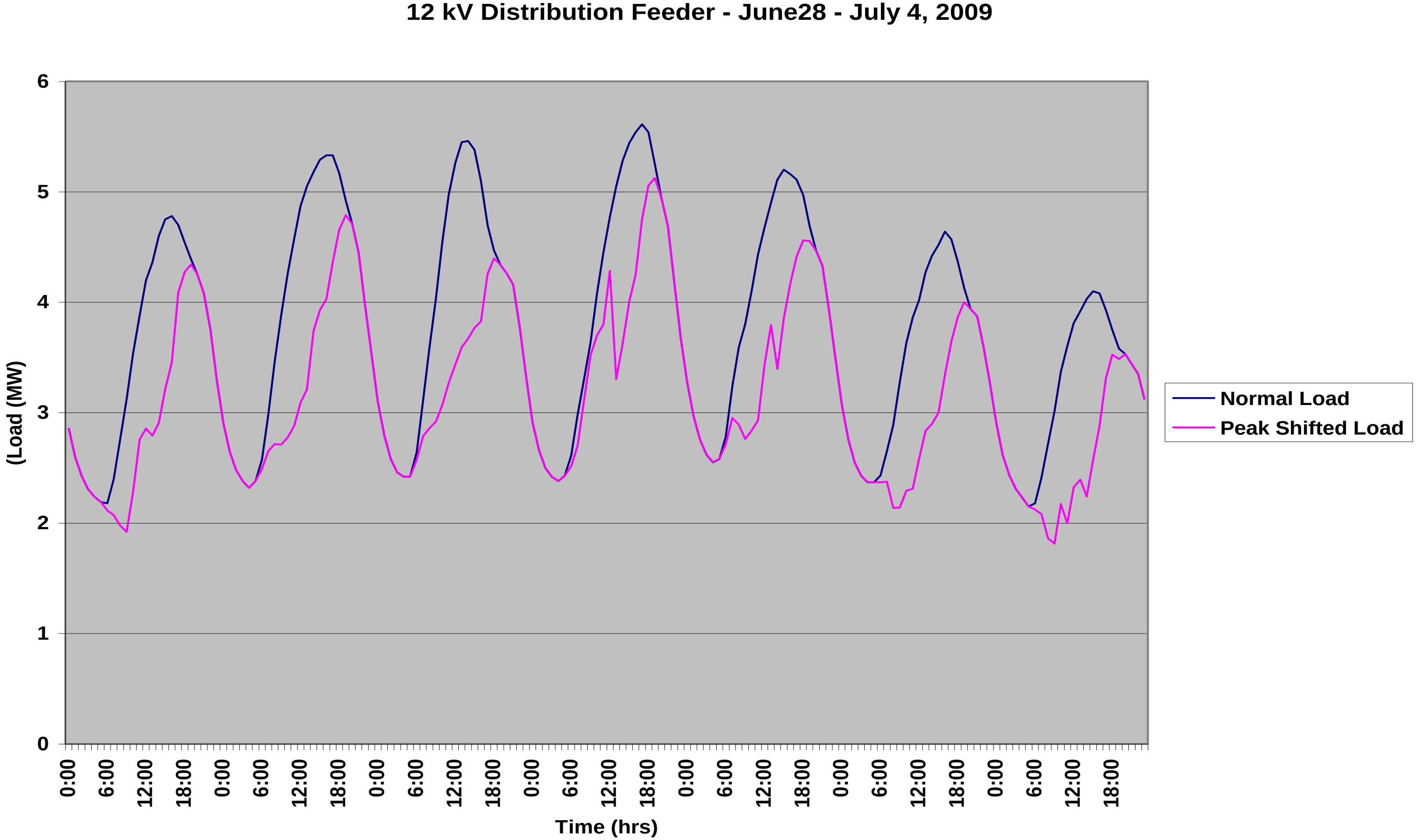
No Startup

Feeder Load Profile – Before & After PV

(Two PV systems 1.7 & 1.3 MWs)

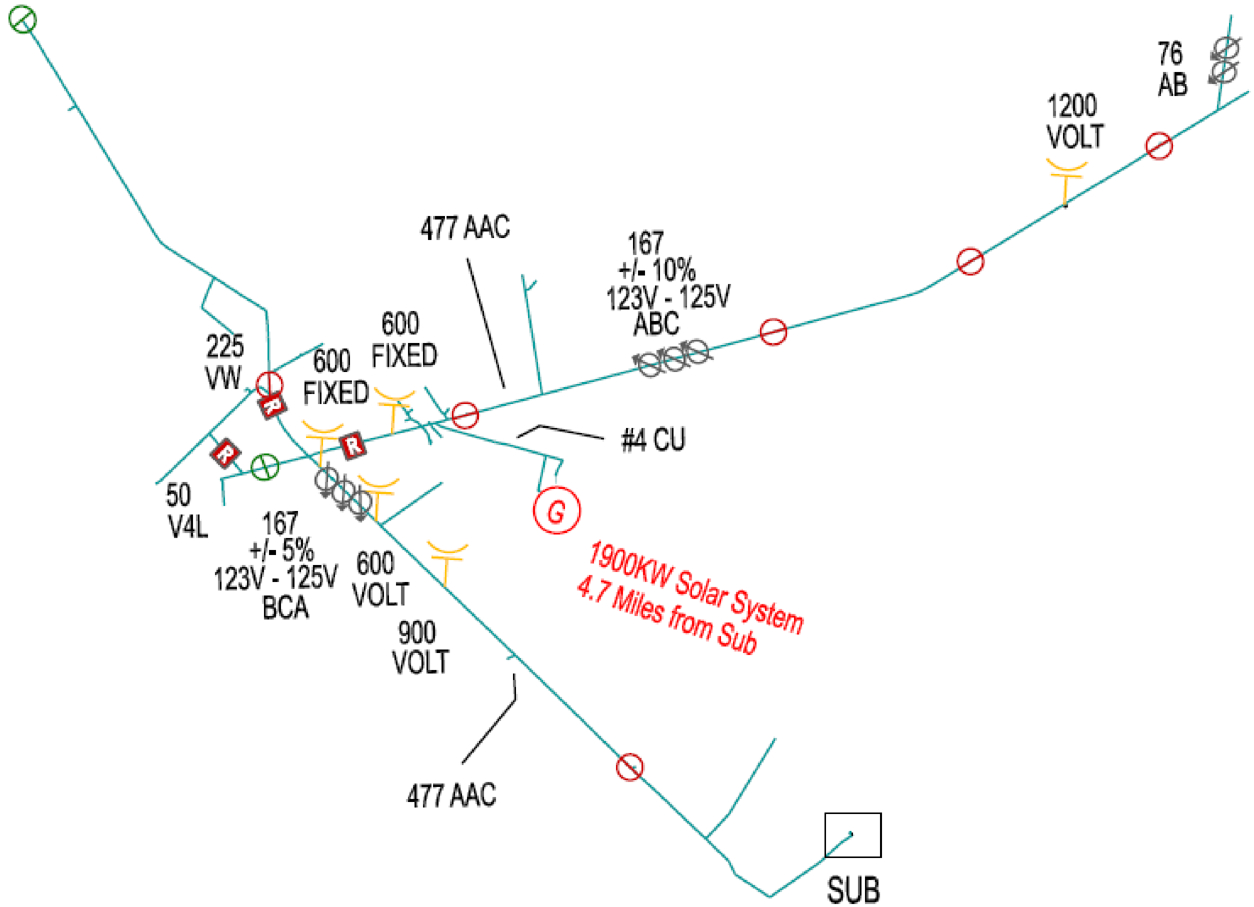


Potential impact of PV on Load Profile

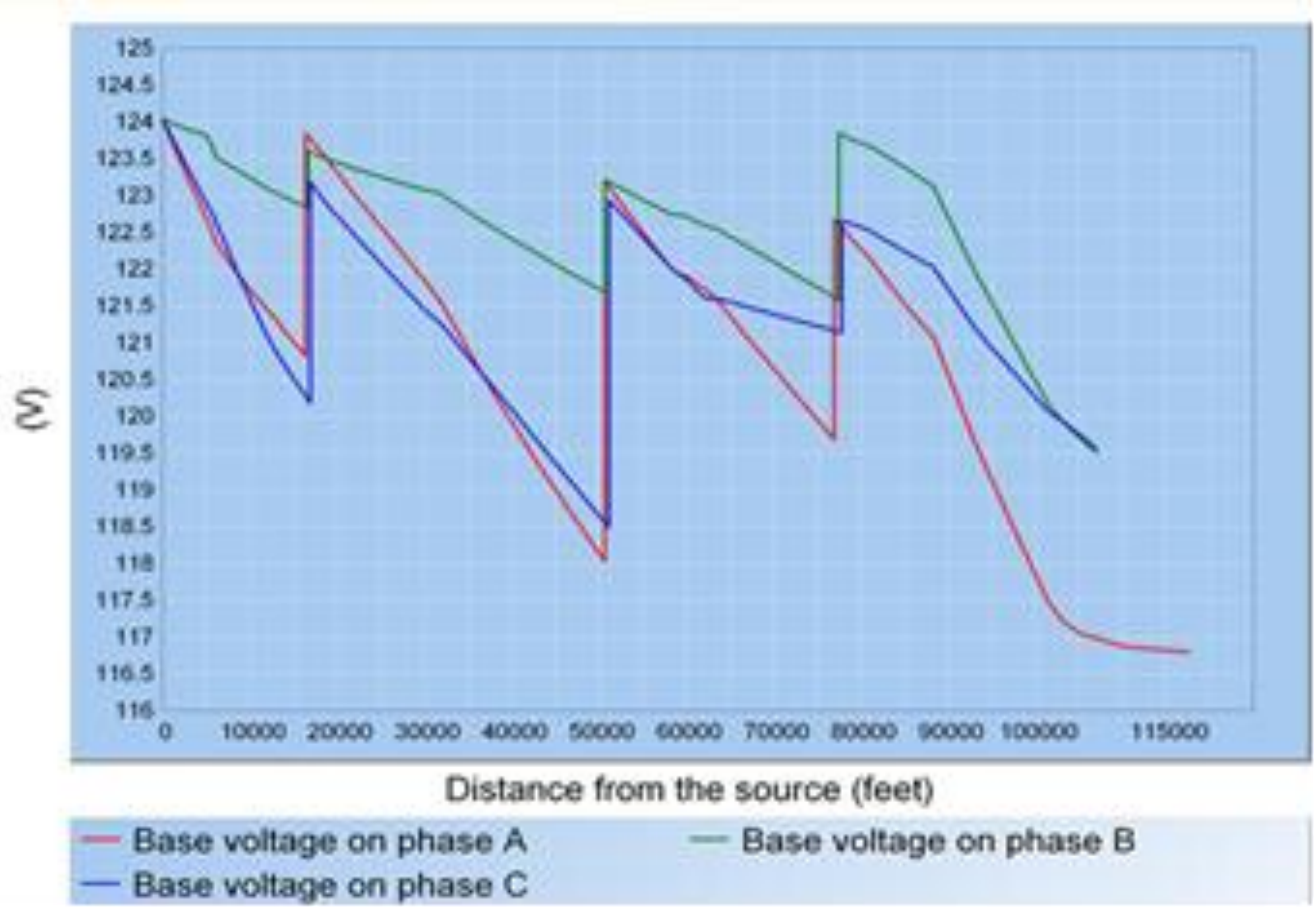


1.9 MW PV System

(Feeder Nominal Voltage: 12,470V)



Plot of Feeder Voltage over Distance



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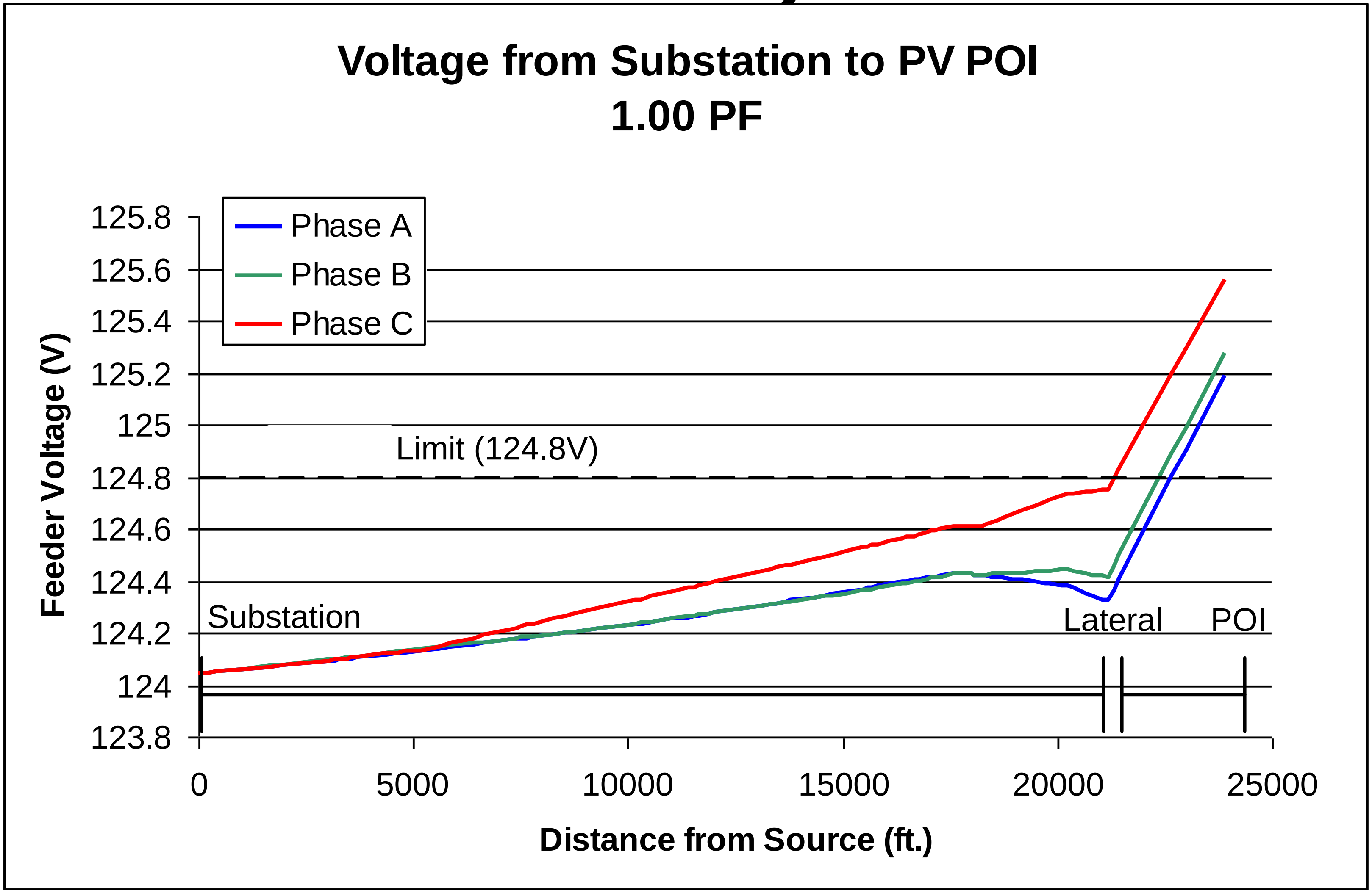
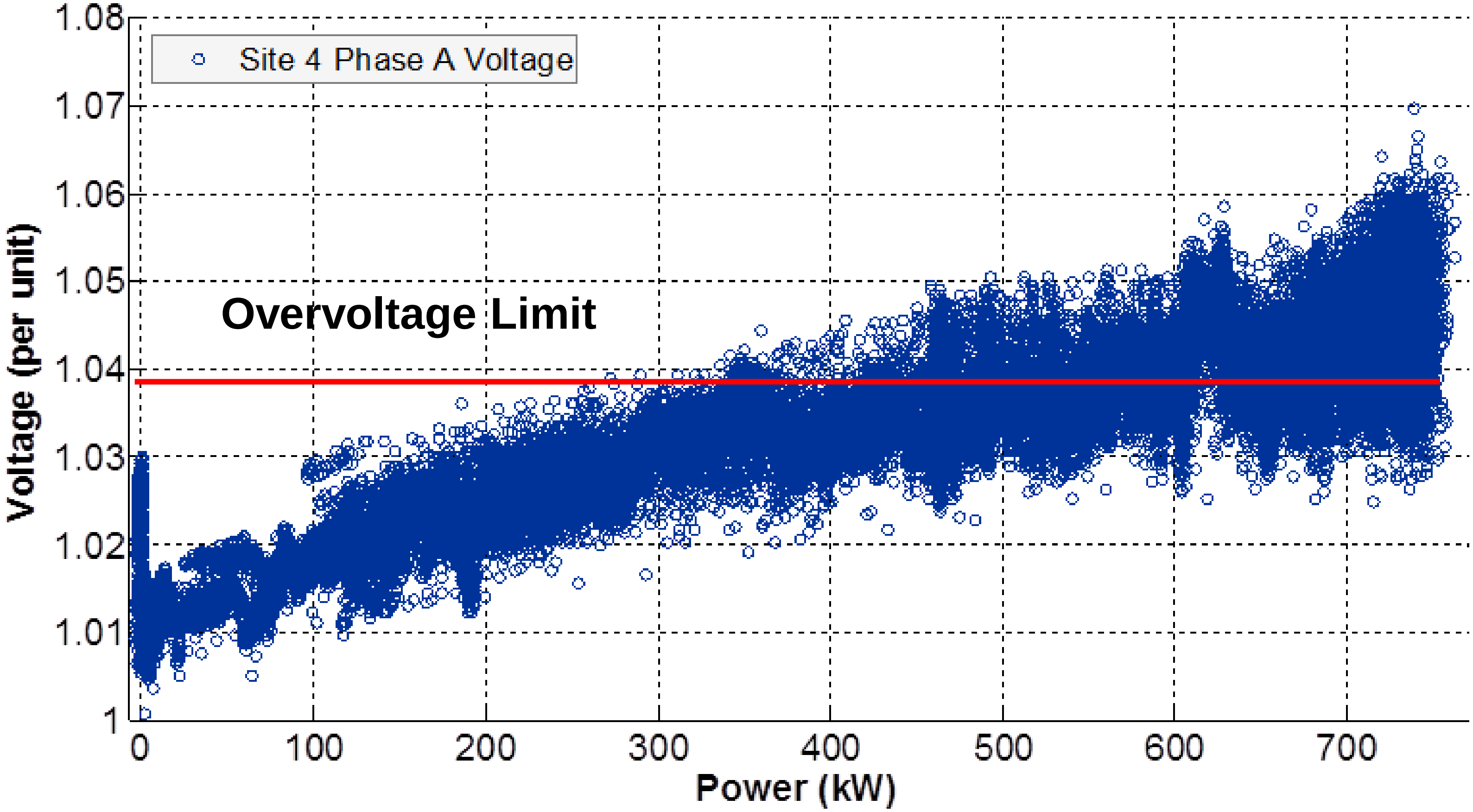
1.9 MW PV System



Overvoltage at the Inverter



Source: EPRI Monitoring

1.9 MW PV System

3 Options to Mitigate Voltage Issues

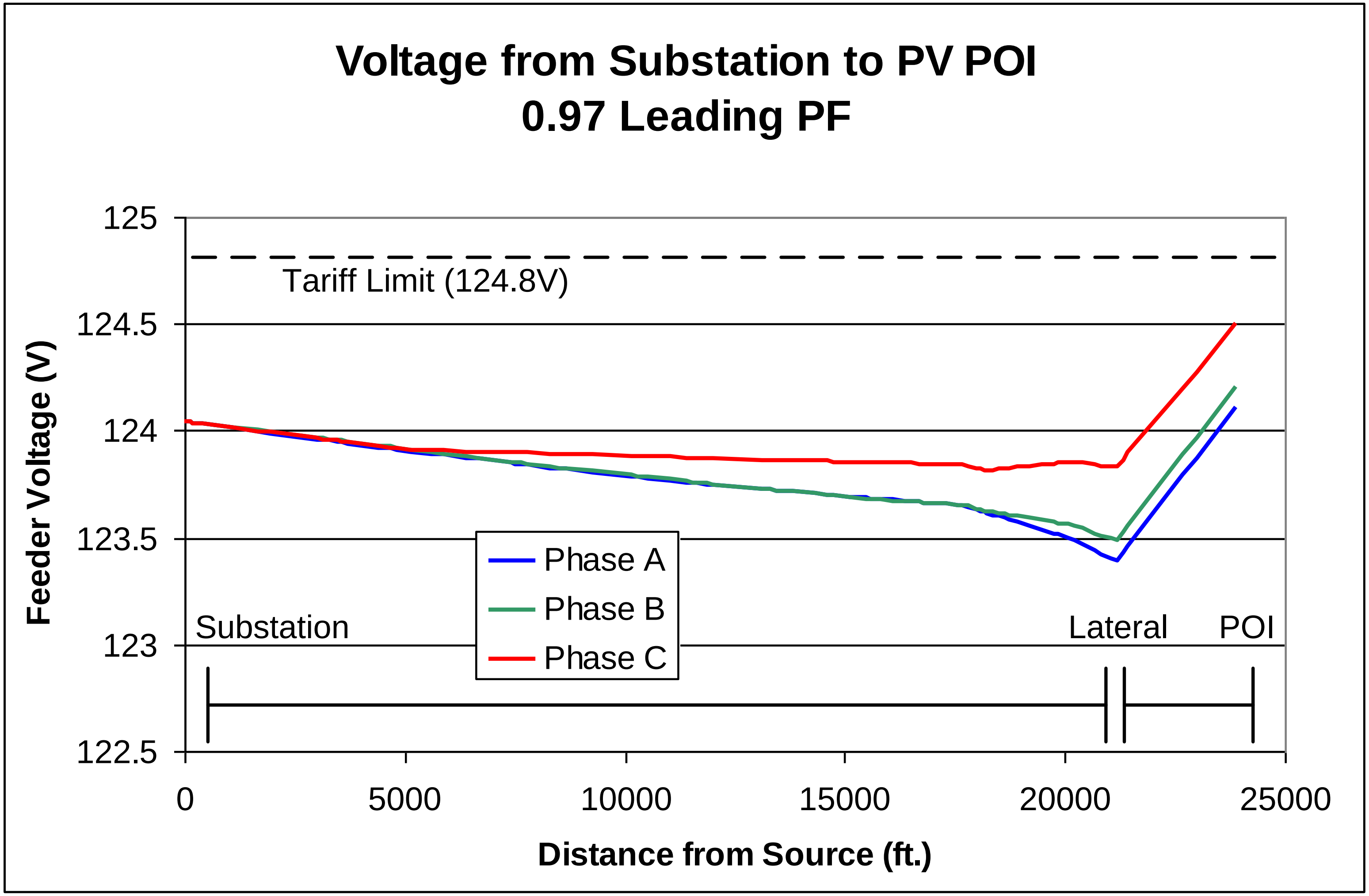
Summary Table				
	*Maximum Steady State Voltage(V)	Maximum Voltage Fluctuation at the PV site(V)	Maximum Voltage Fluctuation at the Upstream Regulator(V)	Cost
Without Mitigation	125.3	2.3	1.0	$0
Absorbing Power Factor Solution**	124.0	1.2	0.2	$2,200
500KVA/1500kWh Battery Solution	125.0	0.5	0.1	$1,115,014
750KVA/3000kWh Battery Solution	124.7	0.0	0.0	$2,189,390
477 AAC Reconductor	124.9	1.3	1.1	$266,000

*All Maximum Steady State Voltages occurred during low load,

**Absorbing Power Factor of .97 was used for this study

***The battery storage solution is unlike the other solutions and may have other operating value streams but also may have maintenance and/or replacement costs over the life of the solar system. These have not been investigated and included in this comparison.

1.9 MW PV System



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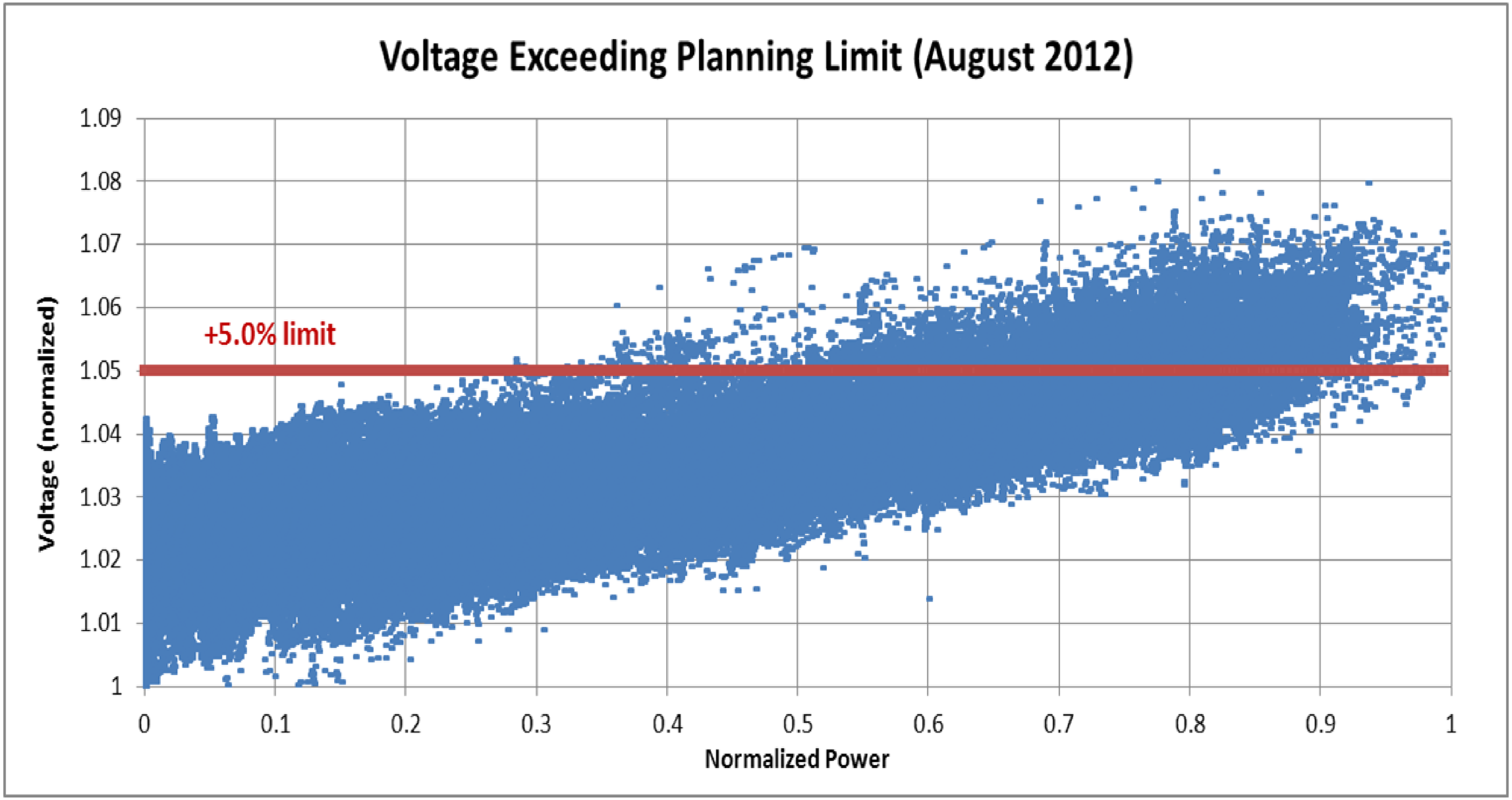
The Wrong PF was Implemented



Reverse Power on Voltage Regulators

- PV System Capacity: 1.33 MW AC
- 1.8 miles from the substation to POI
- Circuit Peak Load = 8.5 MVA, Circuit Voltage: 12,470 Ph to Ph
- 15% of Peak Load = 1.3 MVA

- Screens:
- Installed PV – 15% Screen (Borderline)
- Short Circuit Screen: 4.0% fault contribution at POI (Pass)
- 87.5% of Rating Screen: (Pass)

Problem that Occurred

- The circuit experienced reverse flow on several spring weekends. Further review showed low daytime load on the weekend to be very close to 15% of peak.
- The reverse flow caused a regulator(s) at the sub. with non-reversible controls, to operate to max raise on the line side. This occurred on one or two phases several times.
- This resulted in high voltage on the circuit and damage to some customer equipment.
- Several inverters tripped after the fact but didn't prevent overvoltage.
- The reverse flow on the substation power transformer caused an unacceptable condition from a system protection standpoint

Issues and Solutions for Medium Solar

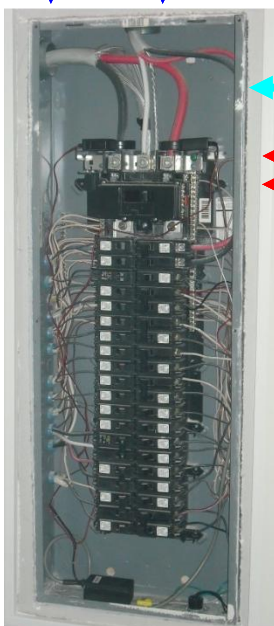
- Voltage Rise and Fluctuation, especially at greater distances from the sub – which can effect automatic line equipment and if high enough cause voltage violations for customers
  - Utilize an absorbing (leading) PF on the inverters (fixed or on a schedule)
  - Move Capacitor or Voltage Regulator further away from POI, adjust settings if necessary
- Distribution Automation schemes have load measurement masked by solar (depending on time when a fault occurs), then when load is transferred and picked up, solar will be off for 5-10 minutes resulting in higher loading. Requires study on both feeder configurations

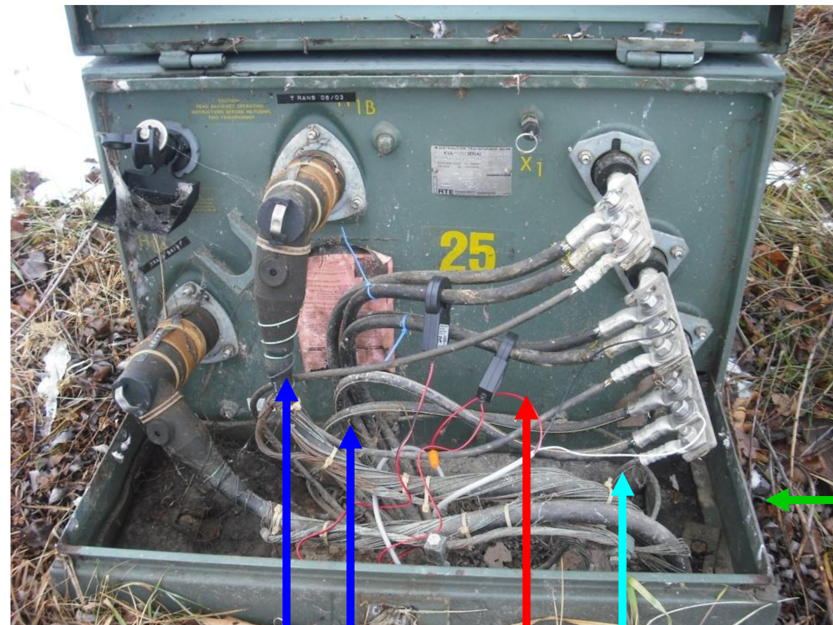
Issues and Solutions for Medium Solar (cont.)

- Utilize battery storage
- Upgrade the conductor size
- Implement Advanced Feeder Management to reduce line voltage during peak solar output
- Utilize flexible load control to increase load at high solar output periods
- Utilize an SVC
- Reduce the size of the PV system
- Use of delta-wye transformer

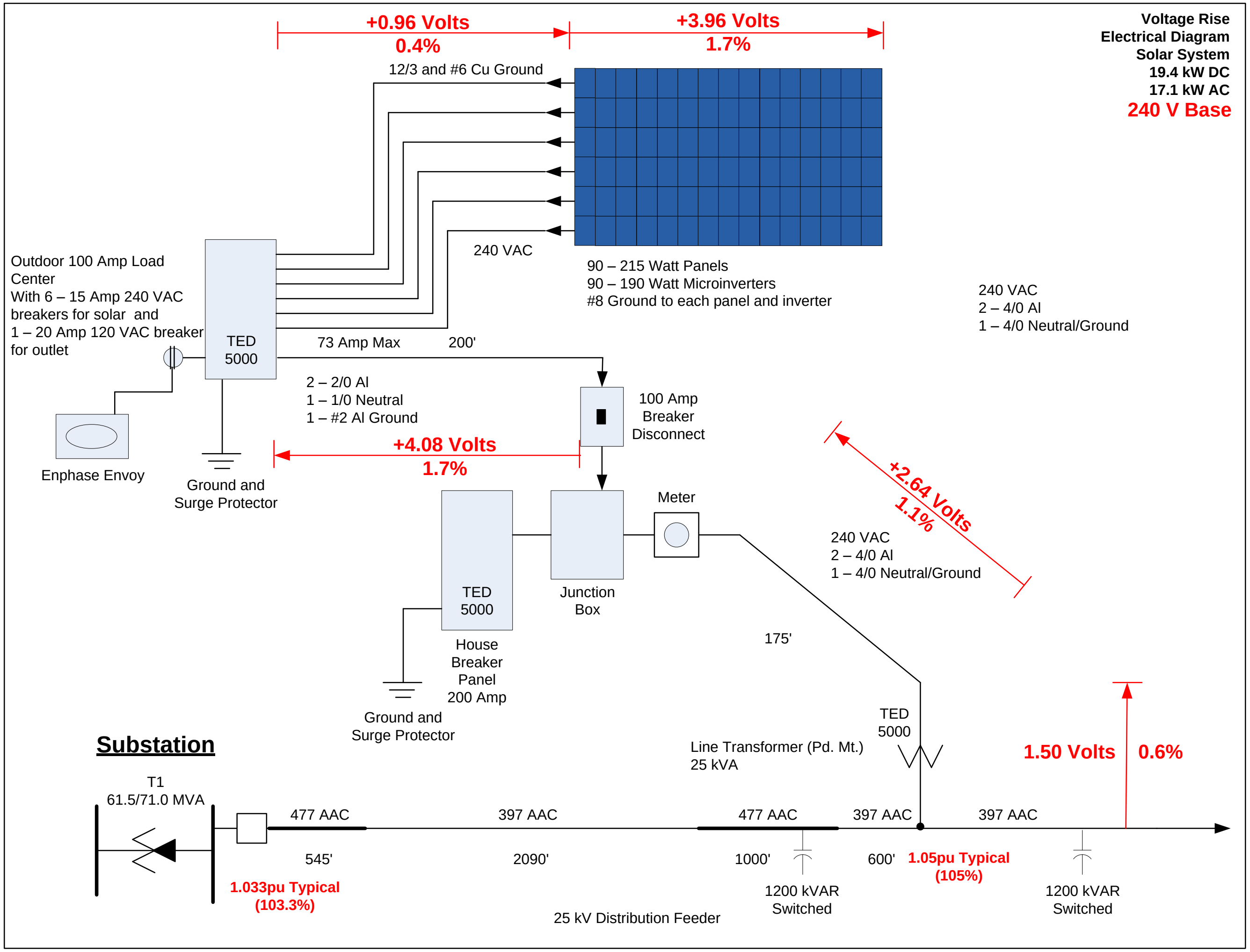
Small Solar – 250 kW or less

TED 5000 installed in House Panel and Line Transformer





System Diagram - Voltage Rise



Voltage Rise Chart

(at max gen and no load)

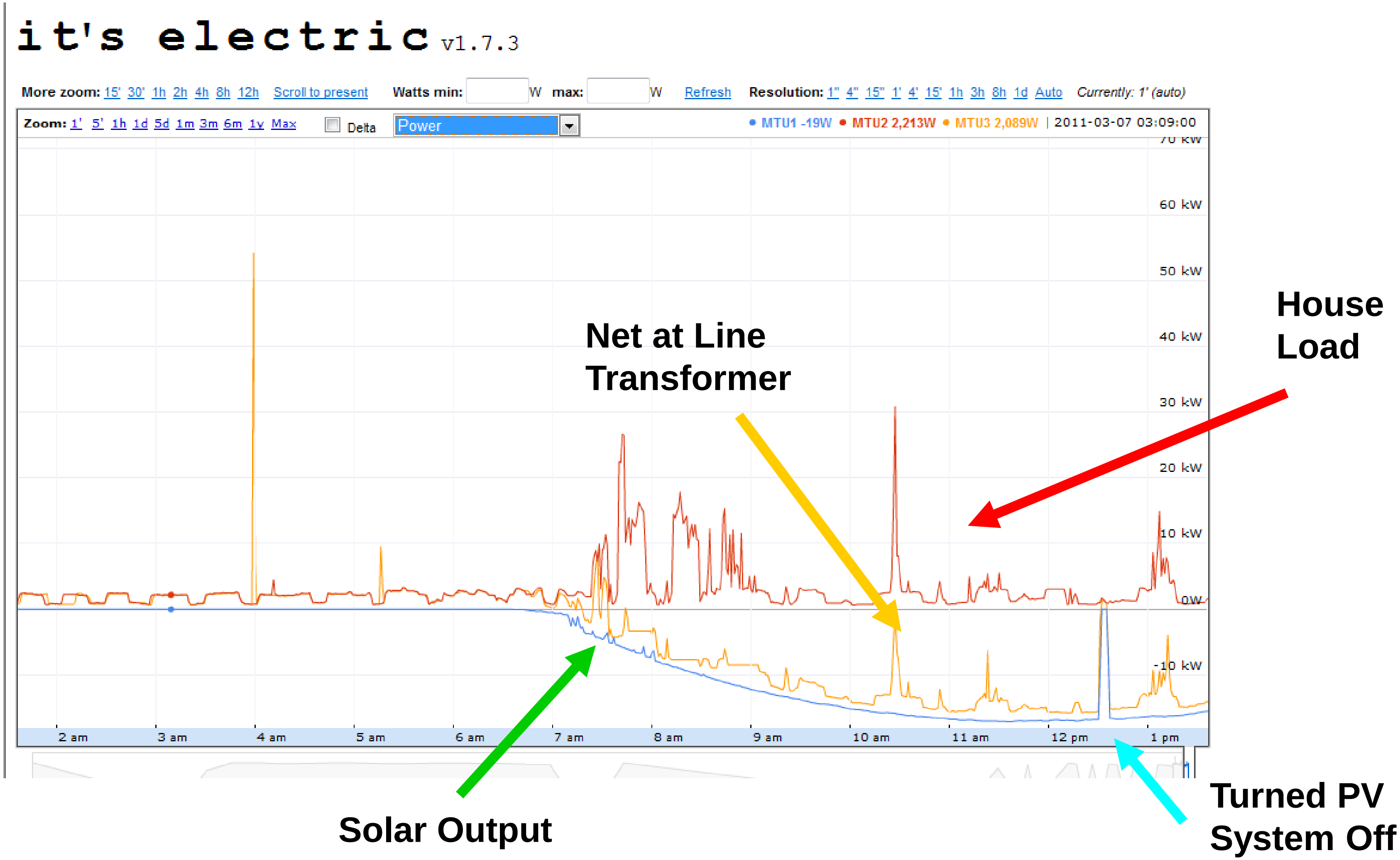
Nominal Voltages: 120V or 240V

Max Design Voltage at Meter: 126V or 252V (per ANSI 84.1)

Electrical Segment	**Voltage Rise**		
	@ 120V	**@ 240V**	**%**
Microinverter String to End	2.0	4.0	1.7
Connection to PV Breaker Panel	0.5	1.0	0.4
Line to PV Disconnect (2/0 Al)	2.0	4.0	1.7
Sub-total	**4.5**	**9.0**	**3.8**
Service Drop	1.3	2.6	1.1
Line Transformer	0.8	1.6	0.6
Total	**6.6**	**13.2**	**5.5**

Note: The microinverter voltage measurement accuracy is +/- 2.5%

Power vs. Time



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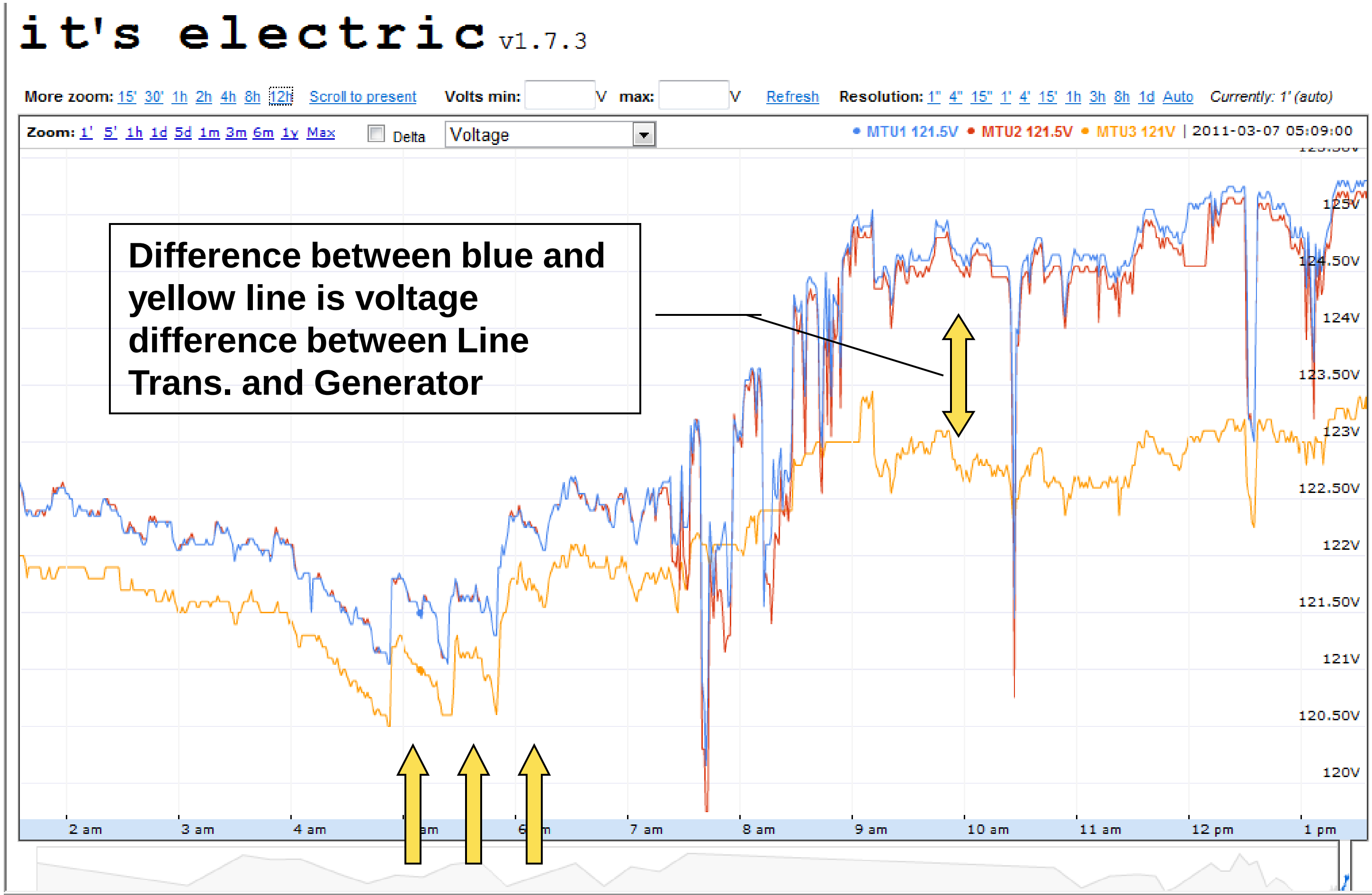
Voltage vs. Time



Substation transformer adjusting voltage

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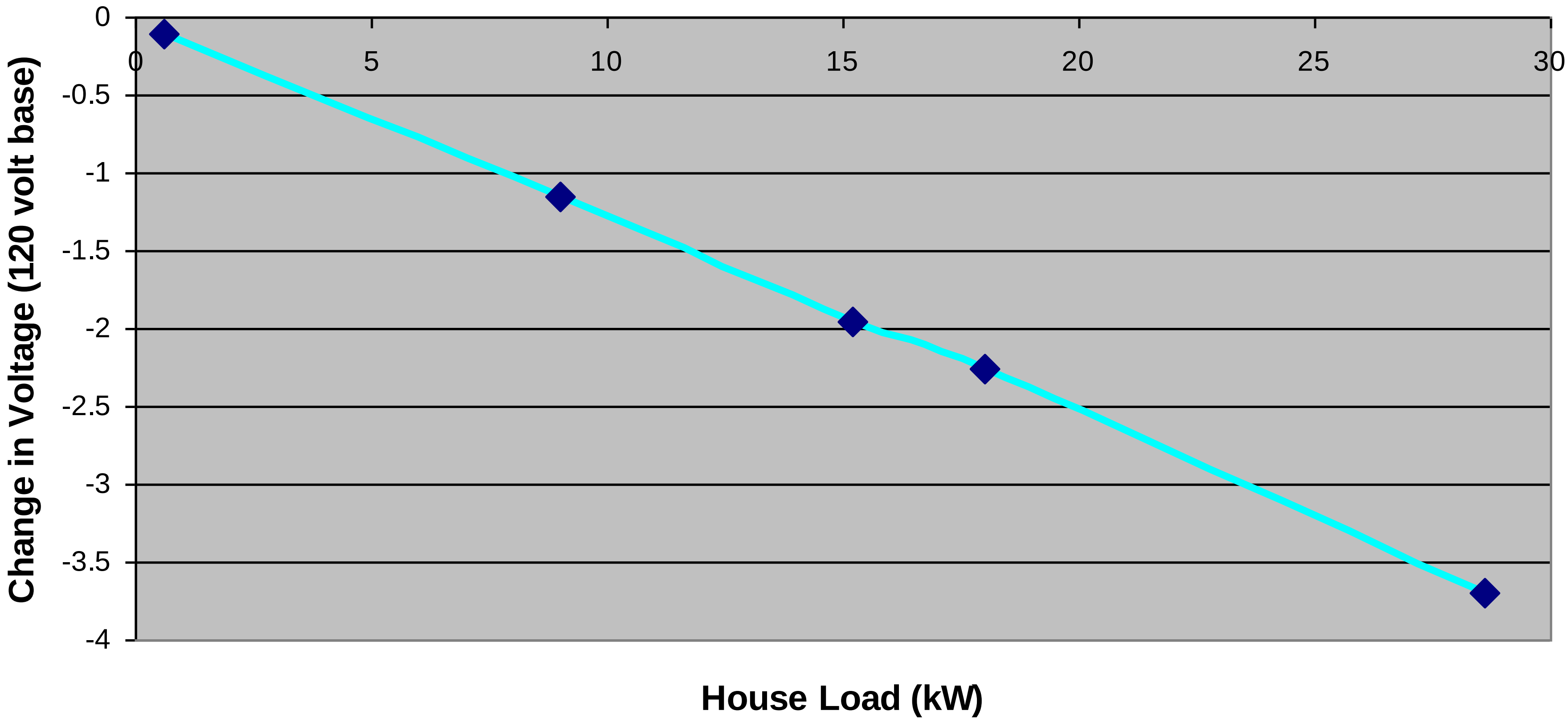
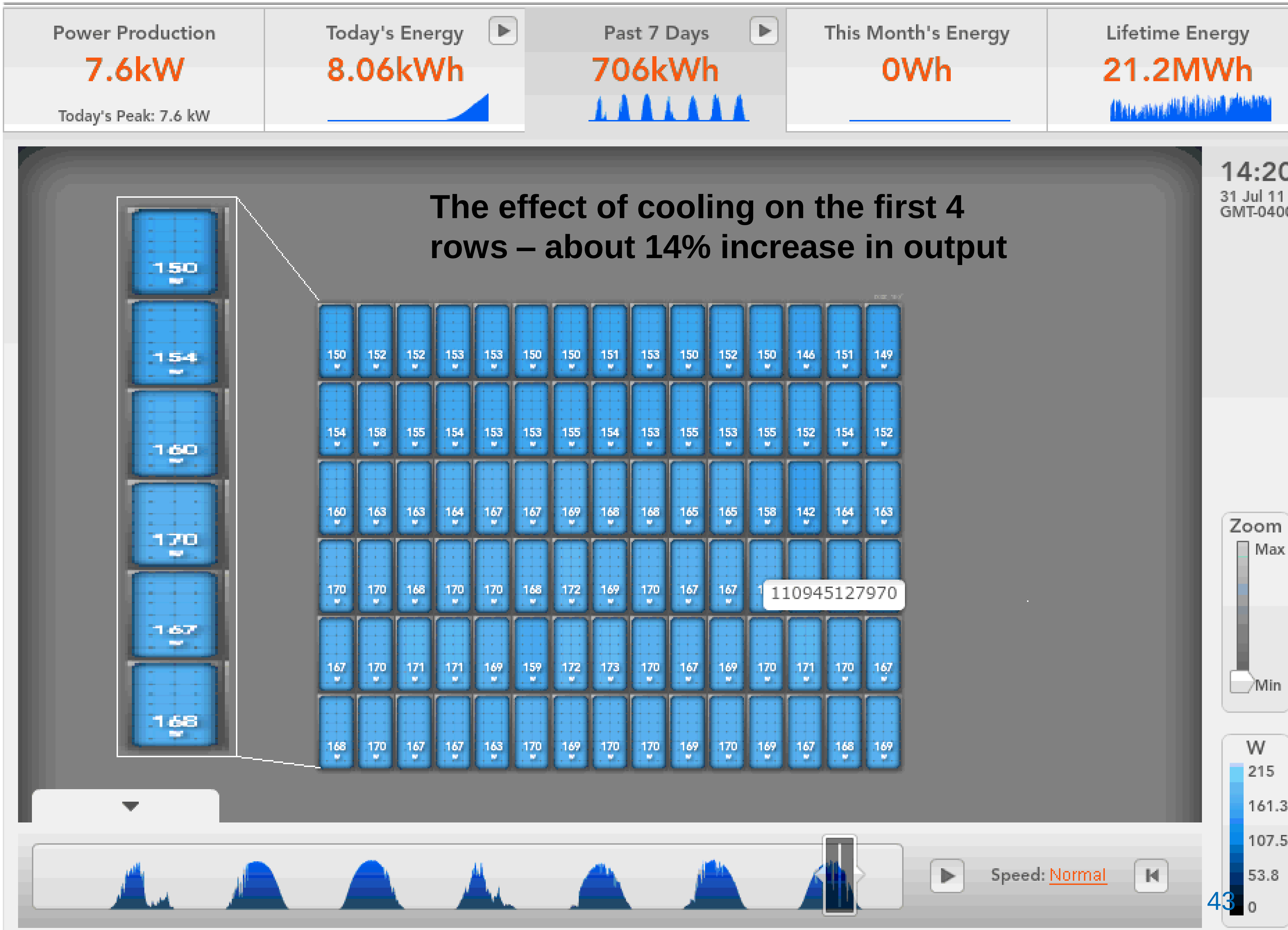
Voltage Drop vs. House Load

Unity Power Factor




Power Production
7.6kW
Today's Peak: 7.6 kW
Today's Energy
8.06kWh
Past 7 Days
706kWh
This Month's Energy
0Wh
Lifetime Energy
21.2MWh
The effect of cooling on the first 4 rows – about 14% increase in output
14:20
31 Jul 11
GMT-0400
150
154
160
170
167
168
150 152 152 153 153 150 150 151 153 150 152 150 146 151 149
154 158 155 154 153 153 155 154 153 155 153 155 152 154 152
160 163 163 164 167 167 169 168 168 165 165 158 142 164 163
170 170 168 170 170 168 172 169 170 167 167
110945127970
167 170 171 171 169 159 172 173 170 167 169 170 171 170 167
168 170 167 167 163 170 169 170 170 169 170 169 167 168 169
Zoom
Max
Min
W
215
161.3
107.5
53.8
0
Speed: Normal

Issues and Solutions for Small Solar

- Voltage Rise - especially with small line transformer, long or small service, and with distance to the inverters – ths can cause inadvertent tripping of inverters and/or high voltage at the premise
  - Contractor or home owner should do careful voltage rise calculation – include potential voltage rise across service and transformer
  - Contractor or owner review design, using larger conductor, shorter distances, etc.
  - Utilize an absorbing (leading) PF on the inverters (not common for single phase inverters)

Issues and Solutions for Small Solar (cont.)

- Use Home Energy Manager to move flexible loads to high output periods, and utilize signals from AMI
- Utility adjust settings on closest Capacitor or Voltage Regulator to reduce voltage a little at the customer meter if necessary
- Customer can utilize battery system to reduce peak output, take advantage of TOU rates (where available) and have premium power
- Inverter learns and adjusts PF during certain times of day
- Utility provides setting changes via AMI (PF or VARS and active power output)

How is Hosting Capacity Determined?

Answer: PV Penetration Level When a Criteria Boundary ***Flag*** is Exceeded

Category	Criteria	Flag
Voltage	Overvoltage	≥ 1.05 Vpu
	Voltage Deviation	≥ 0.833% (½ of 2V regulator bandwidth)
	Unbalance	≥ 3%
Loading	Thermal	≥ 100% normal rating
Protection	Total Fault Contribution	≥ 10% increase
	Forward Flow Fault Contribution	≥ 10% increase
	Sympathetic Tripping	≥ 150A
	Reduction of Reach	≥ 10% decrease
	Fuse Saving	≥ 100A increase
	Anti-Islanding	≥ 50% minimum load
Power Quality	Individual Harmonics	≥ 3%
	THDv	≥ 5%
Operational*	Regulator duty	> Basecase +1
	Capacitor duty	> Basecase +1

*Operational requires time-series irradiance data

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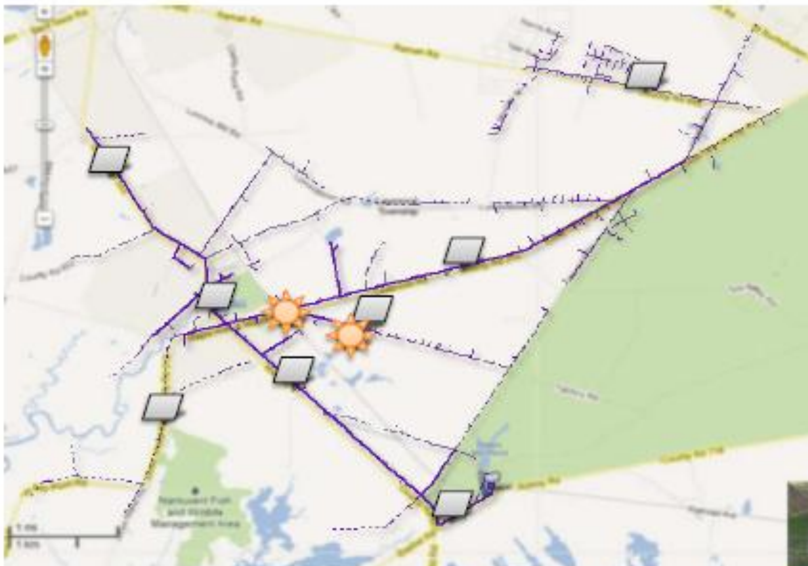
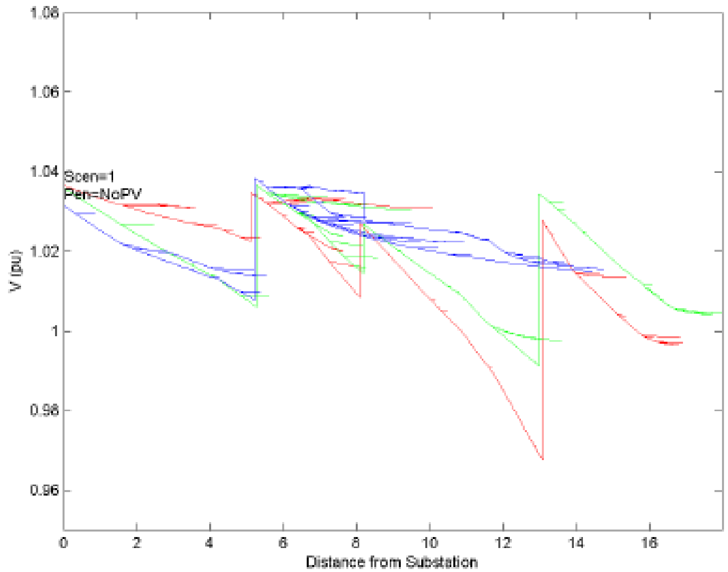
Measurement Data
Solar Monitoring

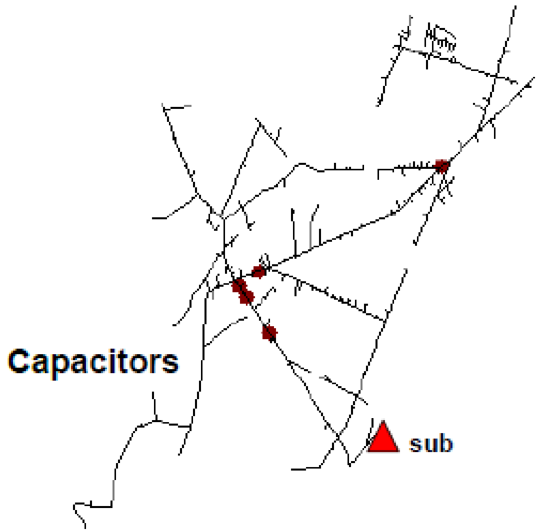


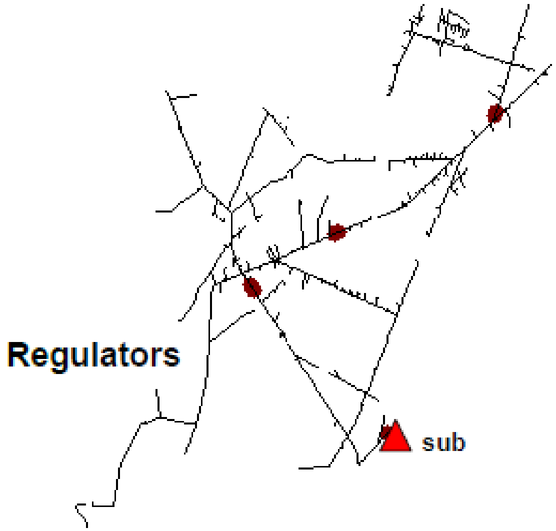
DPV Pole-Mount Panels
Metered Large-Scale PV

Model Characteristics
Control

- Four Regulation Zones
- Existing Control
  - 5 capacitors
  - 9 regulators







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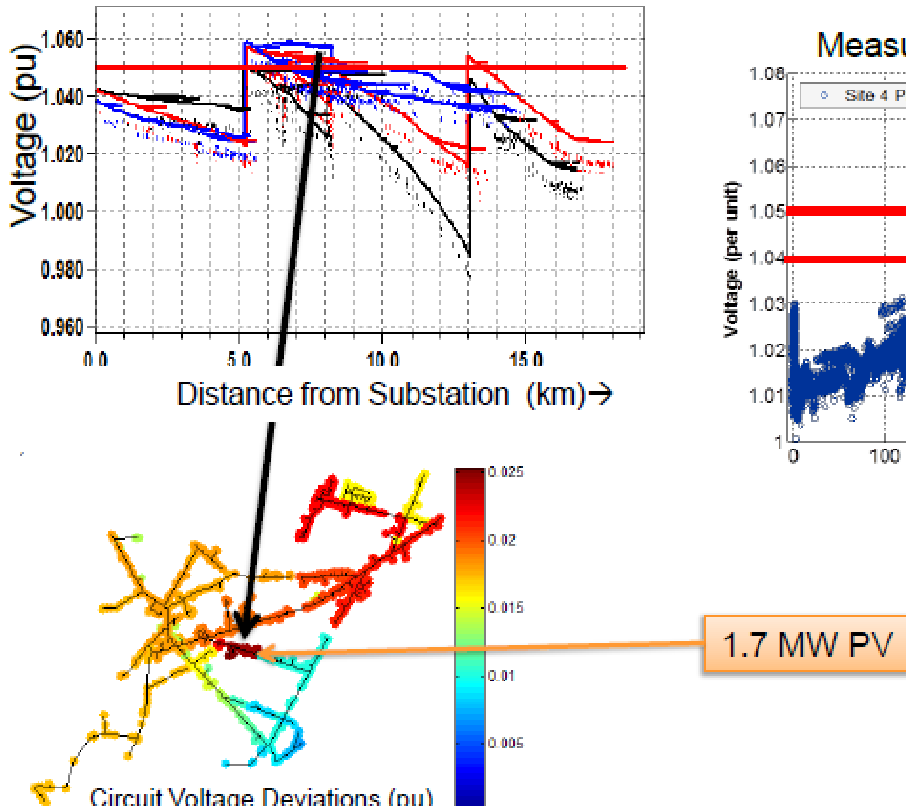
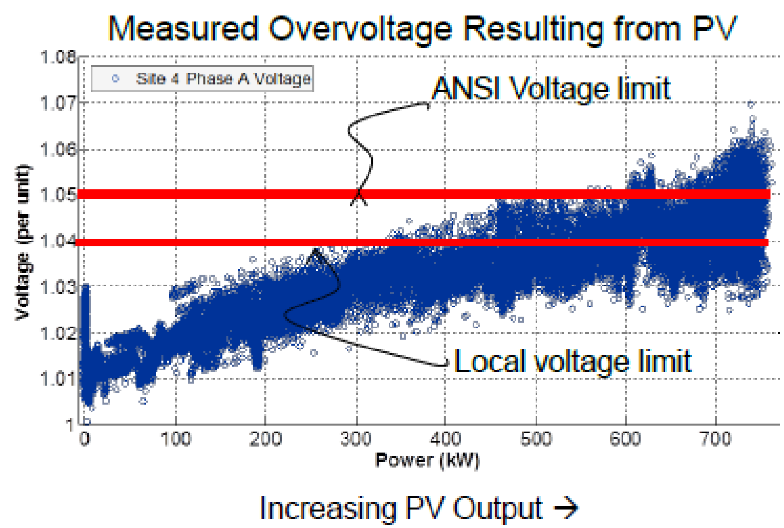
Existing PV Has Adverse Impact to Feeder

Verified Via Measurements AND Simulation

Simulation



Measurements



25

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Stochastic/Time Series Results

Overall Summary of Minimum Hosting Capacity

Category	Criteria	Small Scale (kW)	Large Scale (kW)
Voltage	Primary Overvoltage	421	500
	Regulator Deviation	249	500
	Primary Imbalance	490	>10000
Loading	Thermal	>5000	7500
Protection	Total Fault Contribution	1685	500
	Forward Flow Fault Contribution	2253	500
	Sympathetic Tripping	1426	500
	Reduction of Reach	1489	500
	Fuse Saving	1426	500
	Anti-Islanding – Breaker	390	390
Power Quality	Individual Harmonics	0*	0*
	THDv	0*	0*
Operational	Regulator	249	500
	Capacitor	249	500

* Basecase exceeded threshold

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Comparison to Other Utility Feeder

- Each feeder has **similar** characteristics that are **typically** used to classify feeders (load level and voltage class)
- Two significantly different PV penetration levels can be accommodated before violating voltage criteria

		Feeder J1		Feeder K1	
Category	Criteria	Small Scale (kW)	Large Scale (kW)	Small Scale (kW)	Large Scale (kW)
Voltage	Primary Overvoltage	421	500	>3585	8000
	Regulator Deviation	249	500	>3585	>10000
Protection	Total Fault Contribution	1685	2500	>3585	7500
	Forward Flow Fault Contribution	2253	2500	>3585	10000
	Sympathetic Tripping	1426	>10000	1478	>10000
	Reduction of Reach	1489	2500	>3585	5000
	Fuse Saving	1426	5000	1771	5000
	Anti-Islanding – Breaker	390	390	777	777

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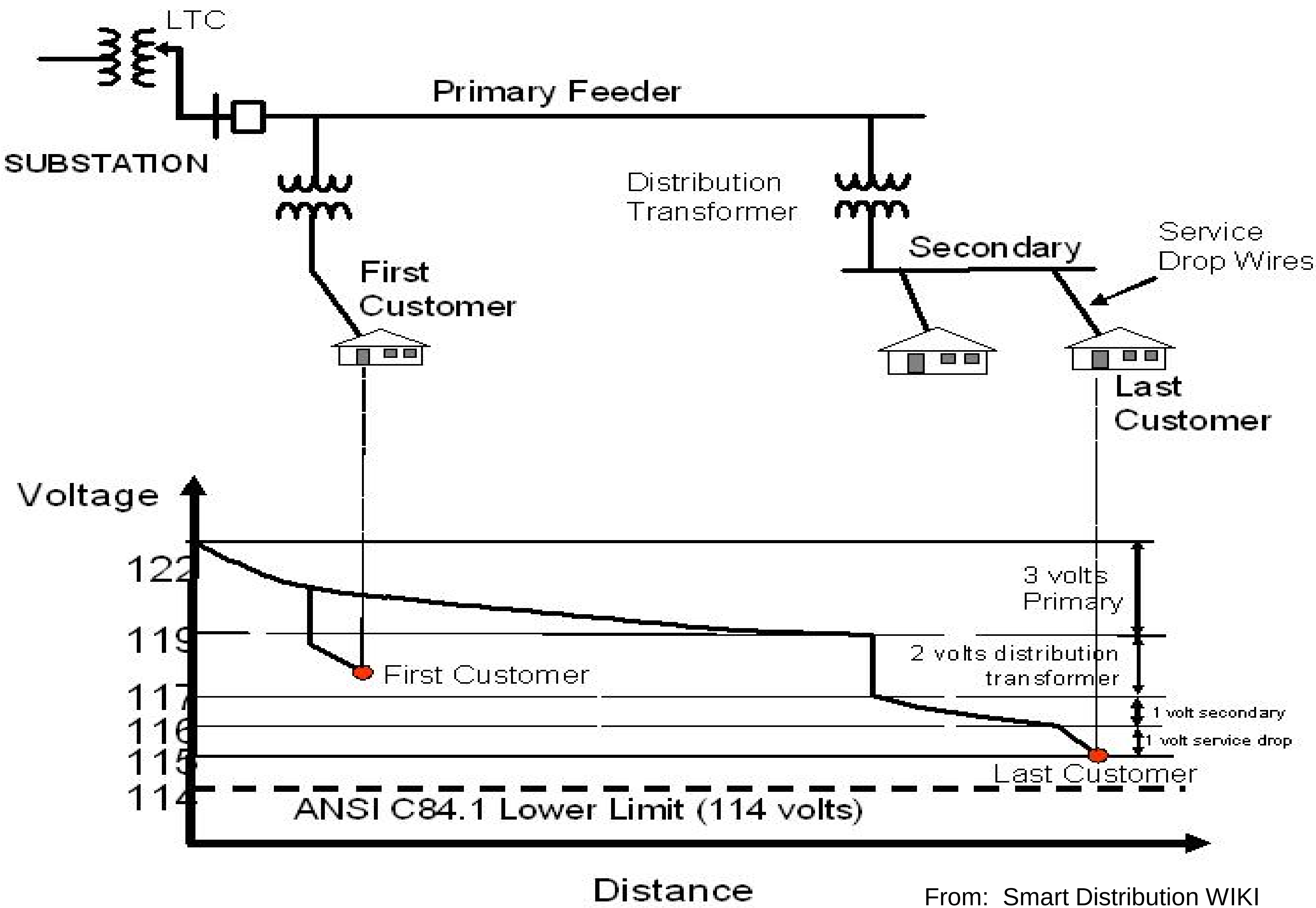
Voltage Regulation: Meter Voltage

- ANSI 84.1 Guideline: Maintain the Nominal Voltage +/- 5%
- If the voltage delivered to the meter is 126V, (the maximum allowable):
  - As soon as generation output exceeds the load of the premise, the voltage at the meter will begin to rise – and will exceed the ANSI guideline
  - Export is almost guaranteed for PV systems because solar has such a low capacity factor, it needs to be sized quite large to net out the annual energy use
  - This can be a bigger problem if more than 1 home feeds into the same transformer or for community energy



From: Smart Distribution WIKI

Approximate Voltage Drop/Rise (%) @ Peak, Minimum Load & with PV

	Approximate at PEAK LOAD without PV	Approximate at MINIMUM LOAD without PV	With PV Solar Causing Export (at minimal load)
Across Line Transformer	- 0.5 to – 2.0%	Negligible	+ 0.3 to +1.3%
On Secondary	- 0.5 to -1.5%	Negligible	+ 0.2 to +1.0%
On Service Drop	- 1 to -1.5%	Negligible	+ 0.5 to +1%
TOTAL	**- 2.0 to - 5.0%**	**Negligible**	**+ 1.0 to + 3.3%**

Note: Negative shows voltage dropping towards the premise and generation system.

Providing Headroom for DERs

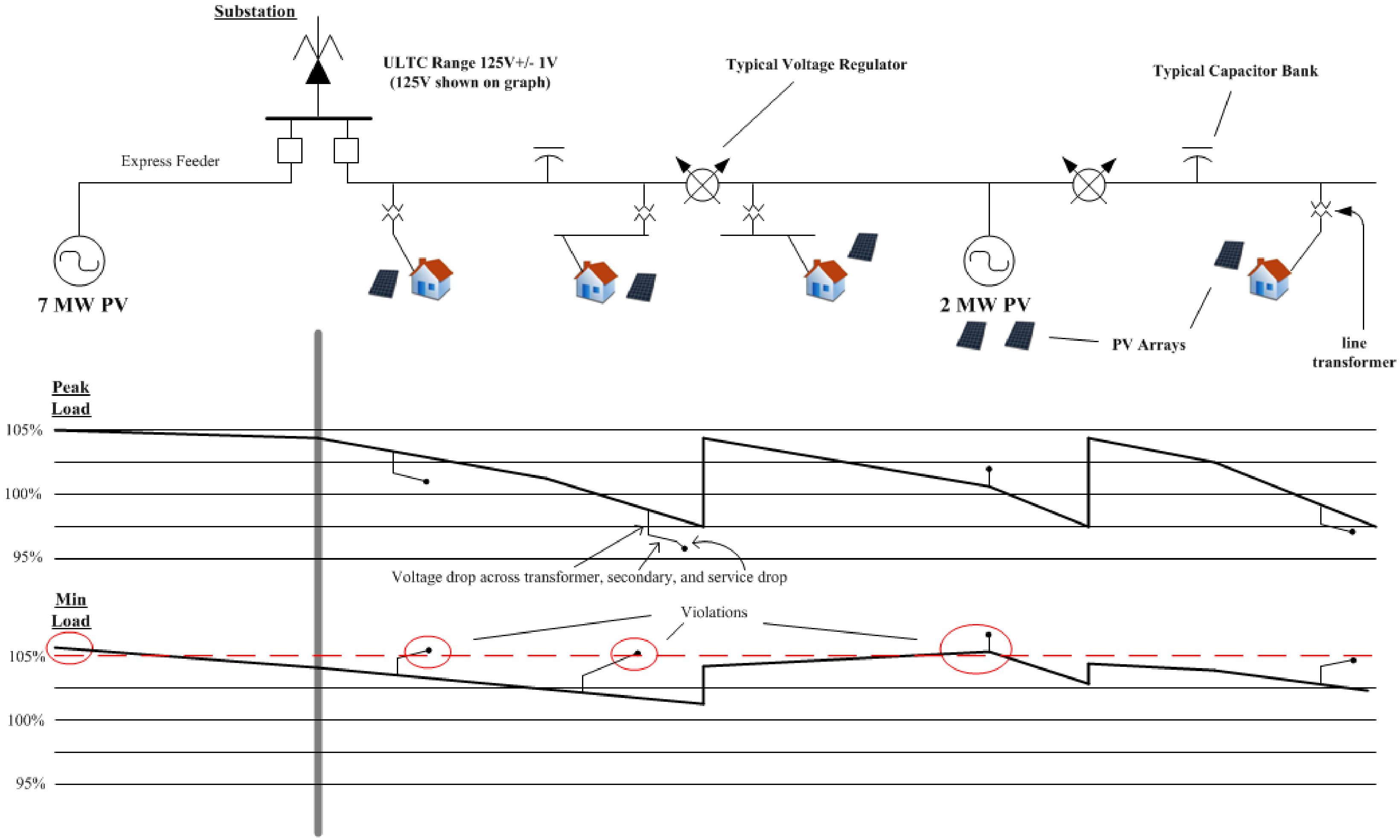
- The utility is required to deliver a high enough voltage to insure adequate voltage at the meter during peak load, but yet low enough to be the proper voltage at low load. Now with DERs, the top voltage needs to give head room to PV and other DERs that may cause export at low facility load.

- Proposal: Deliver a target voltage of 123V (1.025 pu) to the meter. This will give 3 volts or 2.5% headroom for PV or other DERs that cause voltage rise during low facility load and high output, or periods of export.

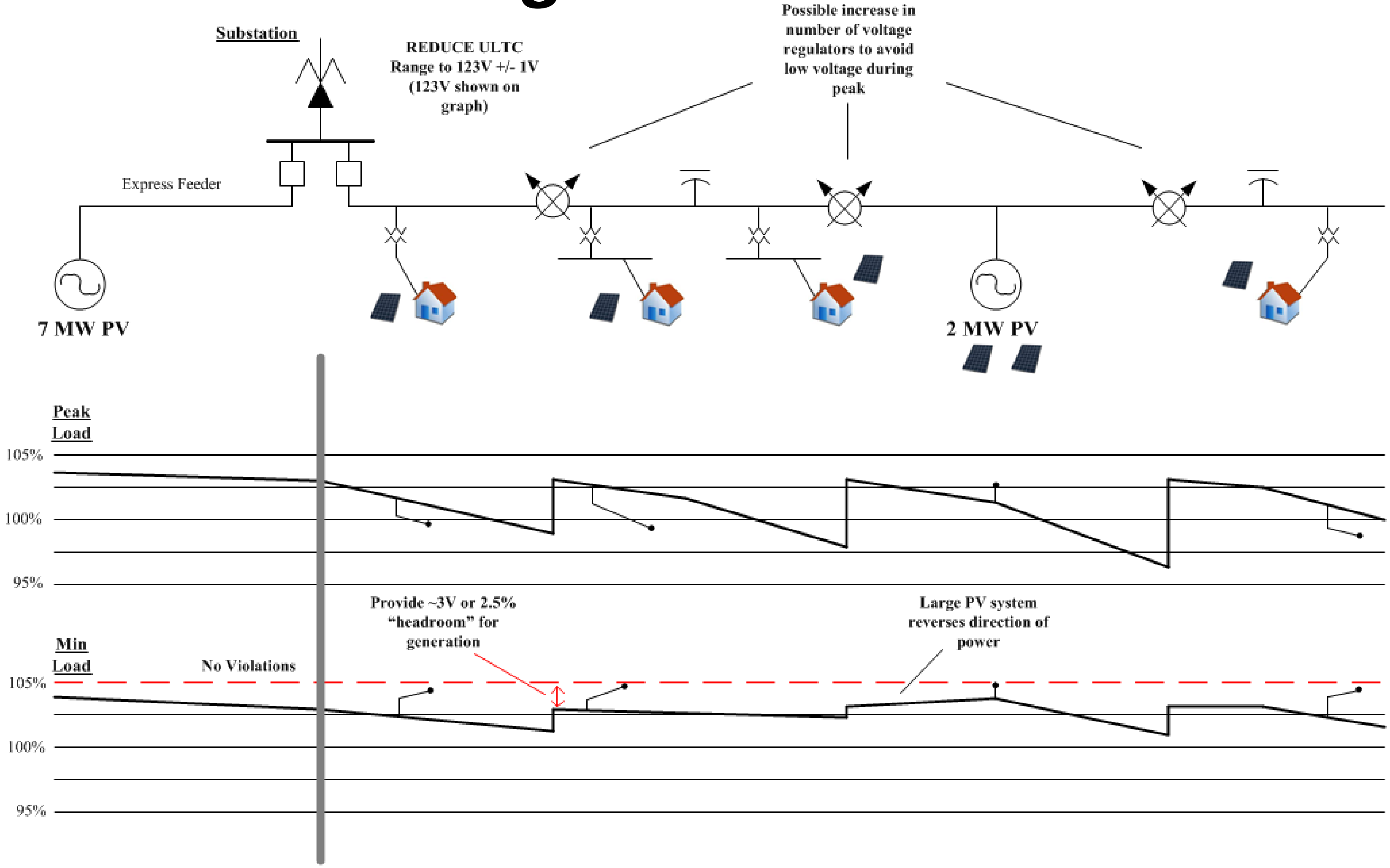
- 123V would become the new target voltage for automatic line equipment. The setting for a bandwidth would be 122-124V.

- The concept is very similar to Conservation Voltage Reduction or CVR. The other approach could drop setpoints during periods with lower net load on the complete feeder or sections.

Typical Voltage Regulation with Violations at the Meter



Voltage Regulation with "Headroom" to Mitigate Violations



Utility Collaborative Efforts to Develop Advanced Solutions

- New electric system model of both the T & D system that will run time series analysis with all renewables and other generation represented as well as load – will provide aggregate impact, large system impact studies and higher penetration studies
- Collaborative R & D on new anti-islanding scheme
- Collaborative R & D on dynamic var control, centrally controlled vars
- Hosting Tests of Advanced Volt/VAR Control

Utility Collaborative Efforts (cont.)

- Collaborative effort on collecting 1 second data from multiple points on a feeder and large PV system output to better understand impact on automatic line equipment and model penetration limit
- Collaborative effort to verify the accuracy of atmospheric data, both historical and predicted
- Effort to utilize AMI to monitor and possibly provide control signals to small size inverters
- Reviewing Cellular SCADA for large size systems

Utility Collaborative Efforts (cont.)

- Integrating PV output data into Distribution Automation schemes
- Reviewing feasibility of a completely online and automated way for applying and approving PV systems, reprogramming the meter, then transmitting output data automatically -- for very small/low impact systems in areas with AMI.

Outside Demo at ACE Training Yard with smart switch, incorporating load, and battery system.
(Work done with DOE SEGIS Grant to Petra Solar)

Outdoor Demo of Micro-grid mode – can operate off PV and battery, then resync with grid

(Work done with DOE SEGIS Grant to Petra Solar)

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Thank You!