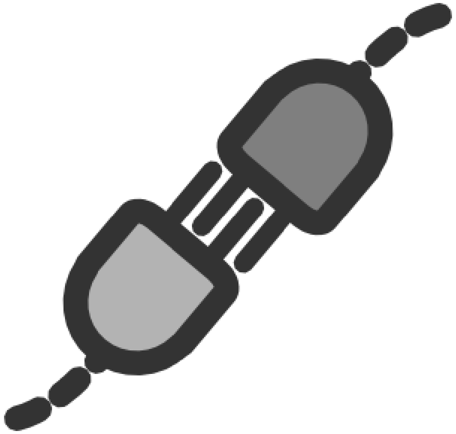
Challenges for Distribution Feeder Voltage Regulation with Increasing Amounts of PV



April 19, 2012
EPRI-NREL-SEPA

Pepco Holdings, Inc

Overview

- A Common Issue – Voltage Rise and Voltage Fluctuation on Various Circuits
- Utility Efforts to Accommodate PV
- Three Critical Areas for Higher Penetration Solutions

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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

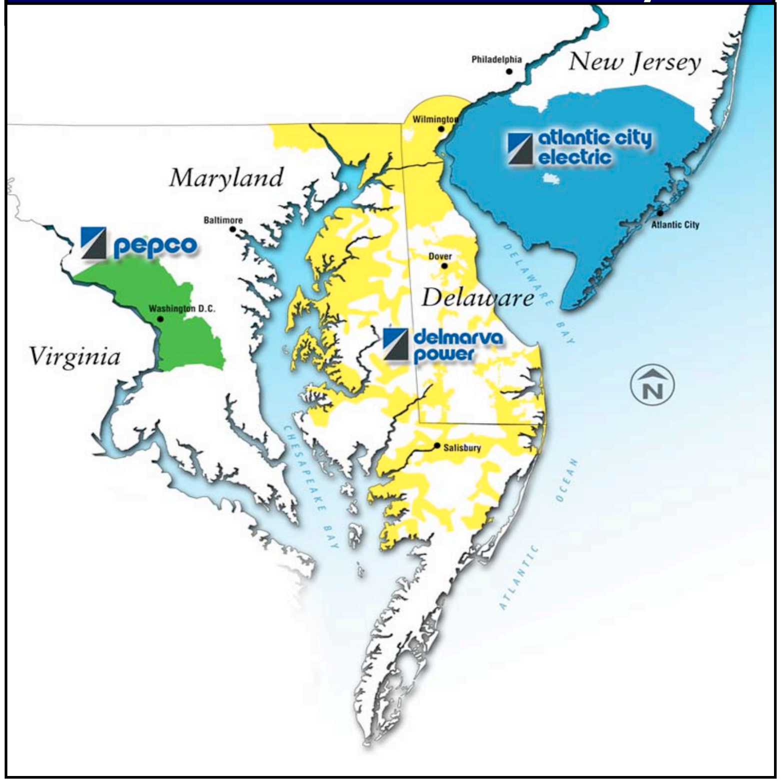
atlantic city electric
A PHI Company

2,700 sq mi

546,000 cust

4, 12, 23, and 34kV distribution

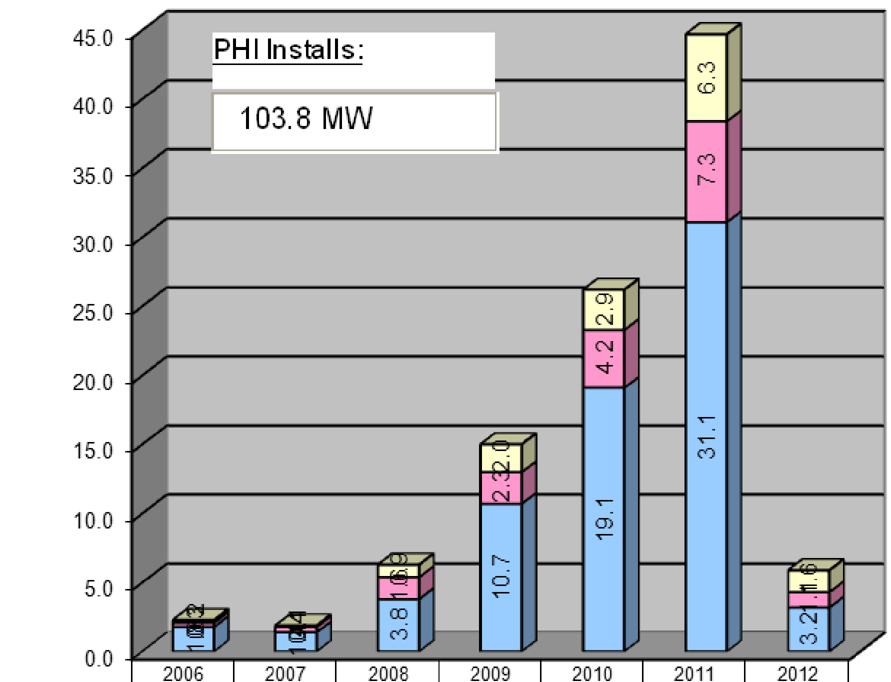
Combined Service Territory



Active NEM PV MWS By Year

PHI Active NEM PV Generation (MW) By In-Operation Year

As Of: 3/1/2012



	2006	2007	2008	2009	2010	2011	2012
Pepco (MW)	0.2	0.1	0.9	2.0	2.9	6.3	1.6
DPL (MW)	0.3	0.4	1.6	2.3	4.2	7.3	1.1
ACE (MW)	1.8	1.4	3.8	10.7	19.1	31.1	3.2

ACE
72.3 MW

DPL
17.5 MW

PEPCO
14.0 MW

TOTAL
103.8 MW

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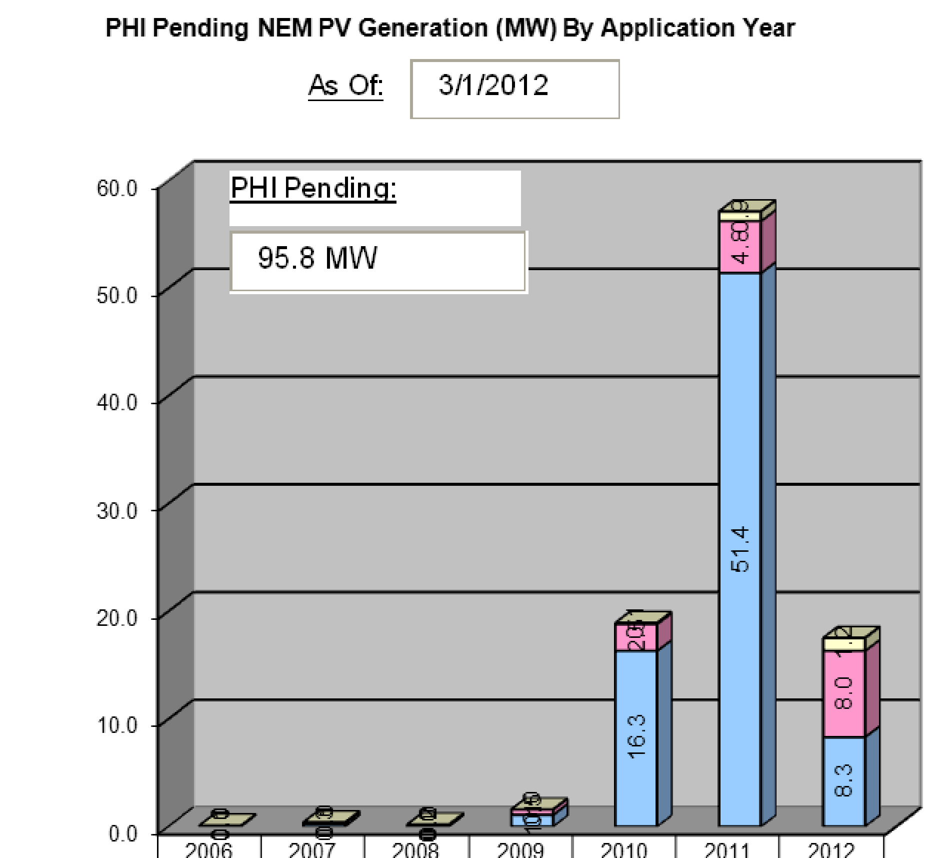
Pending Solar PV NEM (MWS)



	2006	2007	2008	2009	2010	2011	2012
Pepco (MW)	0.0	0.0	0.0	0.0	0.1	0.9	1.2
DPL (MW)	0.0	0.1	0.2	0.5	2.5	4.8	8.0
ACE (MW)	0.1	0.3	0.0	1.1	16.3	51.4	8.3

ACE
77.5 MW

DPL
16.0 MW

Pepco
2.3 MW

TOTAL
95.8 MW

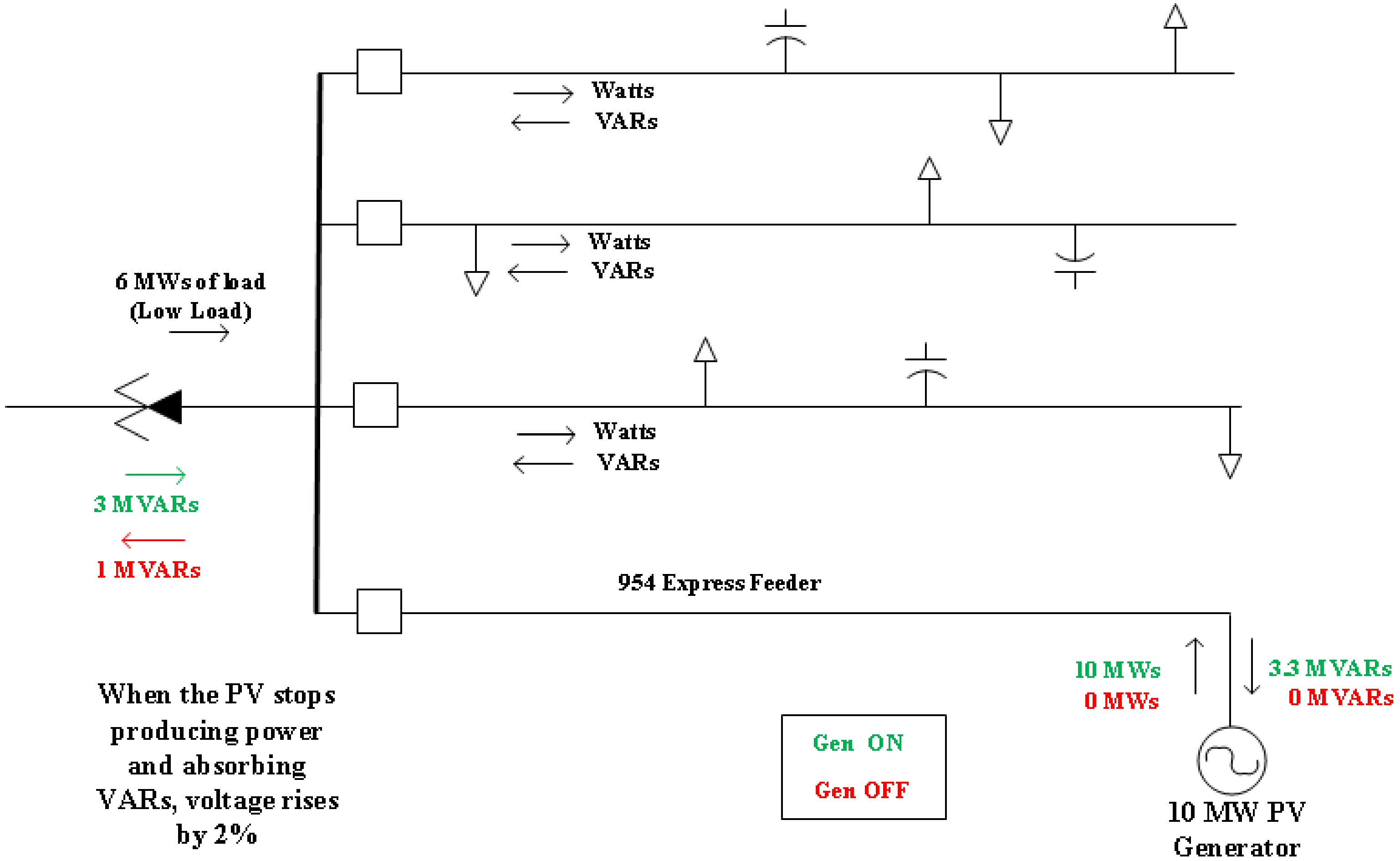
Solar PV on Express Feeders

Solar PV on Radial Load Serving Feeders

Small Solar – 250 kW or less




Substation Bus Voltage Regulation and Impact of VAR Fluctuation



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

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Substation Bus Voltage Regulation

- Where there are load serving feeders and an express feeder from a PV site, they both have conflicting interests in the bus voltage – the express feeder tends to have voltage rise out to the large generator and would prefer a lower bus voltage, while the other feeders have voltage decrease over distance as they server load and would need a higher bus voltage.

- Pictured is another issue, when there can be var flow reversals at the substation bus, especially at low load, the voltage of the bus may change discreetly by a significant amount -- ~2.4 volts on a 120V base for the scenario pictured.

Potential Voltage Rise and Fluctuations

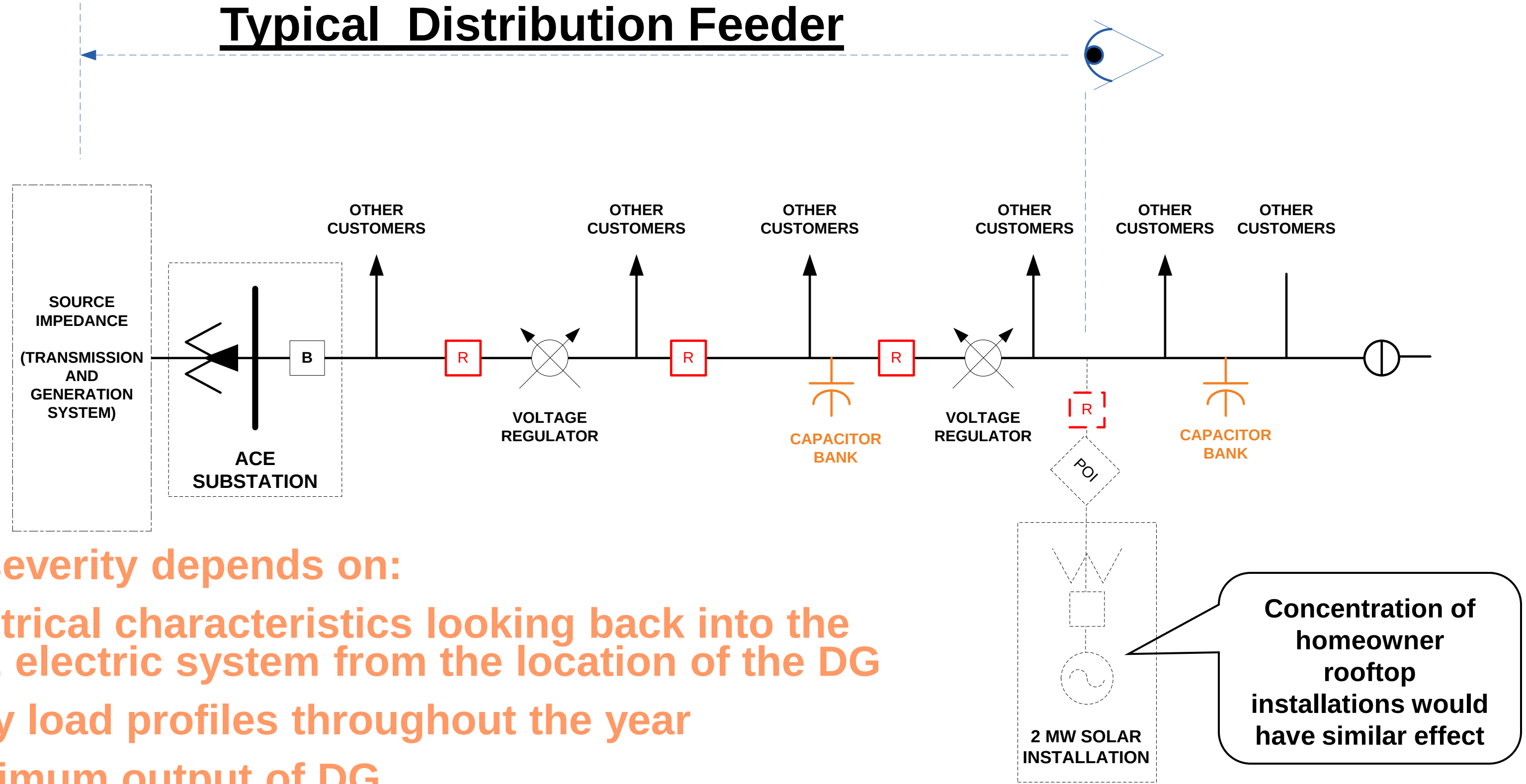
- Simulated Voltage Levels for 18 MW PV System (on 120V base)
  - System Off 124.0
  - 0.97 Leading PF 125.9 ← setting
  - Unity PF 126.8
  - 0.97 Lagging PF 127.4
- State Reqt: 115.2 – 124.8 V (+/- 4%)
- Feeder Voltage: 12,470 V phase to phase
- Injection to Substation: 9MWs each on 2 feeders
- Substation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

Harmonic Issue – Inverter Tripping

- 10 MW Solar System
- Resonant with utility system
- Several times per day it caused some over voltages and unexpected tripping
- Capacitance was added to the inverters to resolve the situation

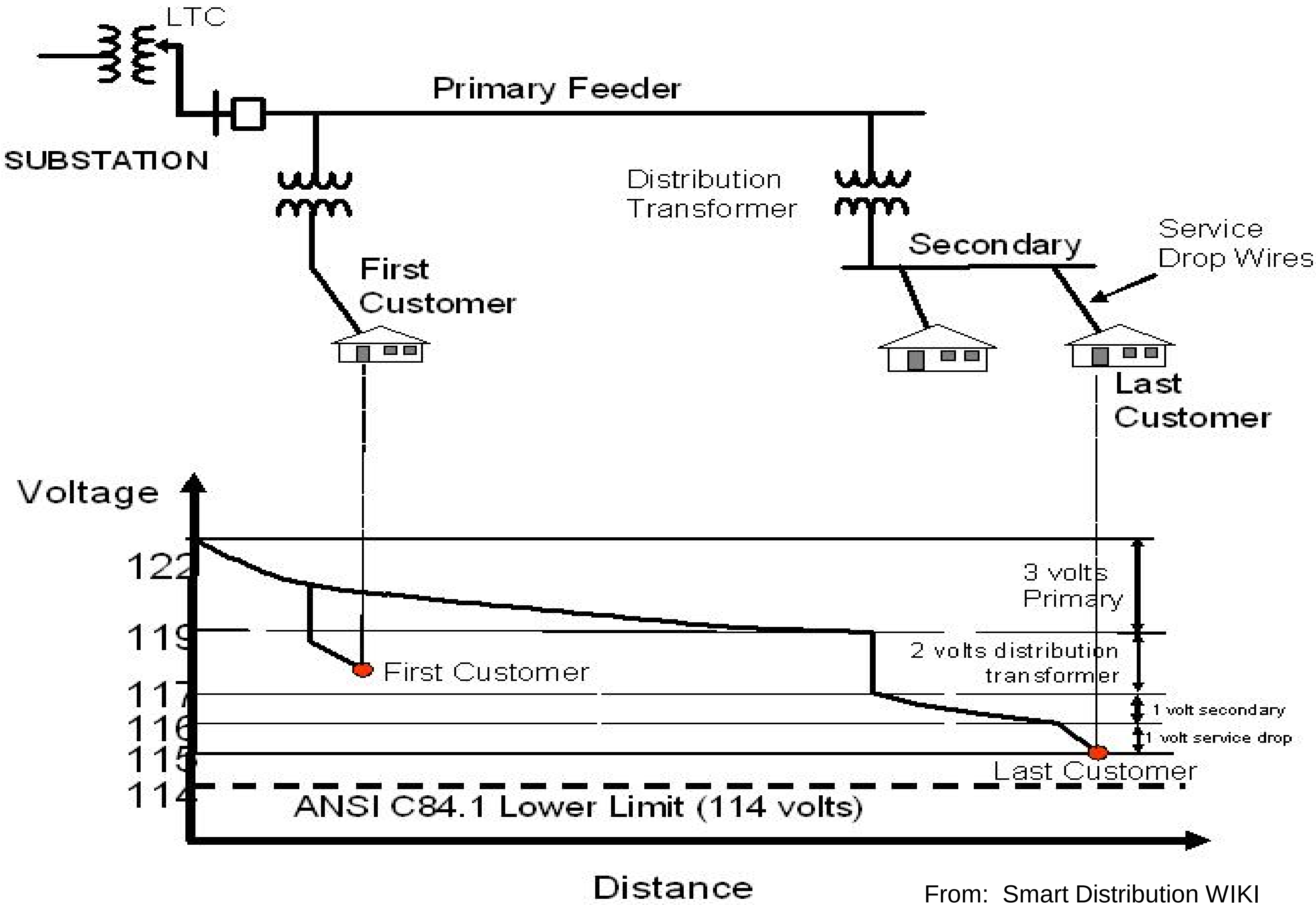
Impacts to a Distribution Feeder

Typical Distribution Feeder



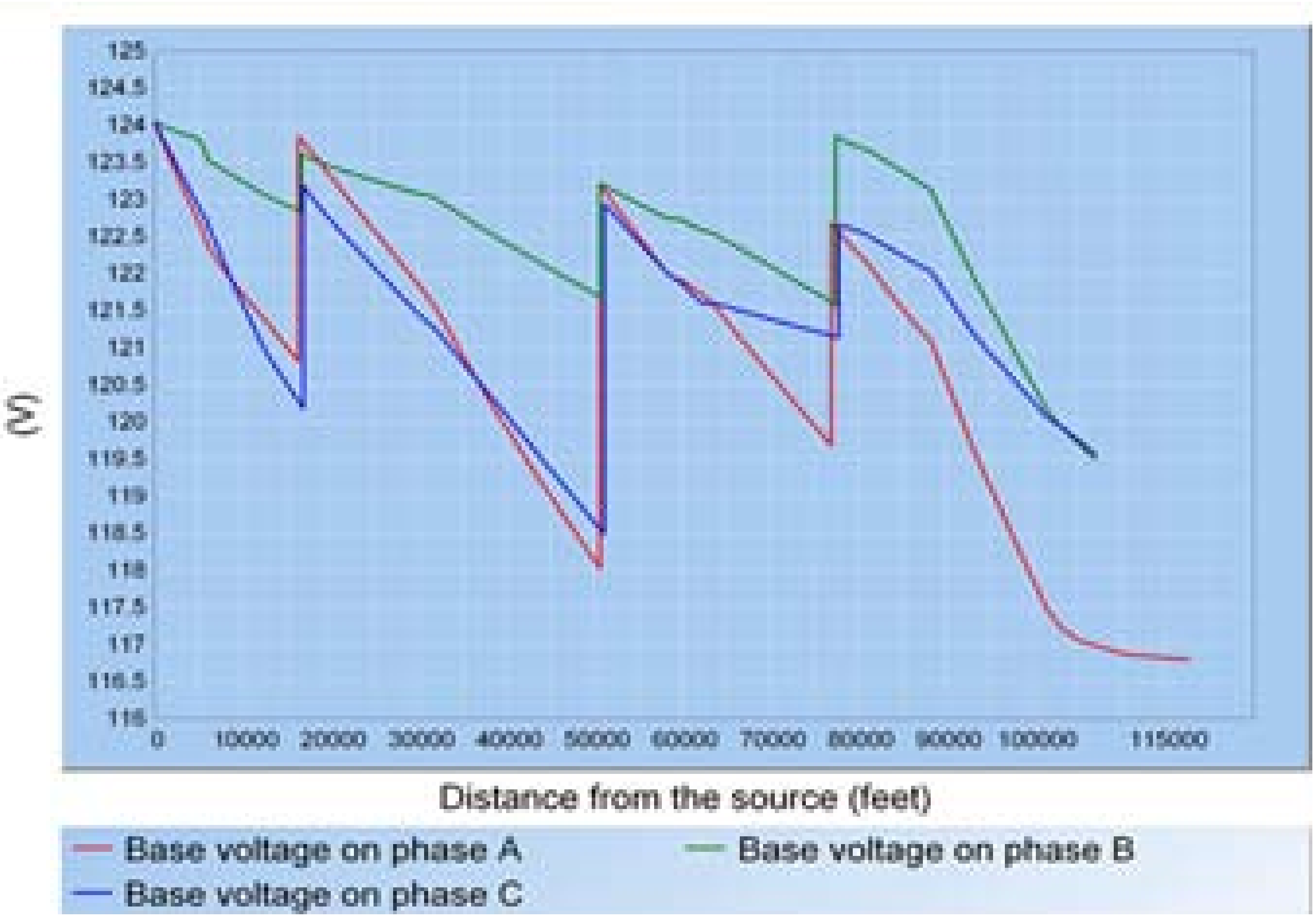
adapted from actual DG customer application

- Impact severity depends on:
  - Electrical characteristics looking back into the ACE electric system from the location of the DG
  - Daily load profiles throughout the year
  - Maximum output of DG
  - Substation transformer settings
  - Location and settings of regulators, capacitors, and reclosers



From: Smart Distribution WIKI

Plot of Feeder Voltage over Distance



Feedor Voltage Regulation

- This feeder is quite long and has 3 sets of voltage regulators besides the voltage regulation of the Load Tap Changer at the substation power transformer
- Because this is from a load flow, it doesn't show the minimum or maximum each voltage rise could be – the voltage regulator typically has a bandwidth of 2 volts so where we see 124V it could be 123 to 125V (state voltage reqt is +/-4% instead of +/-5%)
- Notice that because the loading on each phase differs, the voltages are also different – single phase inverter concentrations on different phases can impact these excursions
- The case we see is peak and the voltage regulators are placed to keep feeder voltage in the required range.

Voltage Drops (%)
@ Peak, Minimum Load & with PV

	Approximate at PEAK LOAD	Approximate at MINIMUM LOAD	With PV Solar
Across Line Transformer	- 0.5 – 2%	Negligible	+ 0.3 – 1.3%
On Secondary	- 0.5 – 1.5%	Negligible	+ 0.2 – 1%
On Service Drop	- 1 – 1.5%	Negligible	+ 0.5 – 1%
TOTAL	**- 2.0 – 5.0%**	**Negligible**	**+ 1 – 3.3%**

Voltage at the Meter

- ANSI 84.1 Guideline: Nominal +/- 5%
- If the voltage delivered to the meter is 126V or +5% over 120V nominal at low load to insure adequate voltage at peak load:
  - 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 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 for more than 1 home feeding into the same transformer or for community energy

Voltage on a Radial Feeder

- Voltage declines over distance and based on load level. Utilities must keep voltage in the limits at minimum and peak loading
- The smaller the bandwidth a utility maintains for voltage, the closer the voltage regulation or switched capacitor banks must be to each other – more must be used at a higher cost.
- So what is the bandwidth w/o solar and with solar:
  - w/o: At peak. If we can have 5.0% voltage drop between line and meter, that would mean the line must be kept to 119 or 120V to insure the customer receives the minimum of 114V
    - Since the line can have a 5% voltage drop, between voltage regulation points, it needs to start at 125-126V at regulation points and will decrease to 119V at some distance.

Voltage on a Radial Feeder (cont.)

- Bandwidth with Solar:
  - Voltage on the Feeder Main would need to be the same to accommodate peak load conditions - - except higher voltages could be expected on long laterals with reverse flow. Underground cable areas are also vulnerable to high voltage
- For shorter, “stiffer” feeders with less voltage drop, feeder voltage may not need to be 125-126V at Voltage Regulation devices (feeder voltage bandwidth can be smaller) but for longer rural feeders, it is common use the whole 5 % drop as the feeder covers long distances

Voltage on a Radial Feeder (cont.)

- At the premise: If the premise exports the maximum amount and is connected at a location near a voltage regulator, voltage could be 126 +3.3% = 130V at the meter.

- With very small solar systems the voltage rise would be far smaller. However with some larger systems, possibly from the Community Energy Concept or other virtual arrangements, we may see the higher amounts.

- Higher voltage at premises will have the opposite effect as CVR (Conservation Voltage Reduction), sought by some state PSCs to reduce energy consumption

- SUMMARY – Using +/- 5% Voltage bandwidth at the meter (or less), and up to 5% voltage drop on line transformer, secondary and service, it is a real challenge to accommodate PV

Hrs/yr where system/feeder is at minimum load and max PV output

System

SUMMARY TABLE: FREQUENCY OF SYSTEM LOADS THAT ARE < = TO A GIVEN PERCENTAGE OF THE SYSTEM PEAK											
		35%		40%		50%		60%		70%	
YEAR	SYSTEM PEAK (MW)	NO. OF DAYS	NO. OF HOURS	NO. OF DAYS	NO. OF HOURS	NO. OF DAYS	NO. OF HOURS	NO. OF DAYS	NO. OF HOURS	NO. OF DAYS	NO. OF HOURS
2011	2955.546	45	142	196	866	302	1373	344	1596	362	1728
	10AM - 2PM		*7.8%*		*47.5%*		*75.2%*		*87.5%*		*94.7%*
	All Hrs		*1.6%*		*9.9%*		*15.7%*		*18.2%*		*19.7%*

Fdr 1

SUMMARY TABLE: FREQUENCY OF FEEDER LOADS THAT ARE < = TO A GIVEN PERCENTAGE OF THE FEEDER PEAK											
		35%		40%		50%		60%		70%	
YEAR	SYSTEM PEAK (MW)	NO. OF DAYS	NO. OF HOURS	NO. OF DAYS	NO. OF HOURS	NO. OF DAYS	NO. OF HOURS	NO. OF DAYS	NO. OF HOURS	NO. OF DAYS	NO. OF HOURS
2011	10.3	16	27	35	139	230	969	316	1402	354	1658
	10AM - 2PM		*1.5%*		*7.6%*		*53.1%*		*76.8%*		*90.8%*
	All Hrs		*0.3%*		*1.6%*		*11.1%*		*16.0%*		*18.9%*

Hrs/yr where feeder is at minimum load and max PV output

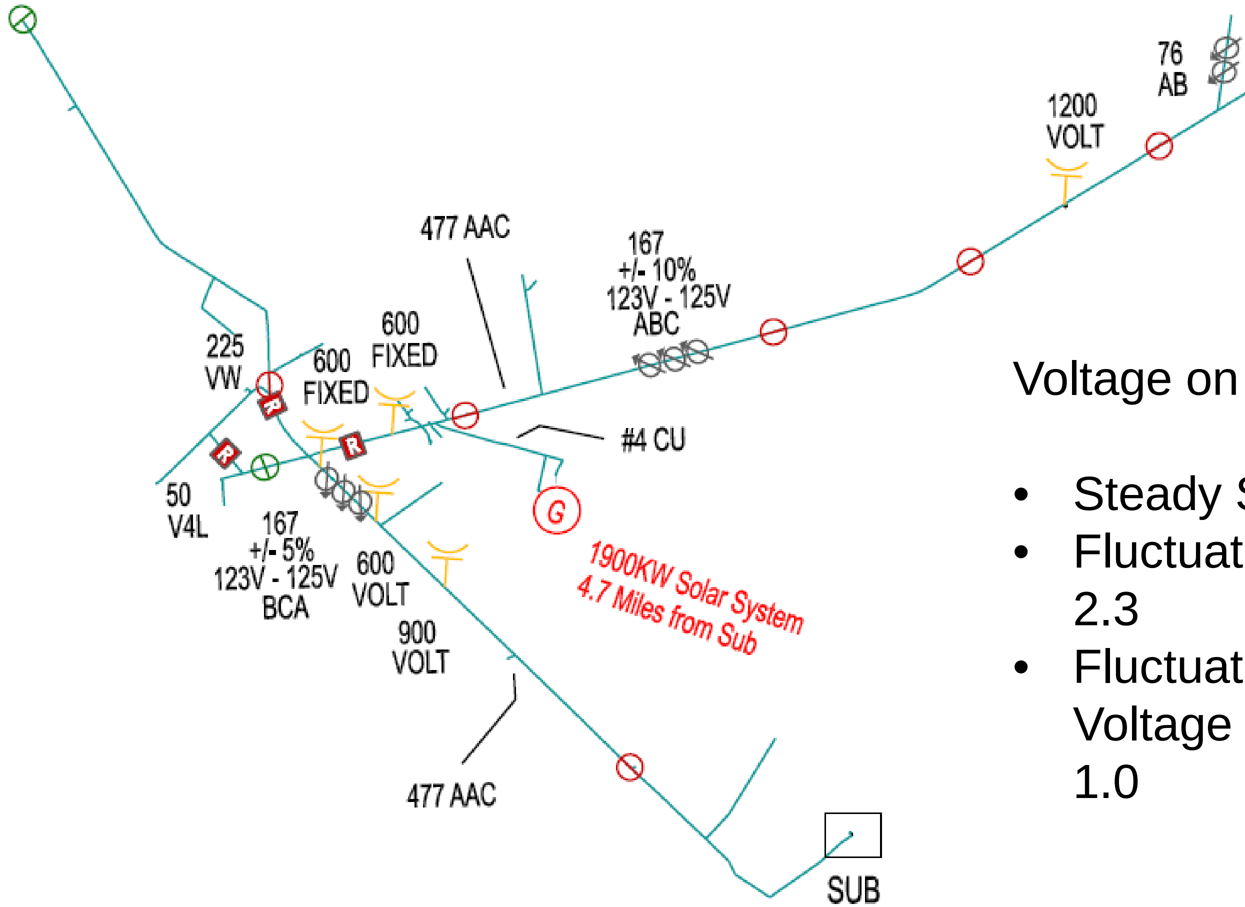
Fdr 2

SUMMARY TABLE: FREQUENCY OF FEEDER LOADS THAT ARE < = TO A GIVEN PERCENTAGE OF THE FEEDER PEAK											
		35%		40%		50%		60%		70%	
YEAR	SYSTEM PEAK (MW)	NO. OF DAYS	NO. OF HOURS	NO. OF DAYS	NO. OF HOURS	NO. OF DAYS	NO. OF HOURS	NO. OF DAYS	NO. OF HOURS	NO. OF DAYS	NO. OF HOURS
2011	4.83	124	463	163	592	243	926	307	1263	348	1578
	10AM - 2PM		*25.4%*		*32.4%*		*50.7%*		*69.2%*		*86.5%*
	All Hrs		*5.3%*		*6.8%*		*10.6%*		*14.4%*		*18.0%*

Fdr 3

SUMMARY TABLE: FREQUENCY OF FEEDER LOADS THAT ARE < = TO A GIVEN PERCENTAGE OF THE FEEDER PEAK											
		35%		40%		50%		60%		70%	
YEAR	SYSTEM PEAK (MW)	NO. OF DAYS	NO. OF HOURS	NO. OF DAYS	NO. OF HOURS	NO. OF DAYS	NO. OF HOURS	NO. OF DAYS	NO. OF HOURS	NO. OF DAYS	NO. OF HOURS
2011	17.77	146	601	220	970	308	1401	338	1598	358	1714
	10AM - 2PM		*32.9%*		*53.2%*		*76.8%*		*87.6%*		*93.9%*
	All Hrs		*6.9%*		*11.1%*		*16.0%*		*18.2%*		*19.6%*

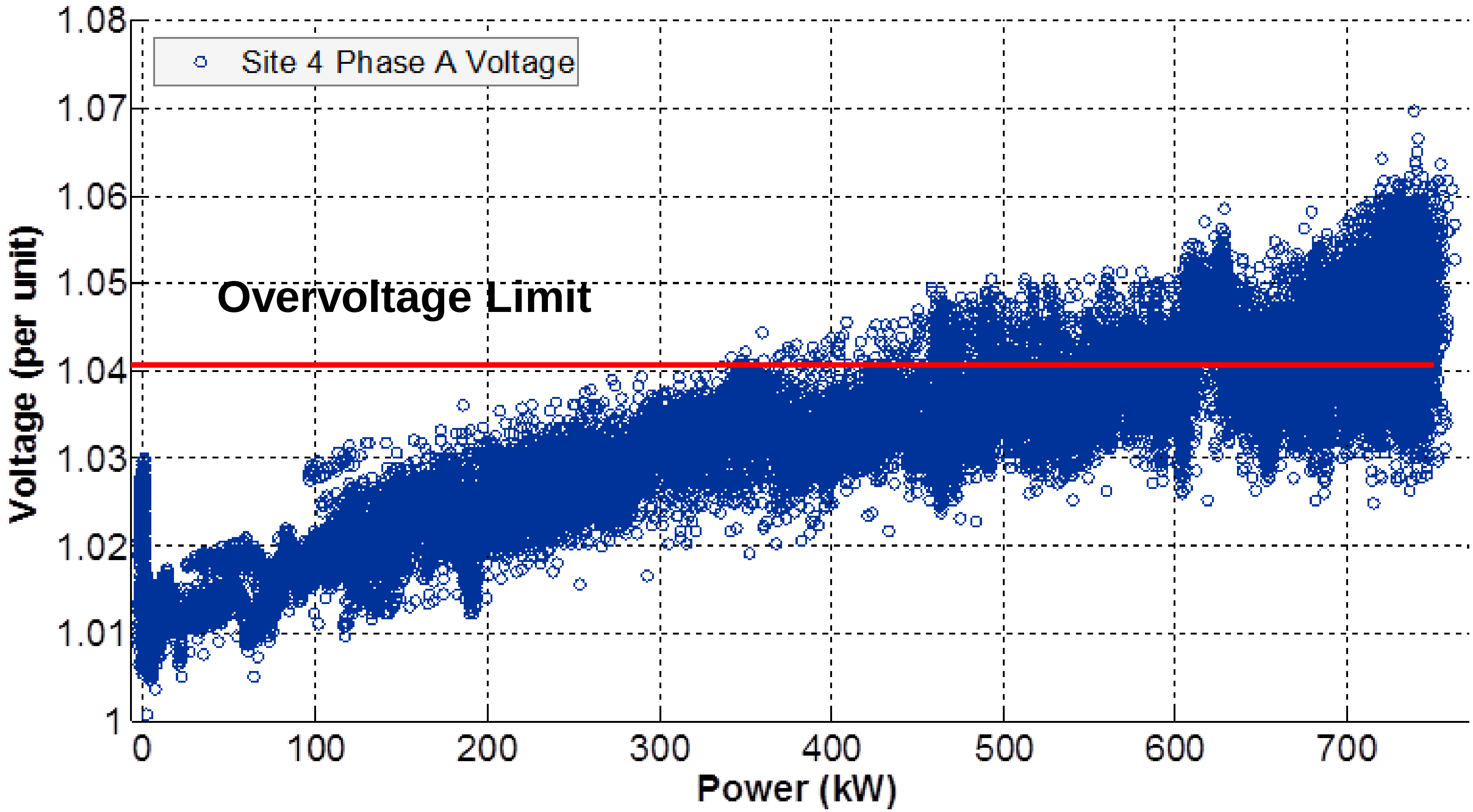
1.9 MW PV System (Feeder Nominal Voltage: 12,470V)



Voltage on 120V base

- Steady State: 125.3
- Fluctuation:at POI: 2.3
- Fluctuation at Voltage Regulator: 1.0

Overvoltage at the Inverter



Source: EPRI Monitoring

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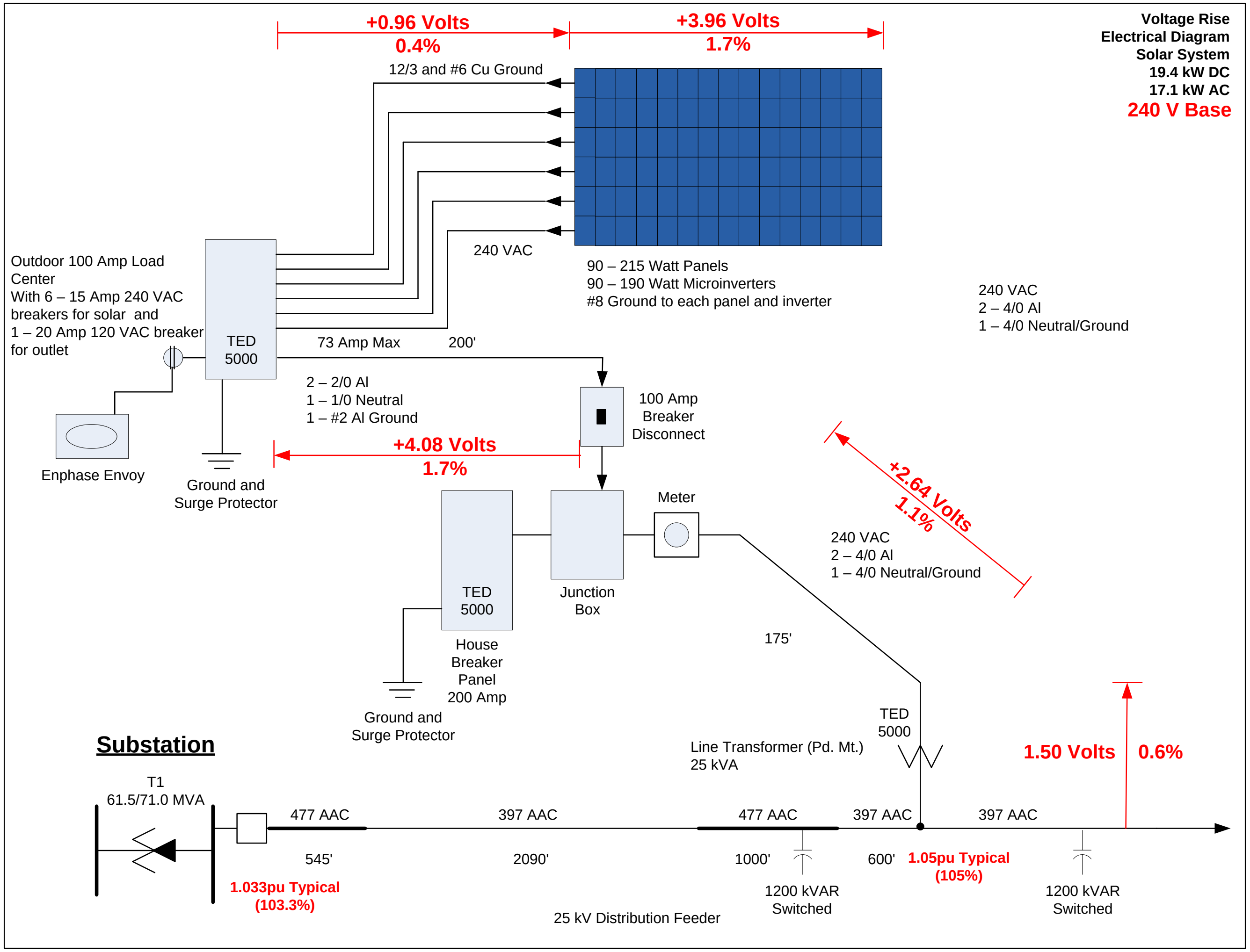
Voltage Rise



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Voltage Rise Chart
(at max gen and no load)

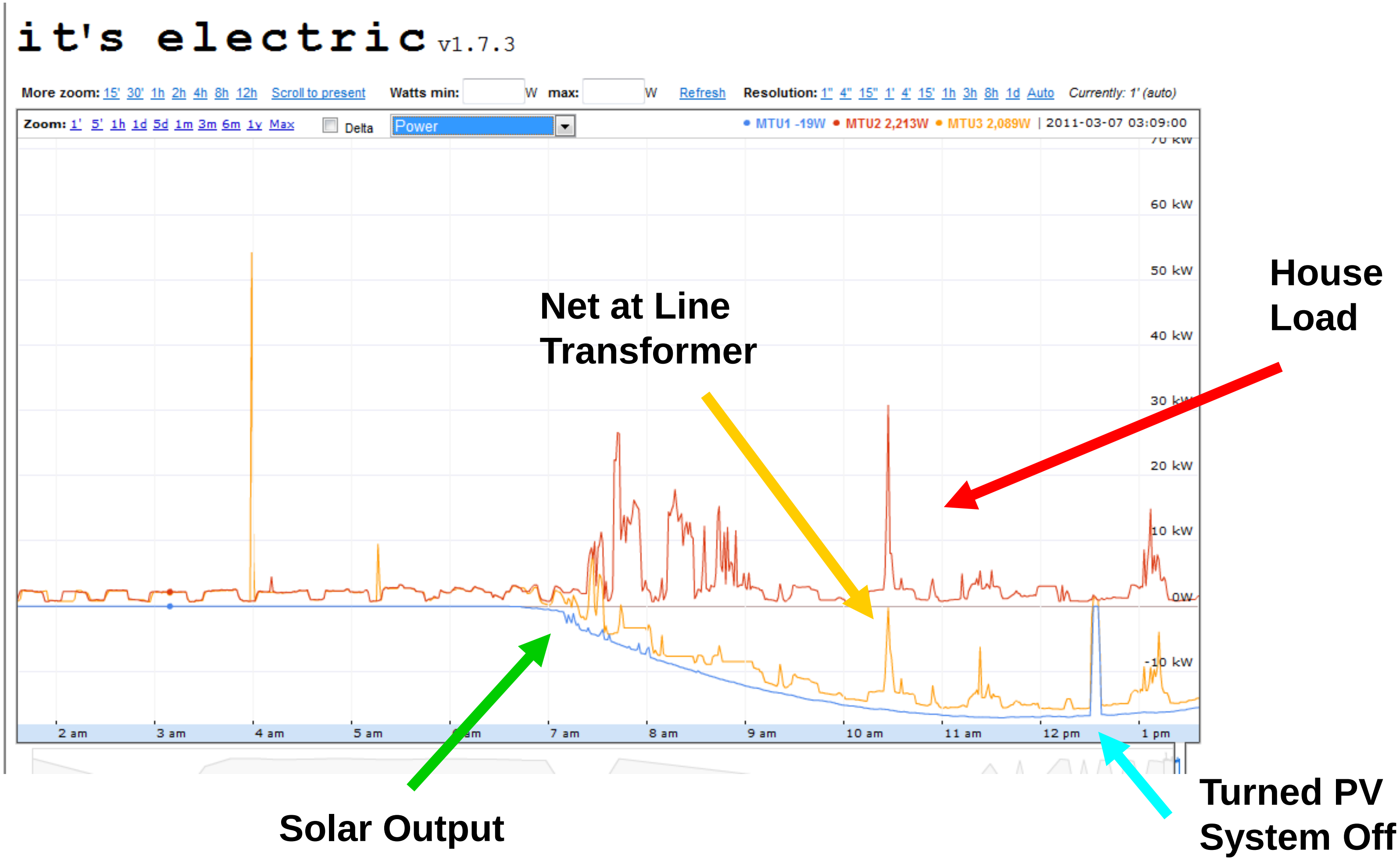
Nominal Voltages: 120V or 240V

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

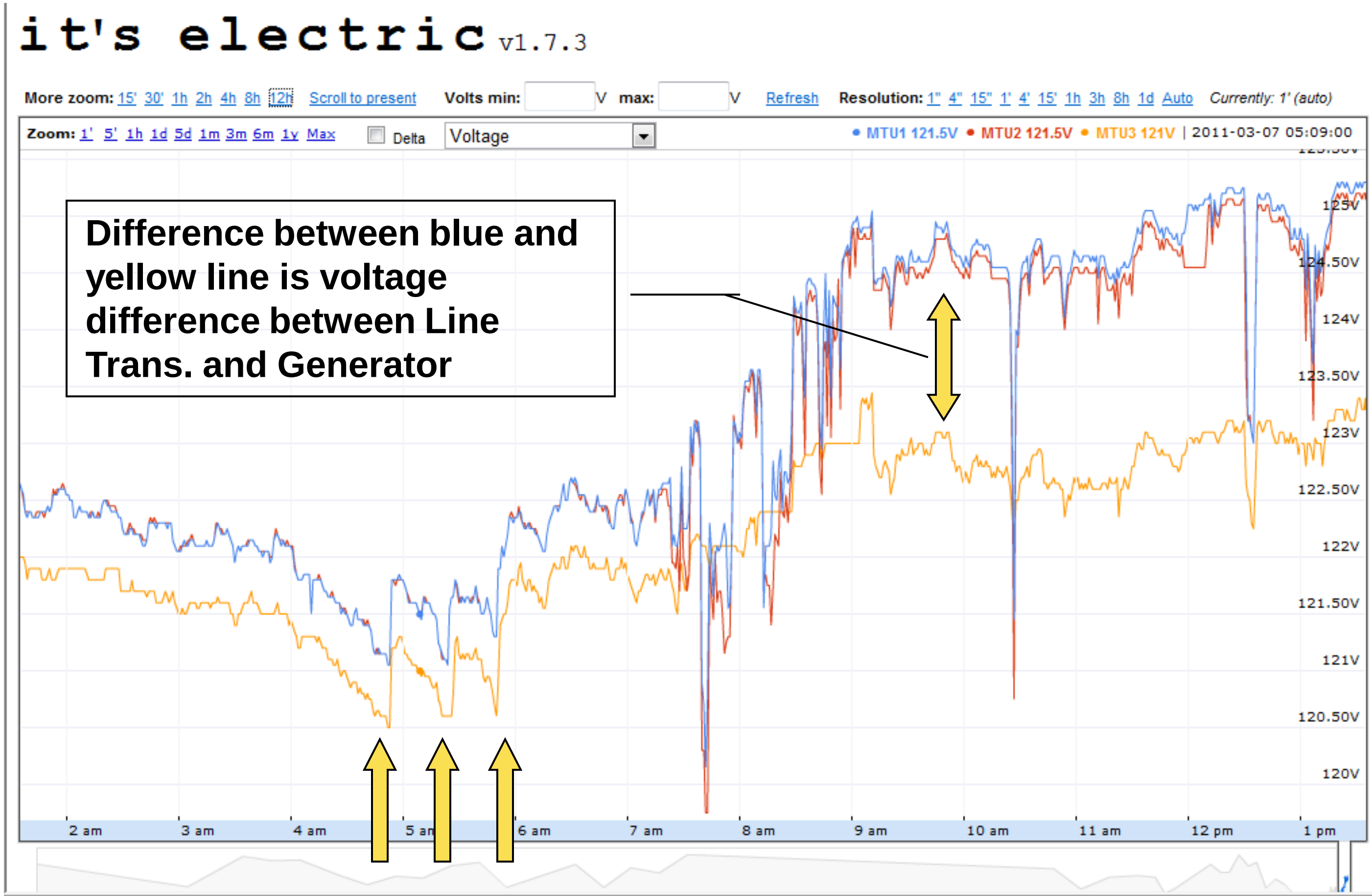
Electrical Segment	Voltage Rise		
	@ 120V	**@ 240V**	**%**
Microinverter String to End	2.0	4.0	1.7
Connection to PV Breaker Panel	0.5	1.0	0.4
Line to PV Disconnect (2/0 Al)	2.0	4.0	1.7
Sub-total	**4.5**	**9.0**	**3.8**
Service Drop	1.3	2.6	1.1
Line Transformer	0.8	1.6	0.6
Total	**6.6**	**13.2**	**5.5**

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

Power vs. Time



Voltage vs. Time



Substation transformer adjusting voltage

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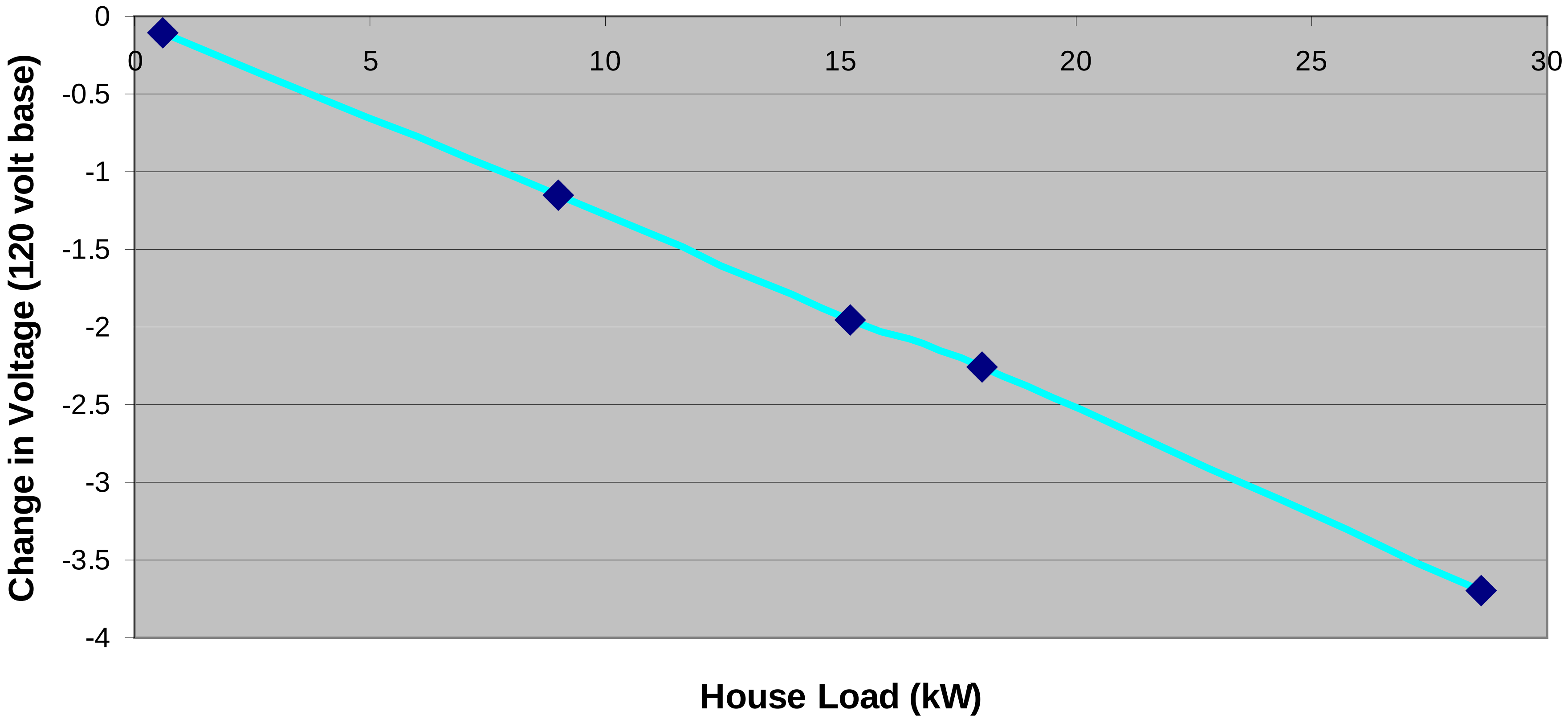
Voltage Drop vs. House Load

Unity Power Factor



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Voltage Regulation Issues/Thoughts

- There are several directions utilities are generally headed: CVR (Conservation Voltage Reduction), IVVC (Integrated Volt/Var Control) – what is needed is a strategy and general voltage guidelines that will lay the ground work for smart inverters to participate, as well as work with the reasons CVR and IVVC are being implemented – especially if we are to create a national standard for how inverters are to do autonomous control.

- The above needs to consider rural long feeders as well as short stiff feeders generally found in urban locations. It also needs to envision different paths that utilities are taking to upgrade or implement "Smart Grid" solutions

Voltage Regulation Issues/Thoughts (cont.)

- The ANSI voltage bandwidth of +/- 5% may need to be revisited - -Germany appears to use +/- 10%.
- Going to a flatter feeder voltage is nice, but can be costly because it may add many more voltage regulation zones to the feeder. Need guidelines where to possibly use a regulating transformer
- It has been difficult for utilities to quantify and mitigate extra operations of voltage regulators and switched caps due to PV but this needs to be taken into consideration
- Smart Load Control options also need to be considered as part of the voltage regulation solution

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Smart Energy

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

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

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

Pepco Holdings Inc

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Thank You!