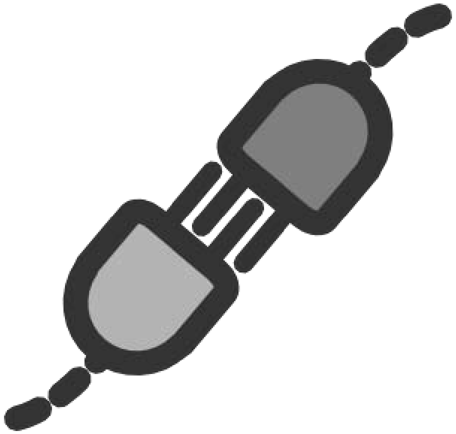
# PV Impact on the Electric Grid



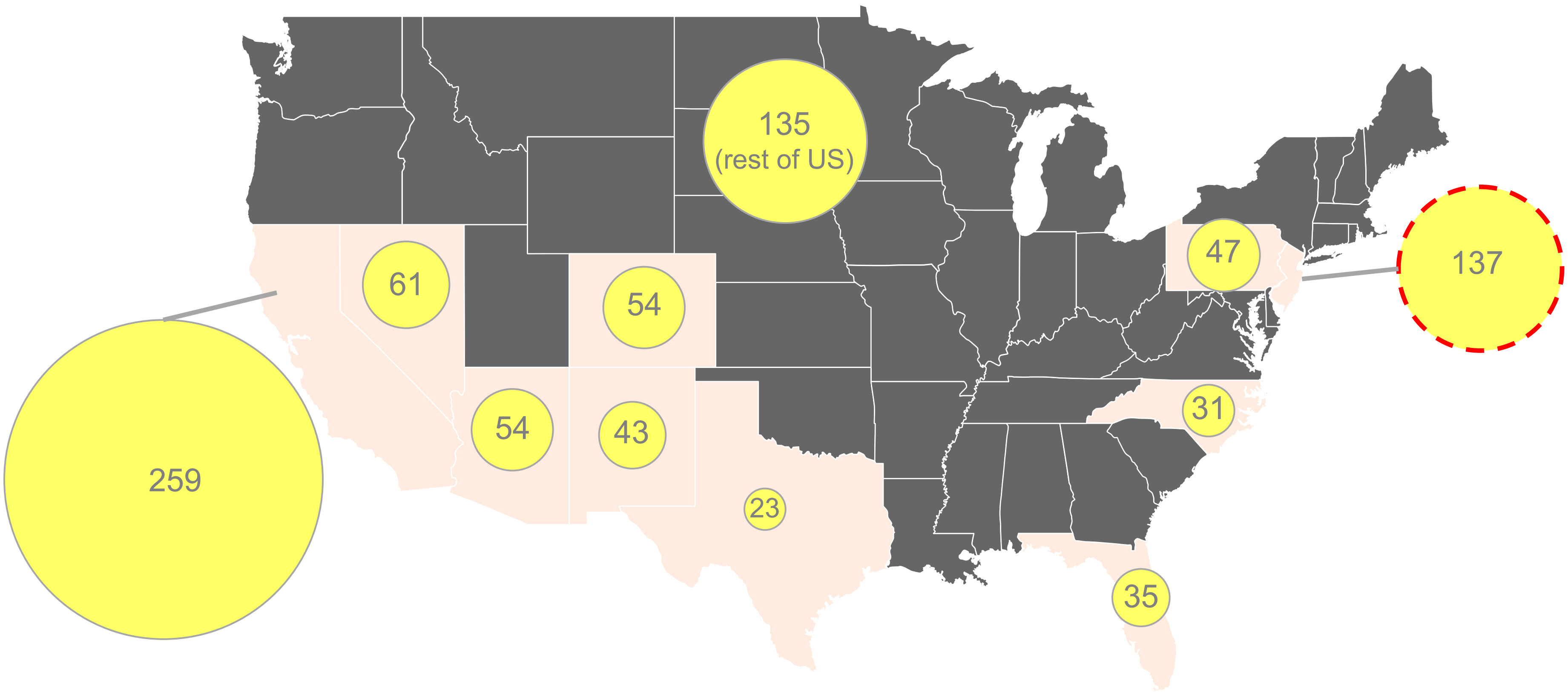
*March 19, 2012*
*PJM NEMSTF*

Pepco Holdings, Inc

# Overview

- PV Issues with Different Size Systems and Potential Solutions
  - Large PV (Greater than 3 MWs)
  - Medium PV (250 kW – 3 MW)
  - Small PV (less than 250 kW)
- Utility Efforts to Accommodate PV
- Three Critical Areas for Higher Penetration Solutions

# 2010 solar PV installations in US: top 10 states
***(in MWs, from SEIA)***




Source: SEIA; all amounts shown are MWs

**US Total installations of PV for 2010: 878 MWs**

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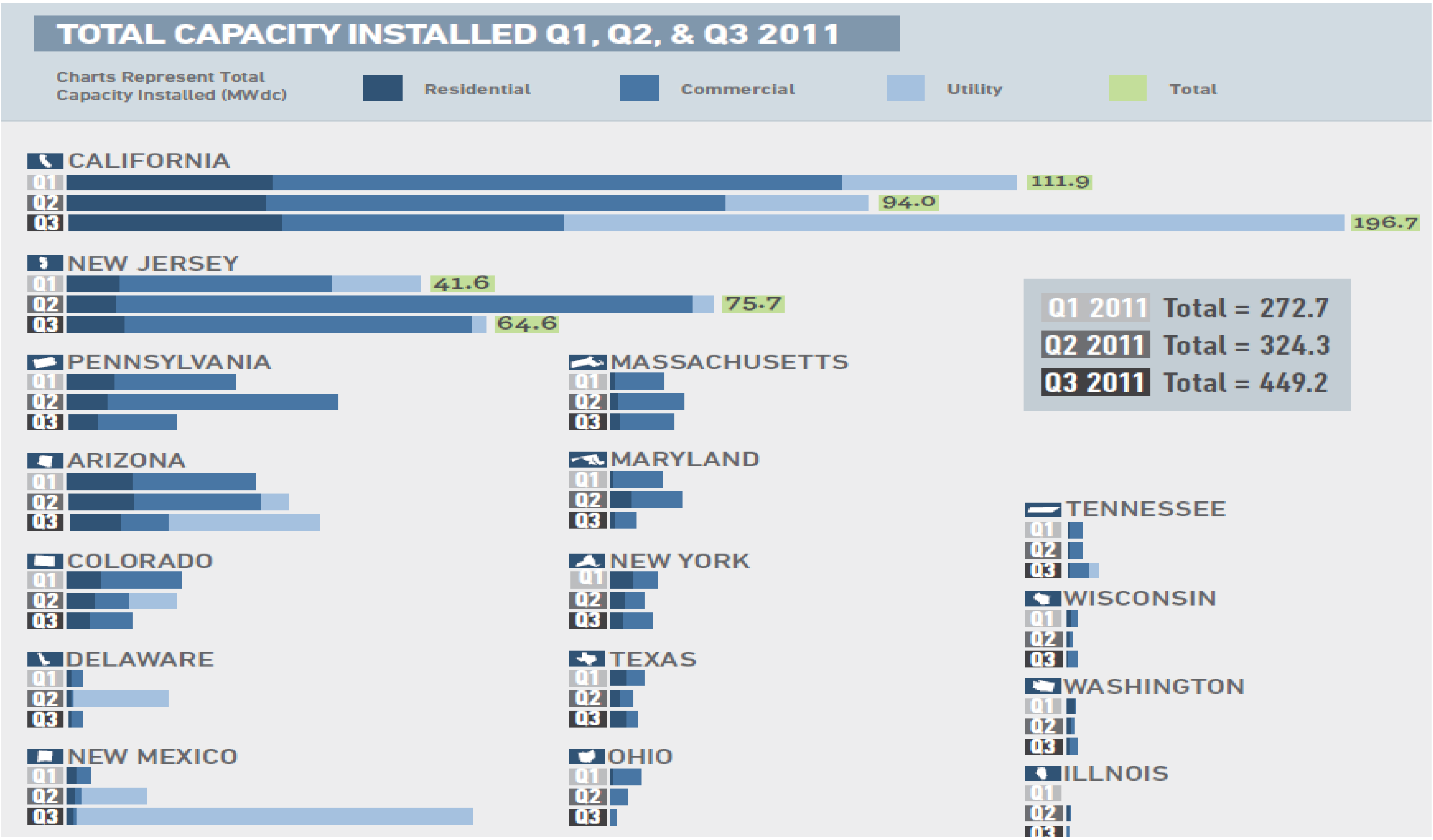
# U.S. PV Activity for 2011
## (in MWs, from SEIA)

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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**

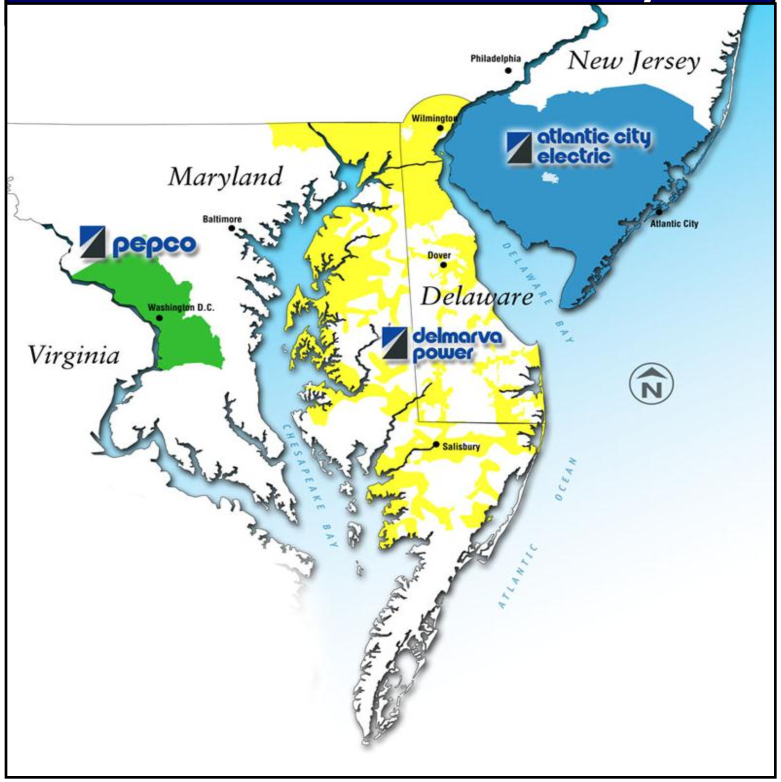
**delmarva power**
A PHI Company

**5,400 sq mi (*3,500 in MD)***
**498,000 cust (*199,000 in MD)***
**4, 12, 25 and 34kV distribution**

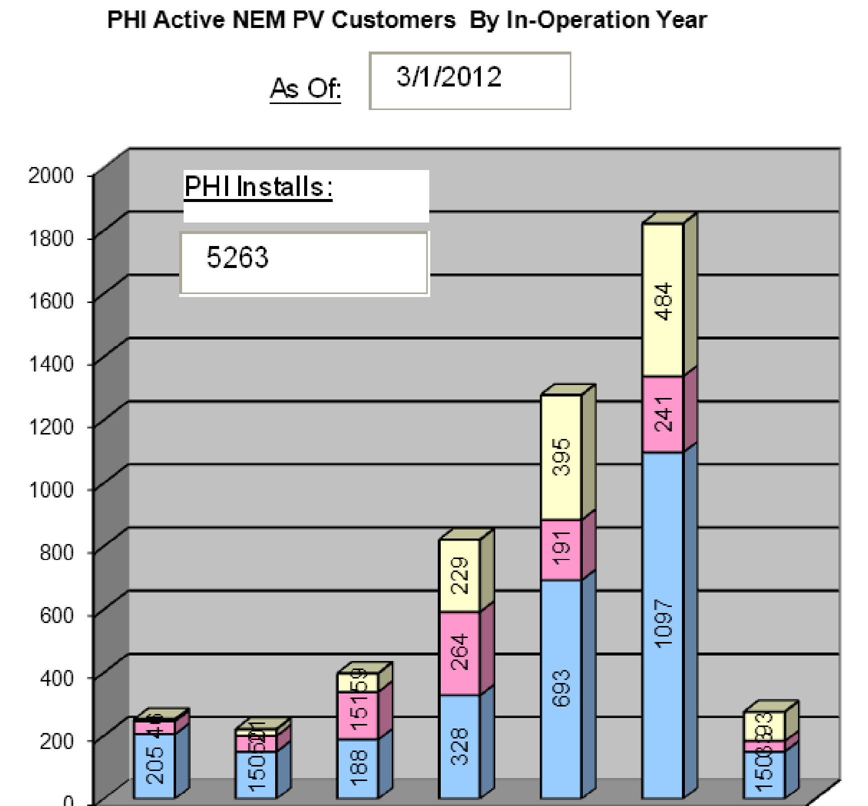
**atlantic city electric**
A PHI Company

**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 |
|---|---|---|---|---|---|---|---|
| Pepco | 6 | 21 | 59 | 229 | 395 | 484 | 93 |
| DPL | 41 | 50 | 151 | 264 | 191 | 241 | 33 |
| ACE | 205 | 150 | 188 | 328 | 693 | 1097 | 150 |

**ACE**
**2984 Installs**

**DPL**
**989 Installs**

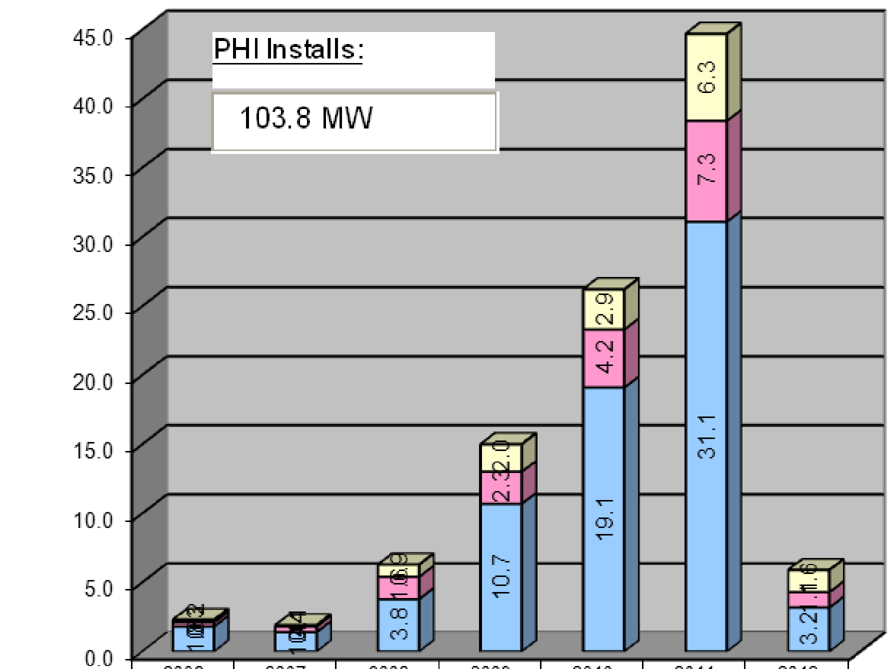
**PEPCO**
**1290 Installs**

**TOTAL**
**5263**
**Installs**

# 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 |

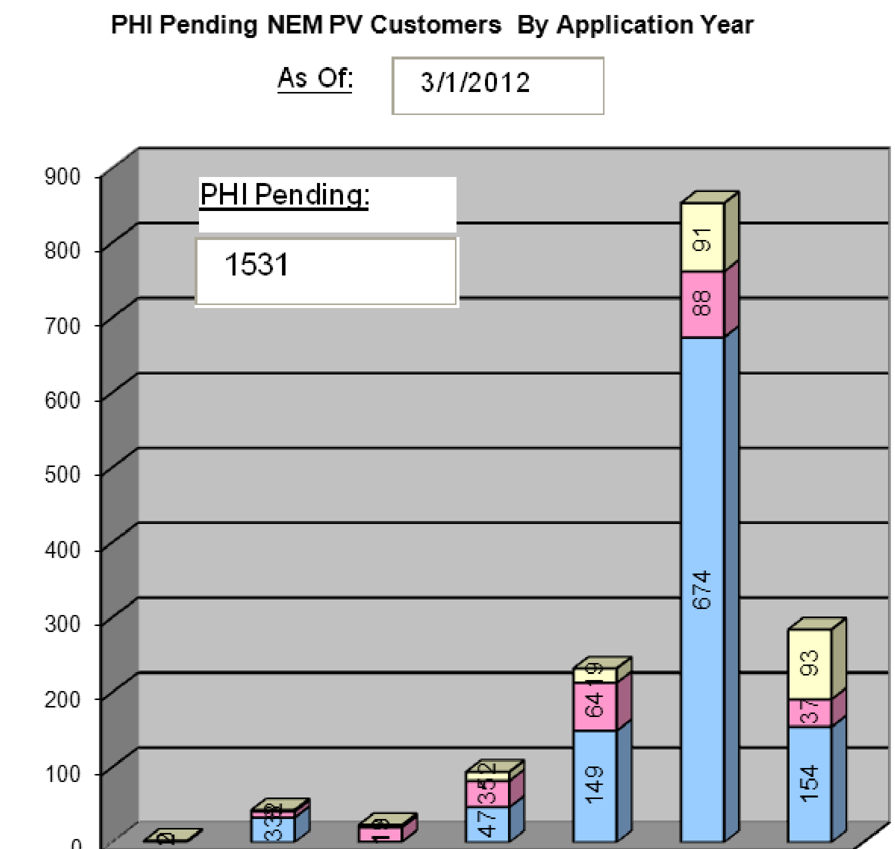
**ACE**
**72.3 MW**

**DPL**
**17.5 MW**

**PEPCO**
**14.0 MW**

**TOTAL**
**103.8 MW**

# Pending Solar PV NEM




| | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|
| Pepco | 0 | 2 | 3 | 12 | 19 | 91 | 93 |
| DPL | 0 | 8 | 19 | 35 | 64 | 88 | 37 |
| ACE | 2 | 33 | 1 | 47 | 149 | 674 | 154 |

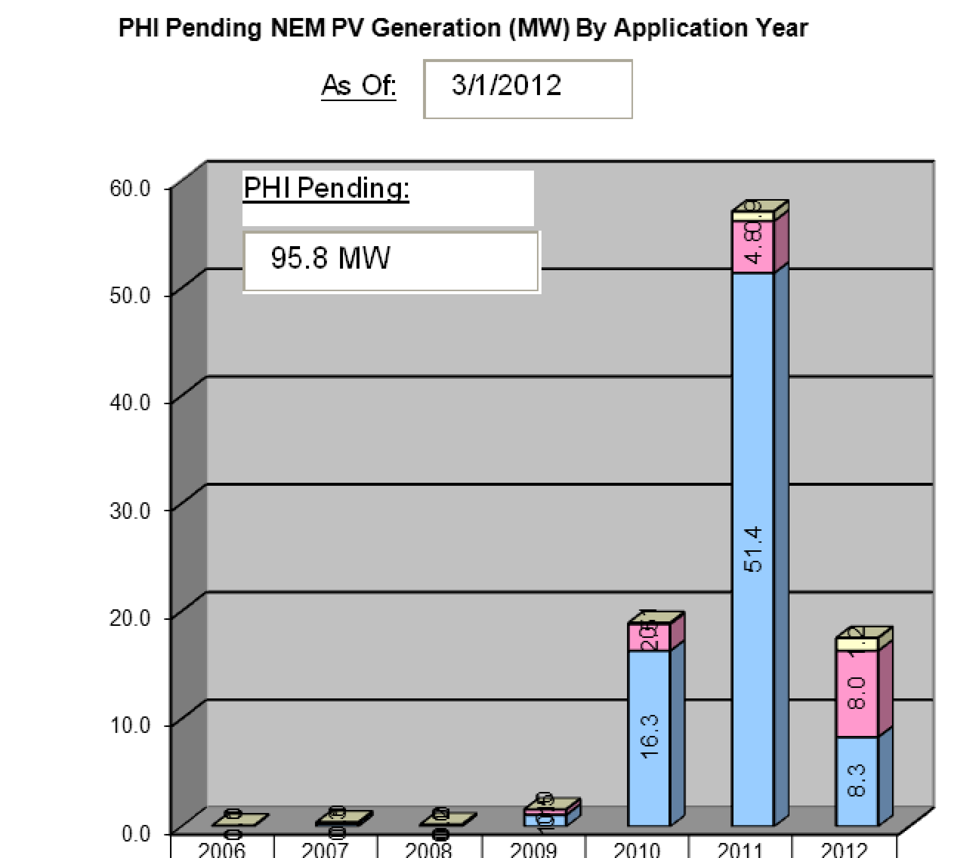
**ACE**
**1060 Apps**

**DPL**
**251 Apps**

**Pepco**
**220 Apps**

**Total**
**1531 Apps**

# 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**

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# Large Solar – 3 MW to 20 MW

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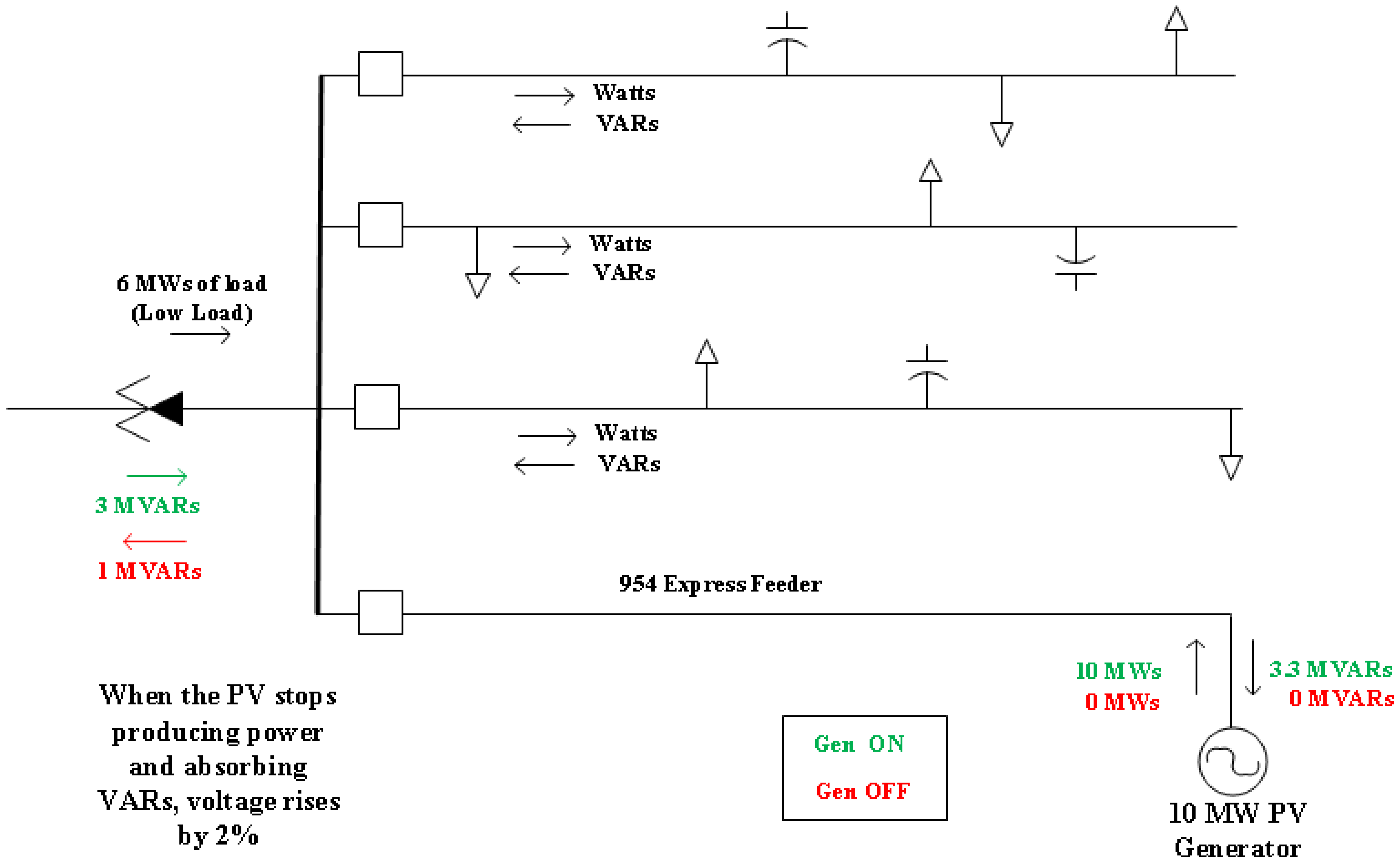
# *Potential Voltage Rise and Fluctuations*

- 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 fdrs.
- Substation has 2 other load carrying fdrs.

# *Low Load Single Line*




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

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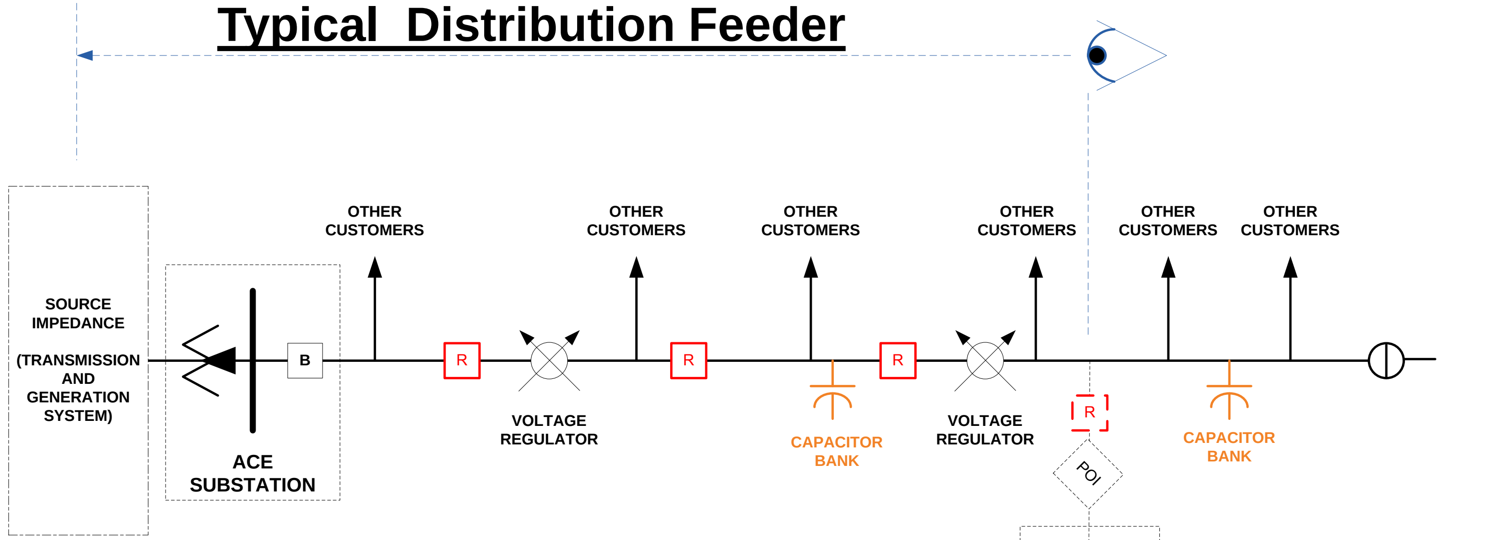
# *Issues and Solutions for Large Solar*

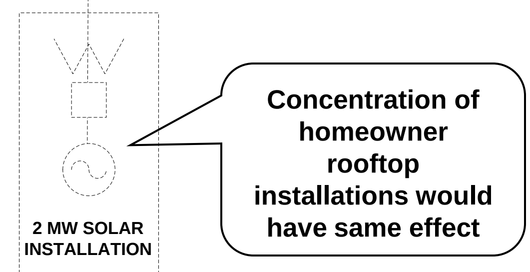
- Voltage Rise or Fluctuation on express feeder - Move interconnection to higher voltage level, PF, future use of dynamic var control, limit ramp rate, curtailment, SCADA
- Voltage regulation for other feeders – smart LTC controls
- Losses – Move to higher voltage level and/or connect load to circuits
- System Stability – Low Voltage Ride Through

# Medium Solar – 250 kW - 3 MW

# Impacts to a Distribution Feeder

## Typical Distribution Feeder



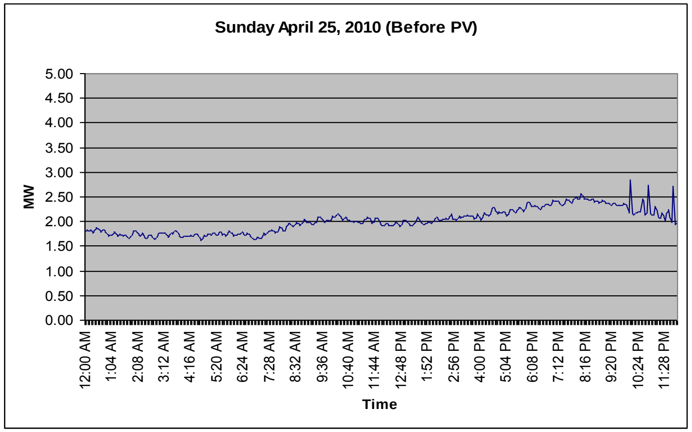



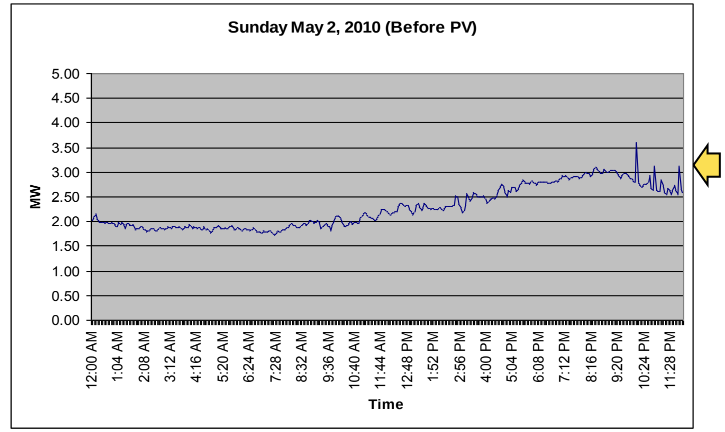

adapted from actual DG customer application

- **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**

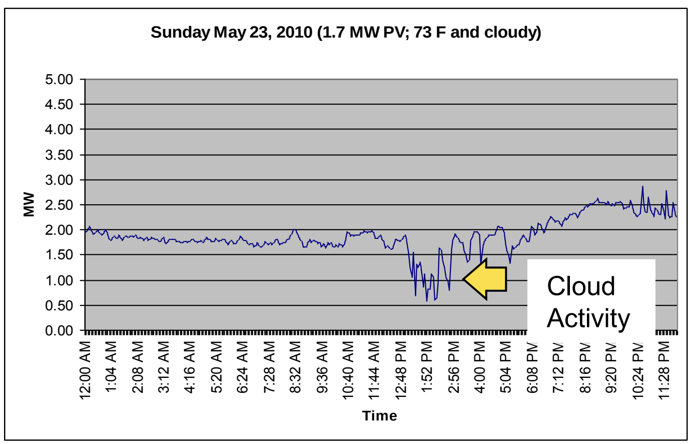
# Distribution System Impacts (cont.)

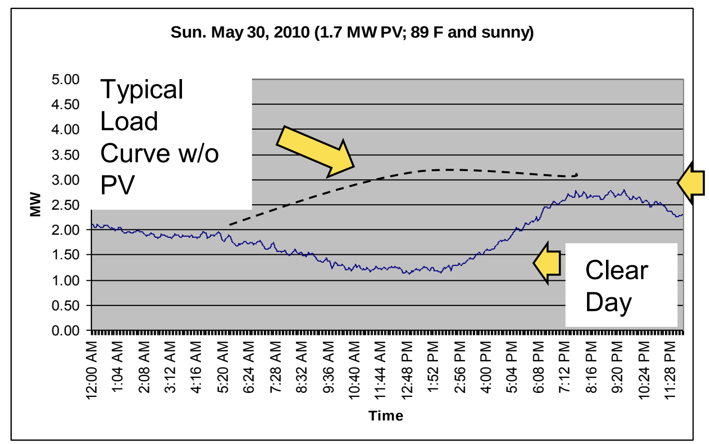
## Sunday Load Profile Before and After 1.7 MW PV Installation as seen at Feeder Terminal




Industrial Load Startup

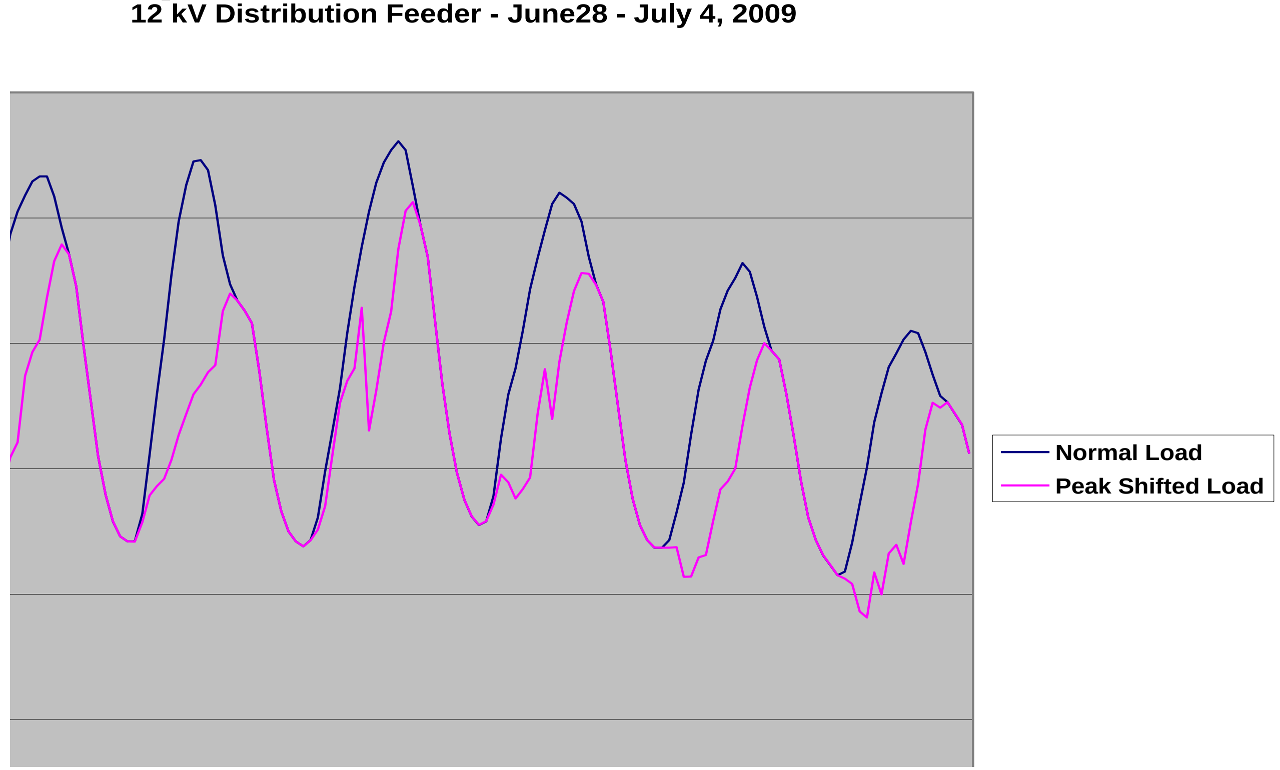


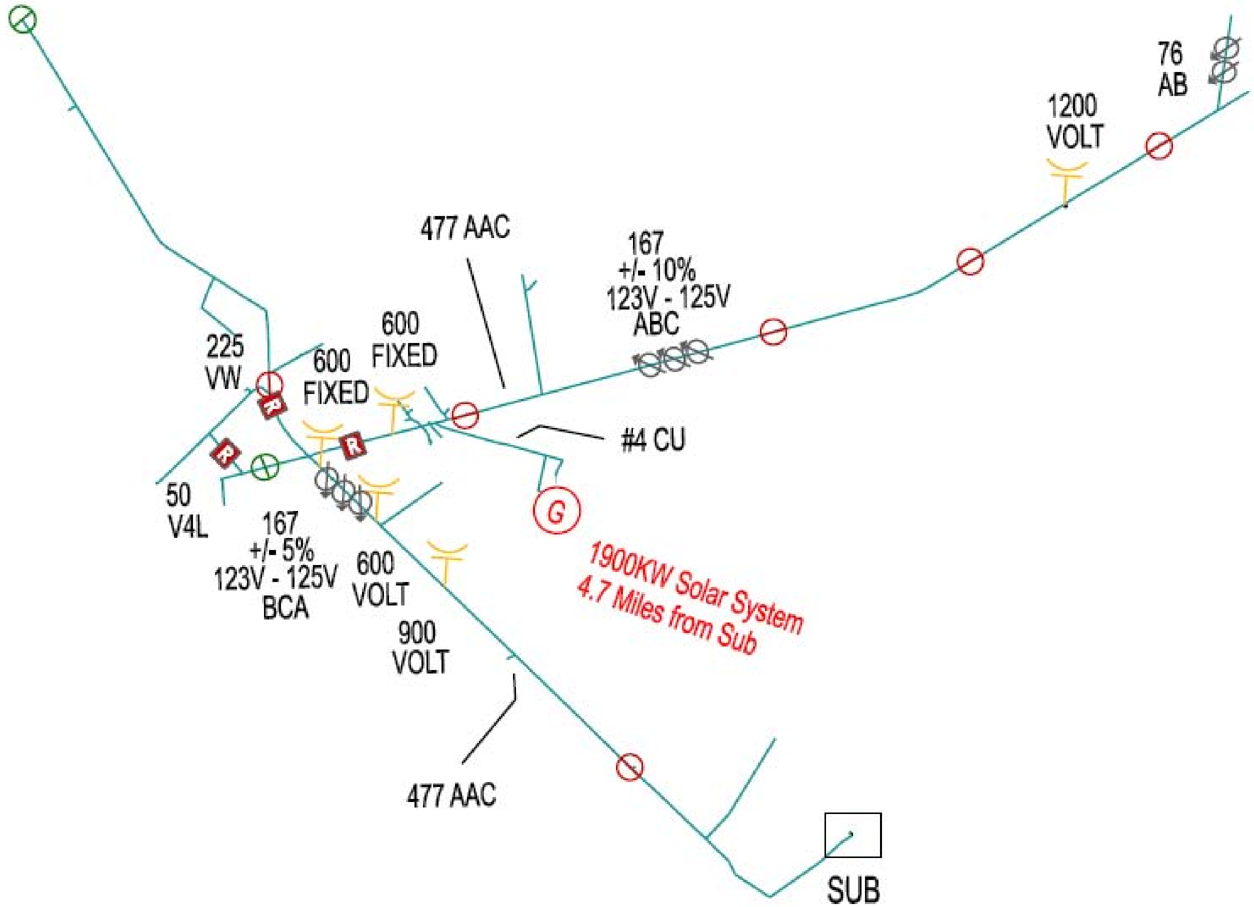

Monday Holiday

No Startup

# Potential impact of PV on Load Profile



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

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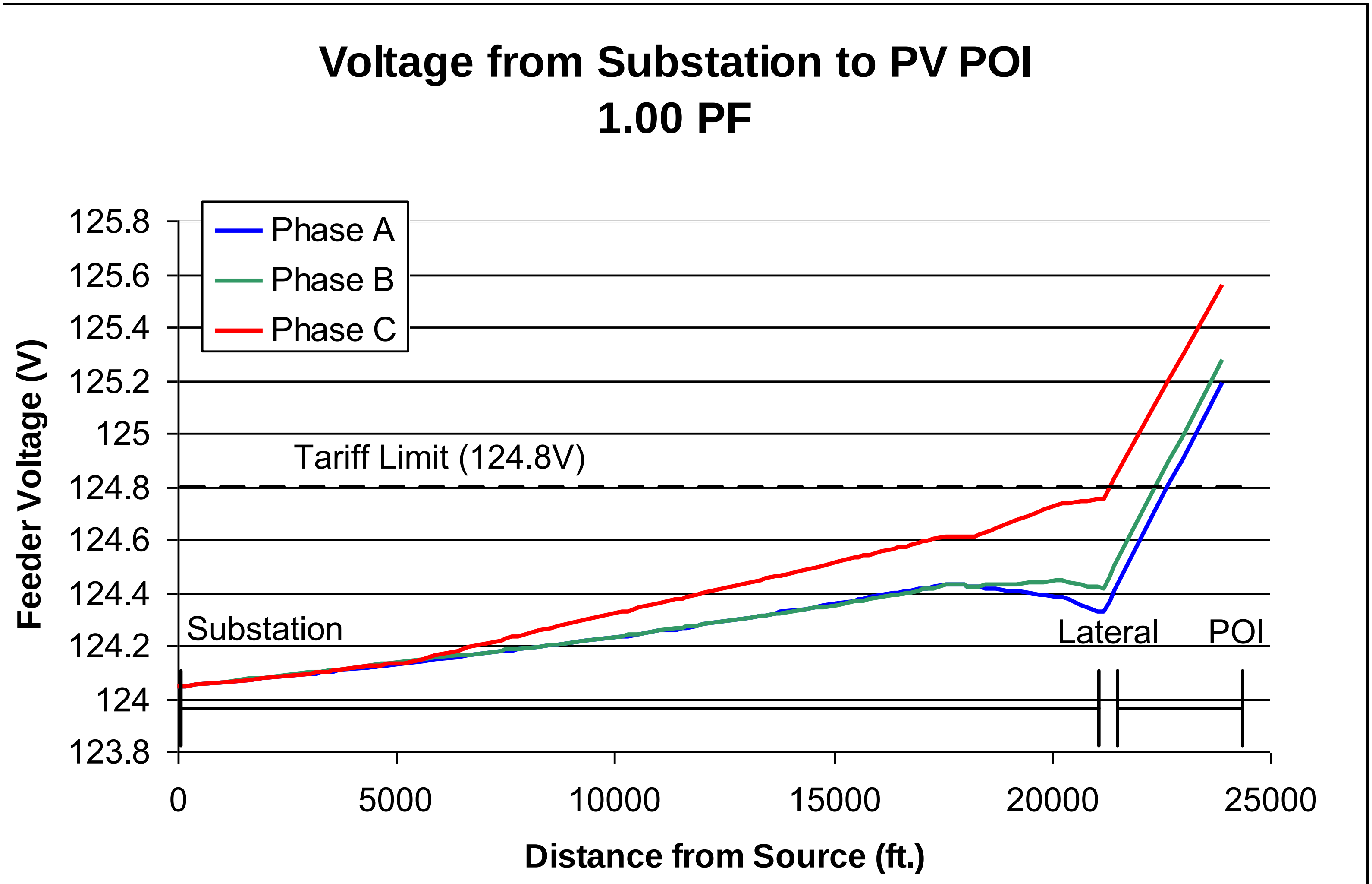
# 1.9 MW PV System

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# 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.

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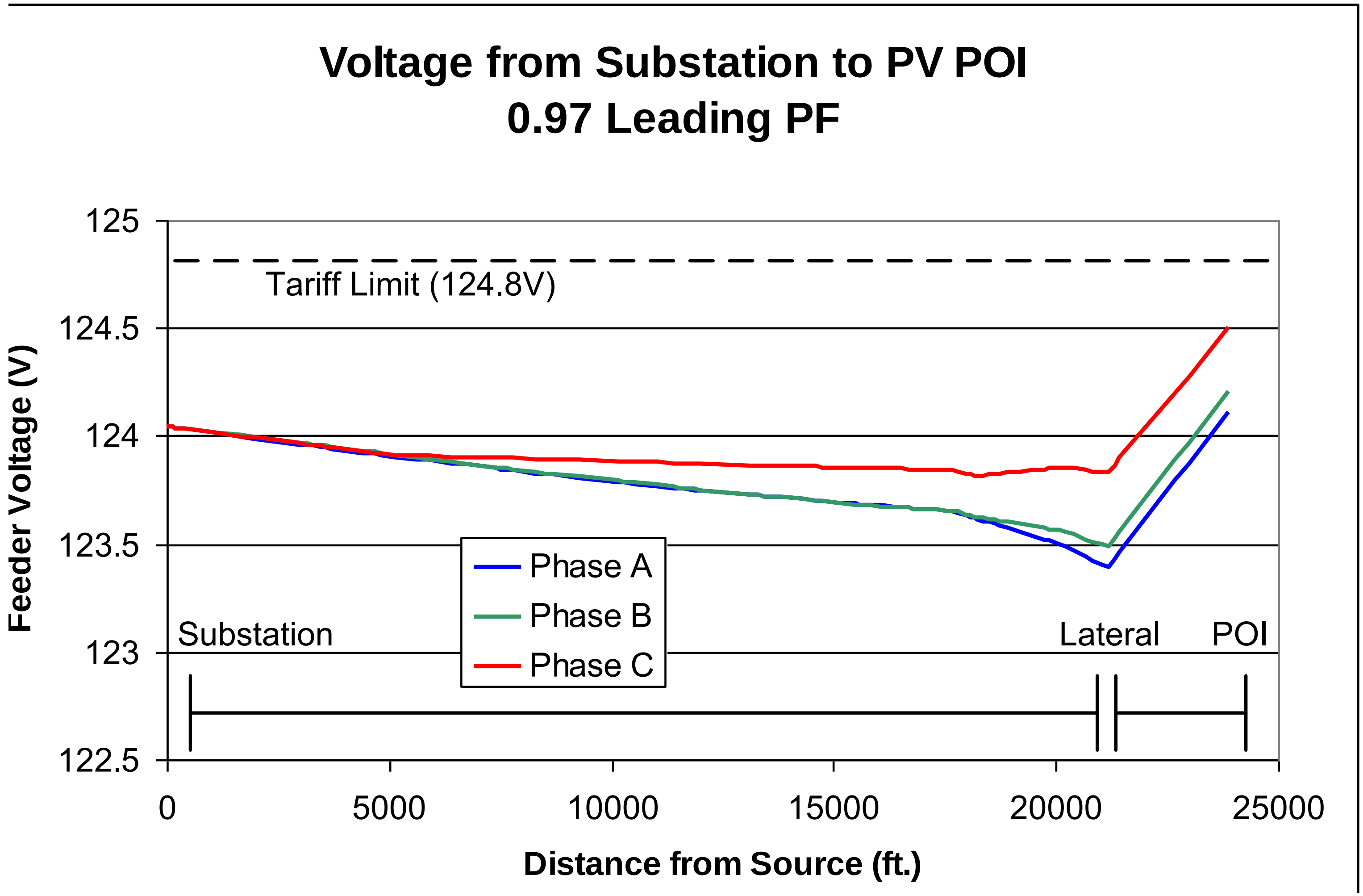
# 1.9 MW PV System

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# *Issues and Solutions for Medium Solar*

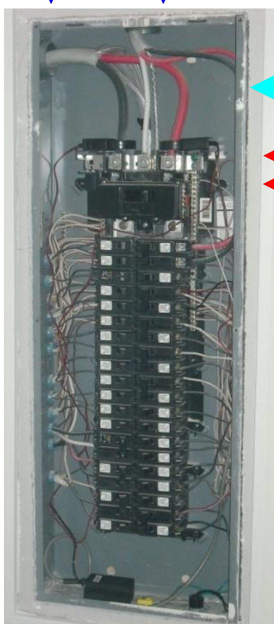
- Voltage Rise and Fluctuation, especially at greater distances from the sub – which can effect automatic line equipment and if high enough cause voltage violations for customers
  - Utilize an absorbing (leading) PF on the inverters (fixed or on a schedule)
  - Move Capacitor or Voltage Regulator further away from POI, adjust settings if necessary

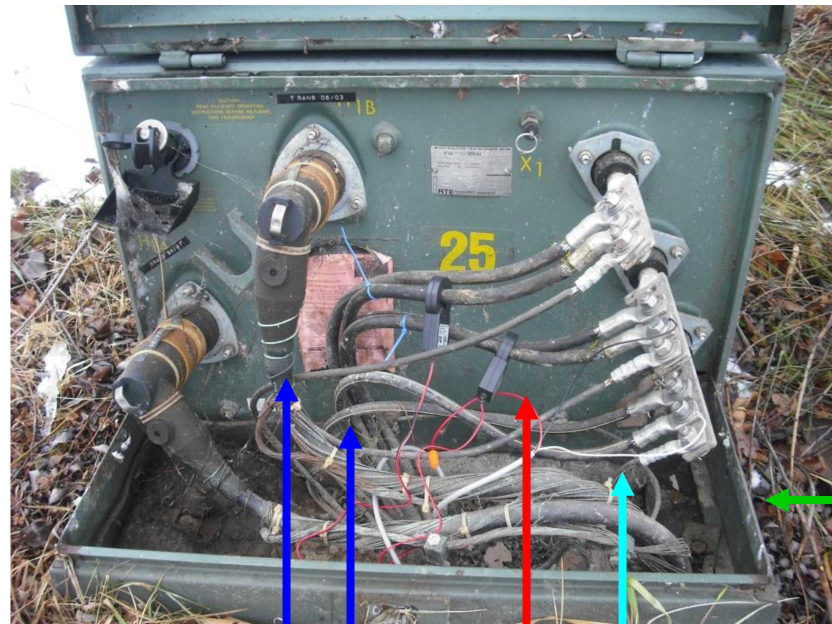
# *Issues and Solutions for Medium Solar (cont.)*

- 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

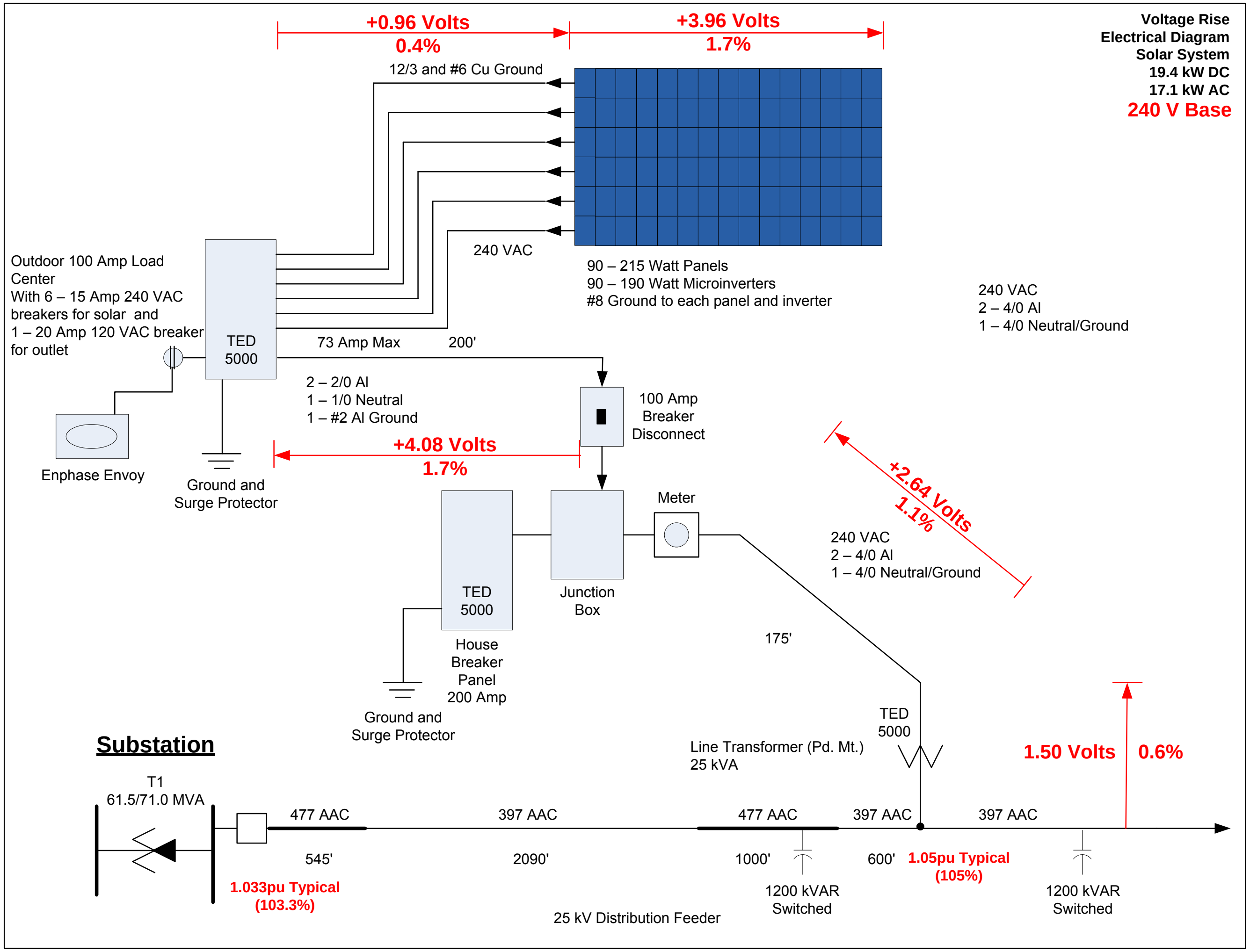
# Small Solar – 250 kW or less

# TED 5000 installed in House Panel and Line Transformer



# Voltage Rise

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# Voltage Rise Chart

## (at max gen and no load)

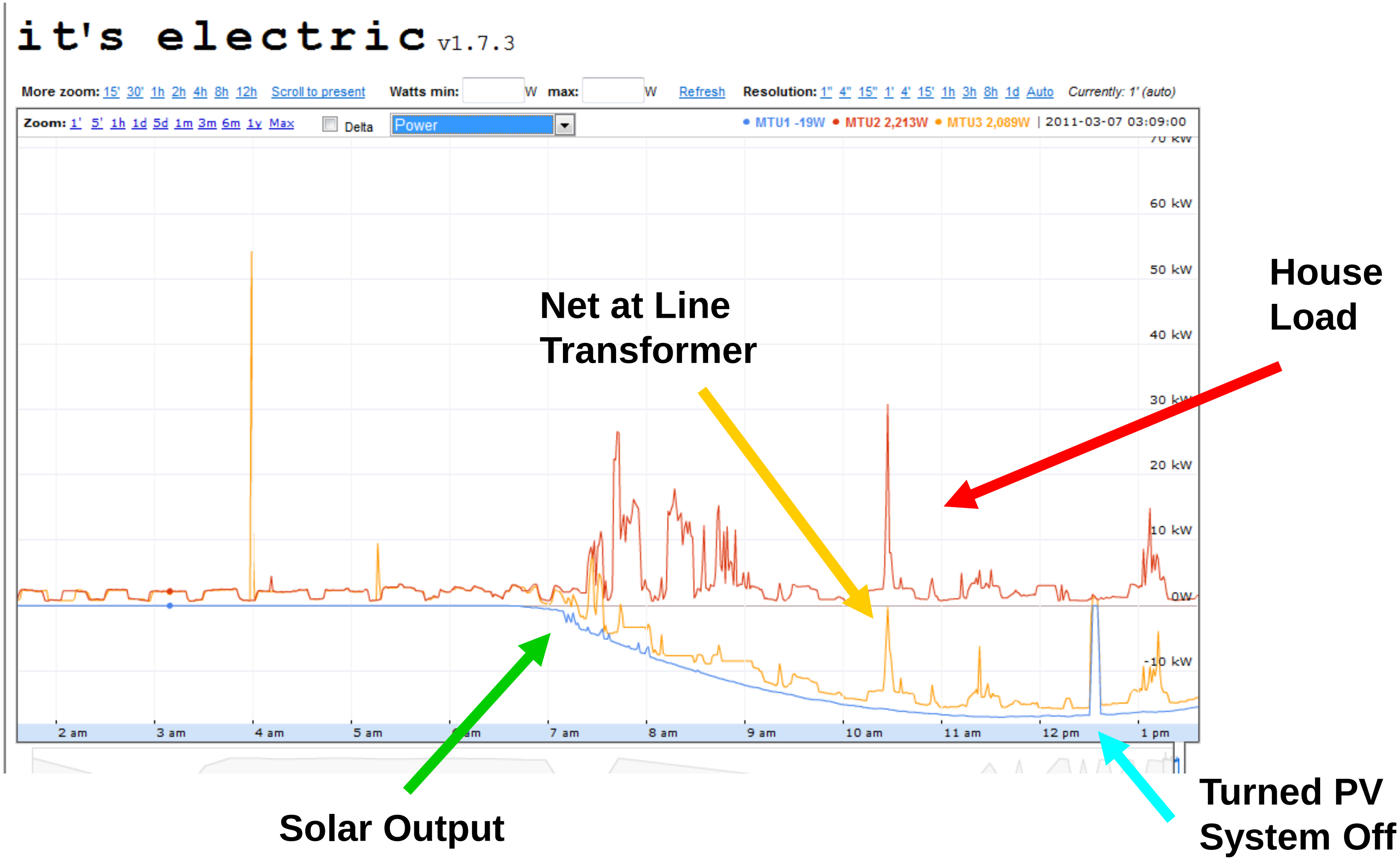
Nominal Voltages: 120V or 240V

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

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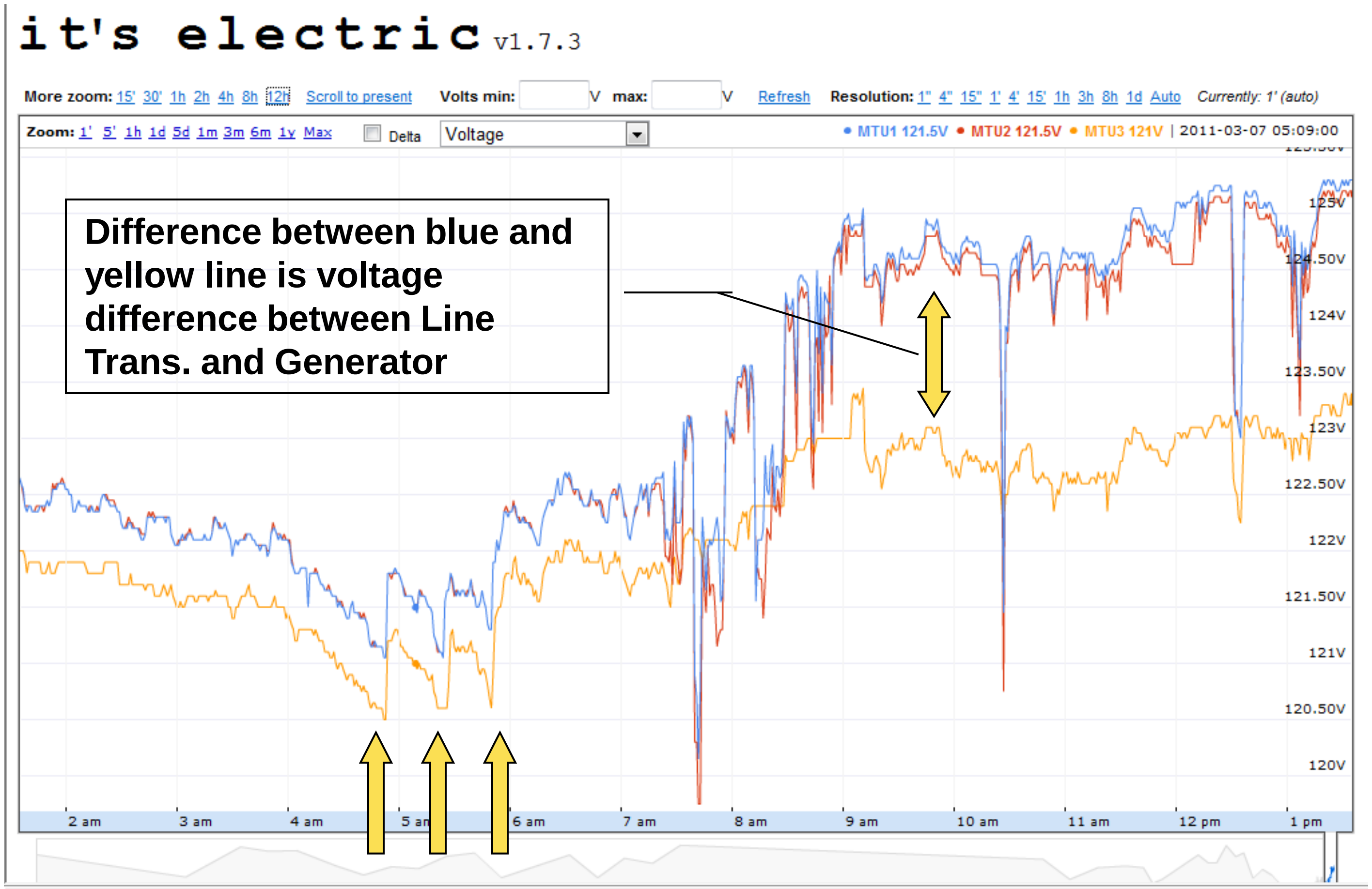
# Voltage vs. Time




**Substation transformer adjusting voltage**

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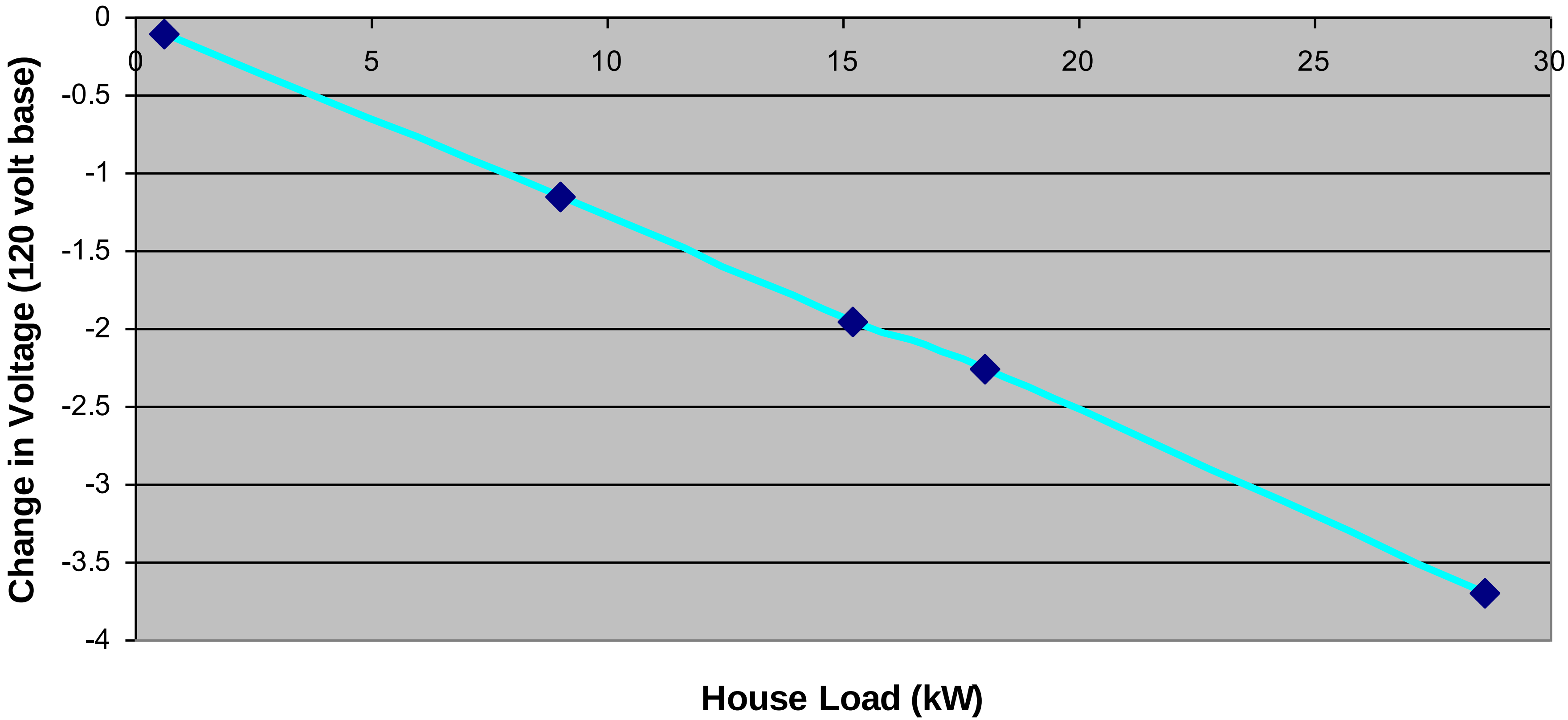
# Voltage Drop vs. House Load

## Unity Power Factor



# *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

# *Issues and Solutions for Small Solar (cont.)*

- 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)
- Use Home Energy Manager to move flexible loads to high output periods
- Utility adjust settings on closest Capacitor or Voltage Regulator to reduce voltage a little at the customer meter if necessary

# *Issues and Solutions for Small Solar (cont.)*

- Customer can utilize battery system to reduce peak output, take advantage of TOU rates (where available) and have premium power
- Use flexible load control via AMI if available
- Inverter learns and adjusts PF during certain times of day
- Utility provides setting changes via AMI (PF or VARS and active power output)

# *Utility Efforts to Accommodate PV*

- 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

# *Utility Efforts to Accommodate PV (cont.)*

- Collaborative R & D on dynamic var control, centrally controlled vars
- 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

# *Utility Efforts to Accommodate PV (cont.)*

- 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

# *Efforts Underway (Cont.)*

- Integrating PV output data into Distributed 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.
- Advanced Volt/VAR Control

# 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

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# Thank You!