# Experiences with High Penetration PV


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**Manager - Distribution Planning**


**PV Grid Integration Workshop**

April 19, 2012

Tuscon, Arizona

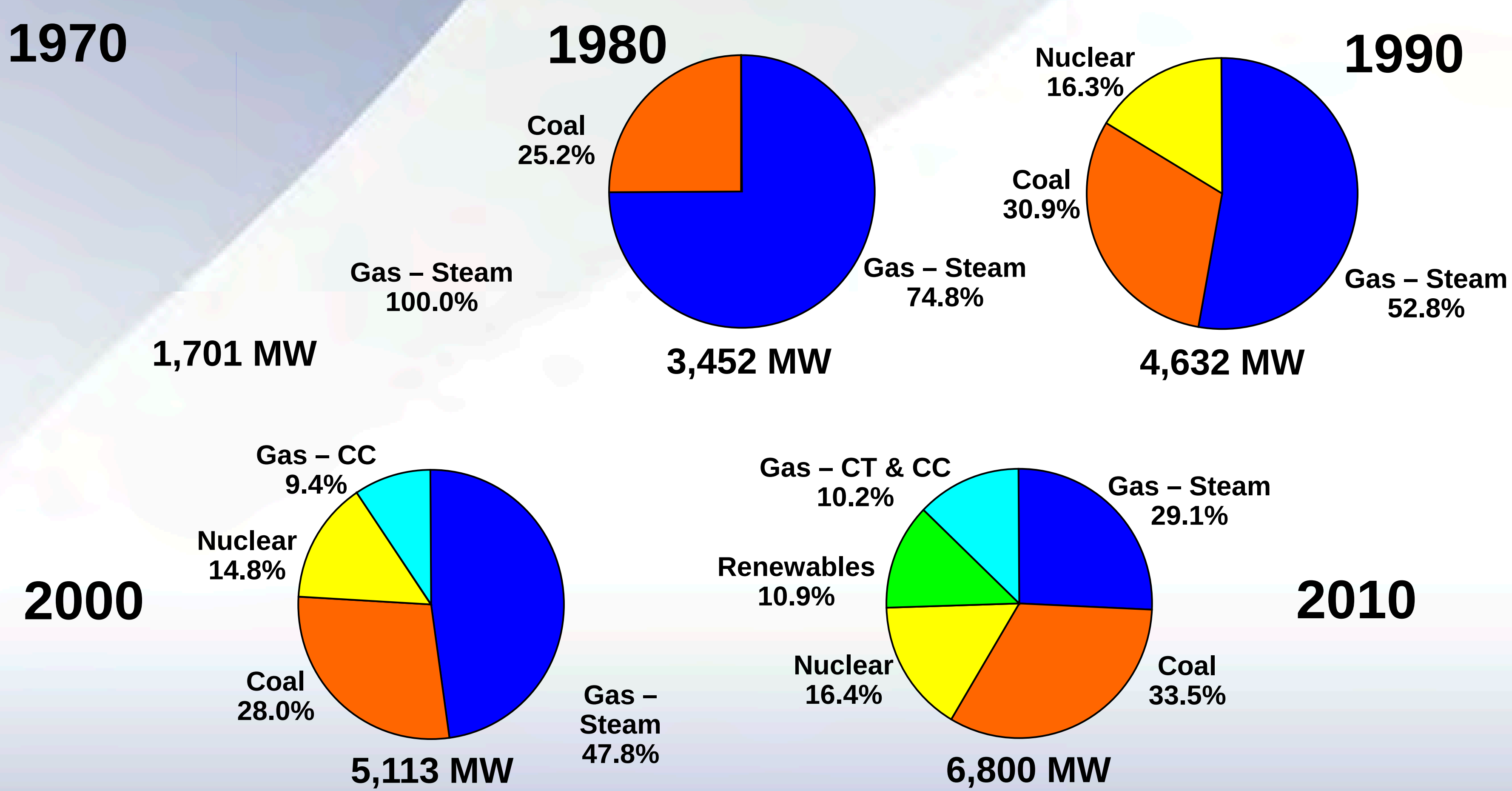
# Overview of CPS Energy

- **Electric & Gas utility serving the greater San Antonio area**
  - Oldest energy utility in Texas – Founded in 1860
  - First service was gas lights in front of The Alamo
- **One of the largest municipally-owned utilities in the U.S.**
  - ~717,000 electric customers
  - ~323,000 natural gas customers
  - ~3,600 employees
- **Integrated Electric utility**
  - 6,800MW of generation
  - 1,489 miles of 138kV & 345kV transmission
  - 103 substations & switching stations
  - 14,500 miles of 13kV & 35kV distribution
  - 1,514 sq. mi. service territory (Bexar county + portions of 6 adjacent)

# CPS Energy's Vision 2020

- **Goals for Renewable Energy**
  - 1,500 MW of renewable energy capacity by 2020
    - Approximately 20% of generation capacity
  - 100 MW from renewable sources other than wind by 2020
- **Goals for Energy Efficiency & Conservation**
  - Save for Tomorrow Energy Plan (STEP) will help avoid 771 MW of electric load growth by 2020
- **Drive local economic development by:**
  - Maintaining affordable retail electric rates
  - Partnering with suppliers and vendors who are committed to investing in the New Energy Economy in San Antonio

# Four Decades of Energy Mix Diversification




Installed Capacity

# Vision for Large Scale Solar

- **Combine large-scale solar energy PPA with local economic development**
  - Leverage a multi-year commitment for new solar farms in exchange for local jobs and capital investment
  - 400 MW of new solar capacity through 2017
- **Economic development goals**
  - At least 800 local jobs
    - Solar or clean technology jobs
  - Minimum annual payroll of $30 million
  - At least $100 million in local, clean tech capital investment
    - Ground breaking within 12 months, operational within 36 months
  - Commitment to local education programs
- **Selected OCI Solar / Nexolon**
  - Ongoing PPA negotiations began in January 2012

# Recent Solar Development

- **Residential (net metered) -** 495 systems installed
- **Commercial (net metered) -** 88 systems installed
- **Solartricity Power Producers Program** – direct connect
  - 3 systems connected and 1 pending
- **Utility (PPA)** – distribution connected
  - 14MW Blue Wing (2@7MW) on-line November 2010
  - 10MW Dos Rios North & 10MW Dos Rios South on-line 4/12
  - 10MW Somerset (2@5MW) on-line 5/12
- **Plant (PPA)** - transmission connected
  - Up to 400MW from RFP on transmission

# Solartricity Power Procucers

- Direct connected systems less than 500kW
- Large rush of applicants for limited 5MW opportunity
- Requirement 90%+ be mounted on structure

- Received more capacity than advertised
- Vast majority have dropped from process
  - Roof leasing arrangements and capability appears to be limitation
- Worked best when facility owner was actively involved
- Need to have design and connection standards in place prior to offering program
- Clear "ownership" within organization

# Blue Wing Site

- Single parcel of land with 14MW
- 2 – 7 MW metering points
- Each on separate 13kV feeders serving customers
  - 4.5mi and 6.0mi from two different substations
  - 8.9/6.5 MW feeder peak loads
- ~21.5/23.0 MW transformers demand peaks (each unit)
  - No additional PV allowed on transformers
- Voltage regulators on each feeder, LTC at substation
- Communications with remote control and monitoring
- Protection via direct transfer trip to reclosers

# Blue Wing Plant

- 215,000 fixed panels across 150 acres

- First Solar thin film PV

- 500 kW testing 8 different technologies

- Visible from IH37 and US 181

# Dos Rios Sites

- Near Wastewater Treatment Plant
- 2 – 10 MW fields
- Each on new dedicated feeders at 13kV
  - 500’ and 3000’ from station
- ~24.5 MW transformers demand peaks (each unit)
  - No additional PV allowed on transformers
- Load Tap Changer (LTC) on each transformer
- Communications with remote control & monitoring
- Protection via direct transfer trip

# Somerset Site

- Single parcel of land with 10MW
- 2 – 5 MW metering points
- Each on separate 13kV feeders serving customers
  - 2.0mi and 3.2mi from one substation
  - 7.5/9.2 MW feeder peak loads
- ~19.5 MW transformers demand peaks (each unit)
  - No additional PV allowed on transformers
- Voltage regulators on each feeder, LTC at substation
- Communications with remote control and monitoring
- Protection via direct transfer trip to reclosers

# Experiences – Utility Scale

- **Voltage regulator settings**
  - Co-gen, widen reverse voltage BW, more op's
- **Spring/Fall most challenging periods**
  - low native load, high generation outputs
- **Power factor requirements**
- **Contractor delays**
- **Equipment failures**
- **Financing / Securing site** – adds time to process
- **Information from owner, general contractor**
- **System acceptance** – strong desire to get it right
- **Site(s) Nomination** - iterative, many want to participate

# On- going Issues

- **Planning Criteria** – regular updates
- **Location Selection** – screening, who leads
- **Education** – public, politicians, management, staff, operators
- **Regulations** – UL, local codes
- **System Impacts** – variability, interactions, power quality
- **Power Factor / Voltage** – control of reactive output
- **Knowledge** – not much depth or breadth yet
- **Output focus** – maximum energy or match peak demand
- **Future planning** – actual output, lifespan, degradation, feeder reconfiguration limitations
- **Market direction** – ERCOT changes
- **Organizational** – ownership within corporation

# Lessons Learned

- **Planning Criteria** – should be in-place prior
- **Voltage Regulation** – VR's will operate more frequently, settings not intuitive, different feeder voltage profile
- **Demand** – contract for real and reactive
- **Protection** – work closely with developer, establish guidelines early, direct transfer trip, remote monitoring
- **Native Load versus desired plant site**
- **System Impacts** – limited so far, no complaints
- **Anxiety** – internal resistance & concerns, involve when possible
- **Building roof limitations & acceptance**
- **Get field devices into SCADA before installation** – history is valuable

# Questions

Contact Information

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# SCE Experience with PV Integration

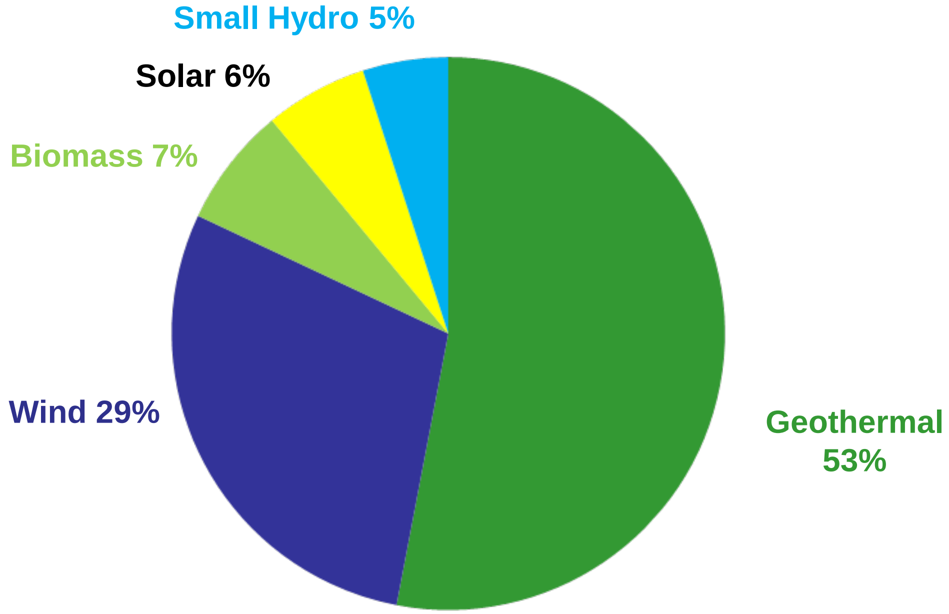
EPRI High Penetration PV Grid Integration Workshop

April 19, 2012

Tucson, AZ

# Leading the Nation in Renewable Power Delivery

**Actual 2010 Renewable Resources**
**14.5 billion kWh**
**19.4% of SCE's portfolio**




SOUTHERN CALIFORNIA EDISON
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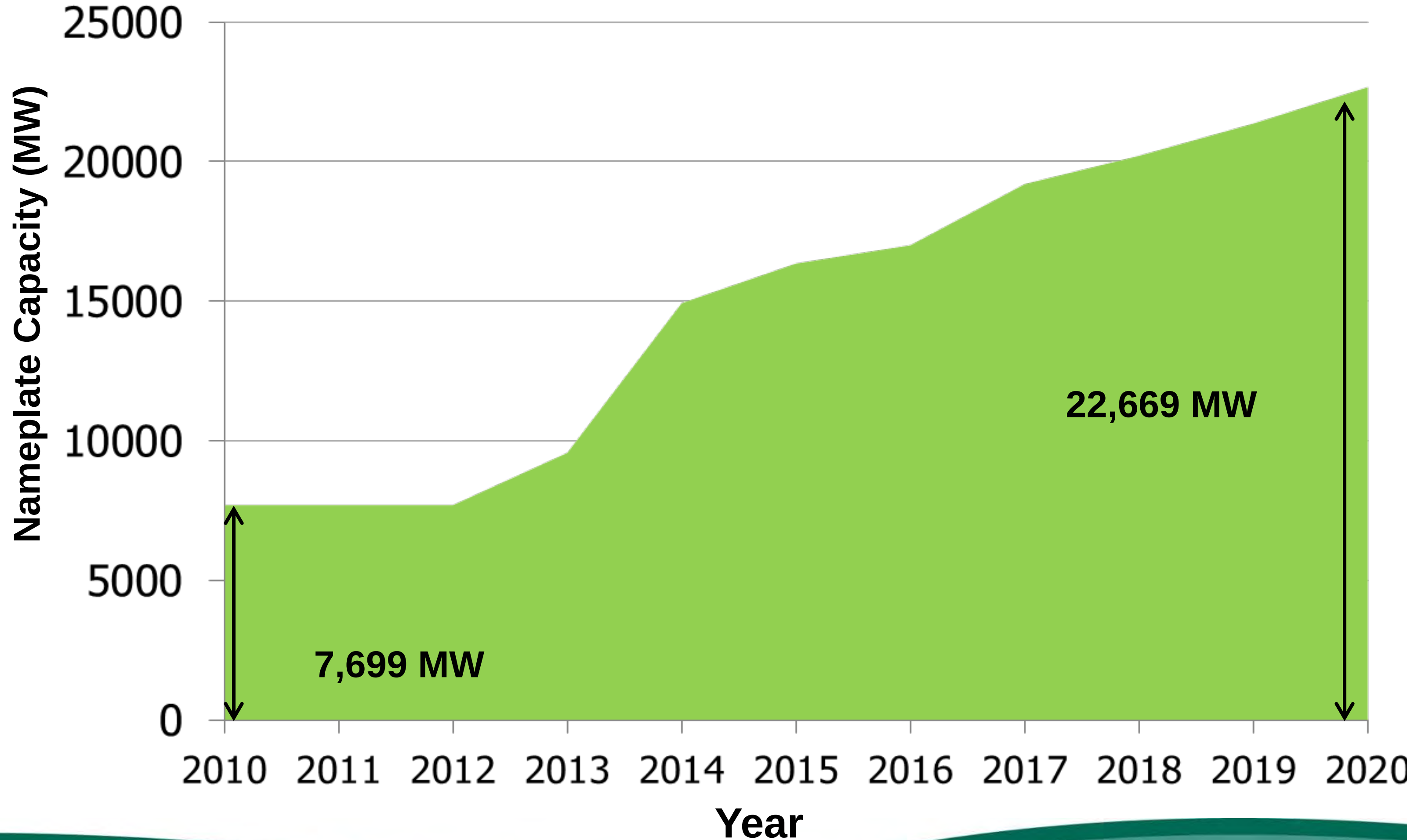
# CA will have 3 times the amount of intermittent resources in 2020 as we had in 2010



# Background



- Significant amount of generation is being "proposed" to be interconnected to SCE's distribution systems
- High influx of proposed generation has resulted from state sponsored programs such as:
  - Solar Photovoltaic  Program (SPVP) – 500MW of PV generation mostly installed on roofs of large warehouse buildings
  - Feed In programs such as the California Renewable Small Tariff (CREST)
  - Net Generation Metering Program – Primary a residential and commercial program
  - 12,000MW of Localized Energy Resources Initiative
- Distribution systems were not originally design for generation injection at the distribution level
- System operations, planning, and standards need updates to accommodate distributed generation being connected to distribution feeders
- New technology operating characteristics are not very well known

# Incentivized and Mandated Renewable Energy Programs in California

Customer

- Net-Energy-Metering (NEM)
- California Solar Initiative (CSI)
- CA Renewable Energy Small Tariff (CREST)
- Self-Generation Incentive Program (SGIP)
- Multifamily Affordable Solar Housing (MASH)
- New Solar Homes Partnership (NSHP)

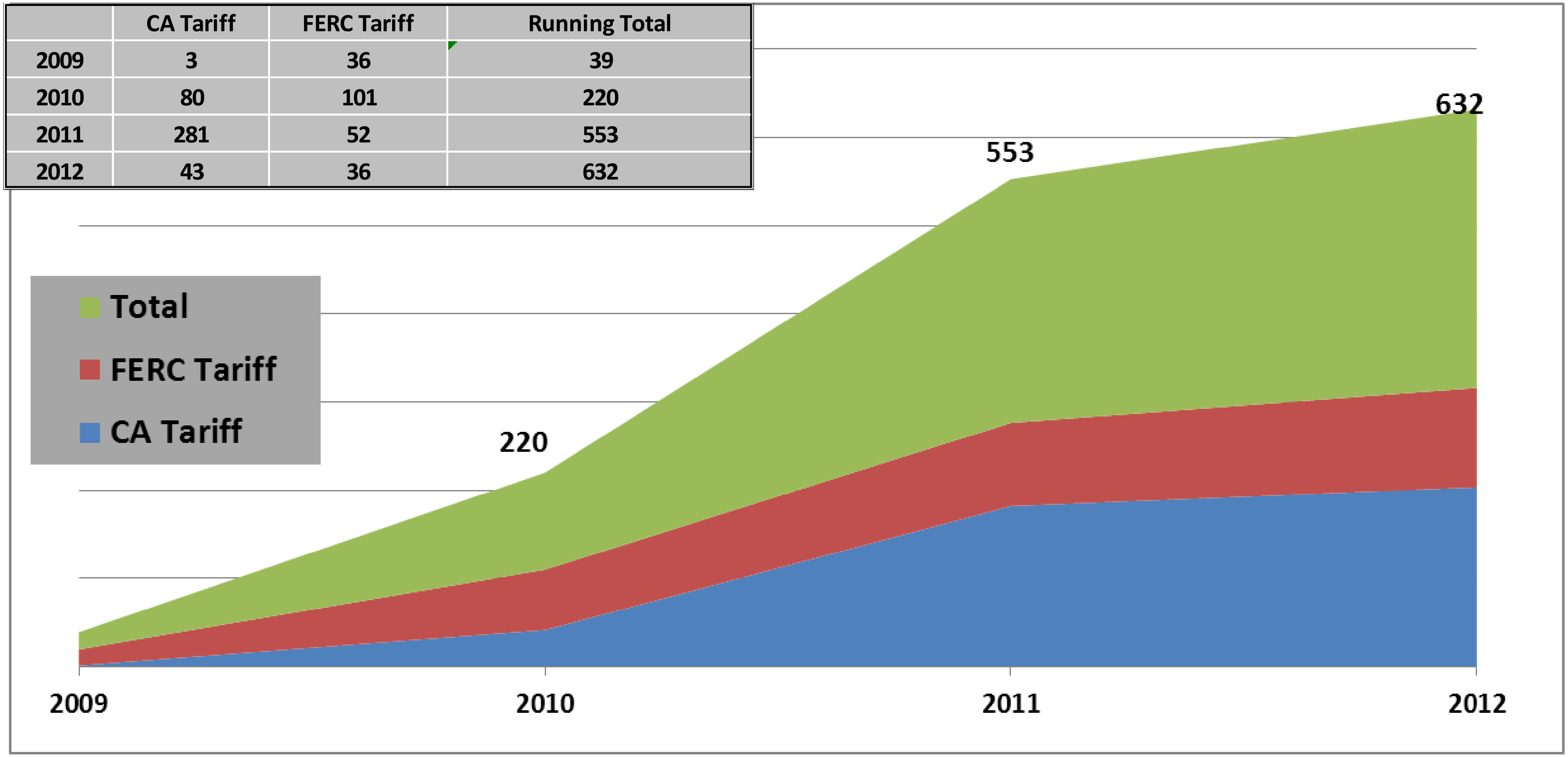
Supply

- 33% Renewables Portfolio Standard (RPS)
- SB 32 Feed-in-Tariff (FiT)
- Renewable Auction Mechanism (RAM FiT)
- QF Settlement
- AB 1613 – FiT for combined heat and power
- Solar Photovoltaic Program (SPVP)

# Interconnection Issues

# "Active" Interconnection Requests to SCE's Distribution System

| | CA Tariff | FERC Tariff | Running Total |
|---|---|---|---|
| 2009 | 3 | 36 | 39 |
| 2010 | 80 | 101 | 220 |
| 2011 | 281 | 52 | 553 |
| 2012 | 43 | 36 | 632 |



# California Interconnection Tariff ( CPUC Rule 21)

- **Projects studied in a sequence as they apply and each project is studied individually to determine impacts and cost responsibilities**
  - This can lead to issues as developers cancel their projects and re-studies are triggered
- **Projects are responsible for the upgrades that the project triggers**
- **Recent changes to this Tariff which will change the study process**

# FERC Interconnection Tariff ( SCE WDAT)

- **Projects can be studies under various methods**
  - **Cluster Study Process**
    - Study as group and share the cost of the upgrades
  - **Independent Study Process**
    - Study on a serial manner
    - Projects are responsible for the upgrades it triggers
  - **Fast Track Process**
    - Evaluation consists of 10 screens
    - Supplemental review is further used if one of the screens fails
    - Designed for simplest of the projects – connecting to highly loaded circuits

# CA Tariff and FERC Tariff Interaction

- **These are two separate tariffs with their own processes**
  - Can be difficult to manage and study projects which are in two track (tariffs) but yet affect the same distribution system

- **Can be difficult to determine distribution cost upgrades**
  - Distribution cost certainty is difficult to achieve

- **Timelines associated with the study process in one tariff may create problems for projects interconnecting in the other tariff**
  - Especially if projects are proposing to interconnect to the same circuit/substation

# Typical Distribution Upgrades

- Areas with low penetration
  - Switching devices
  - Line extensions
- Areas average penetration
  - Cable/Conductor upgrades
  - Protection devices
  - Voltage regulating devices
- Areas with **high penetration**
  - New distribution circuits
- Areas with **very high penetration**
  - Substation transformer upgrades
- Areas with **extreme penetration**
  - Sub transmission/transmission upgrades

# Existing Solar Photovoltaic Program (SPVP) Overview

– Existing SPVP Program (250 MW UOG + 250 MW PPAs) approved June 2009

- 250 MW of Utility-Owned Generation
  - Primarily 1 to 2 MW projects installed on commercial warehouse rooftops, with up to 10% (25 MW) ground-mount
  - 50 MW per year with an average cost of $3.97/Watt ($ ’11)*

- 250 MW from IPP PV Solicitation
  - RAP coordinates annual solicitations for up to 50 MW per year for 5 years
  - Price capped at the utility LOCE, 26 cents per kWH
  - Other terms similar to UOG constraints

*** Reasonableness cap approved in 2008 is $3.85/w dc installed. $3.97/w is escalated to 2011 dollars.**

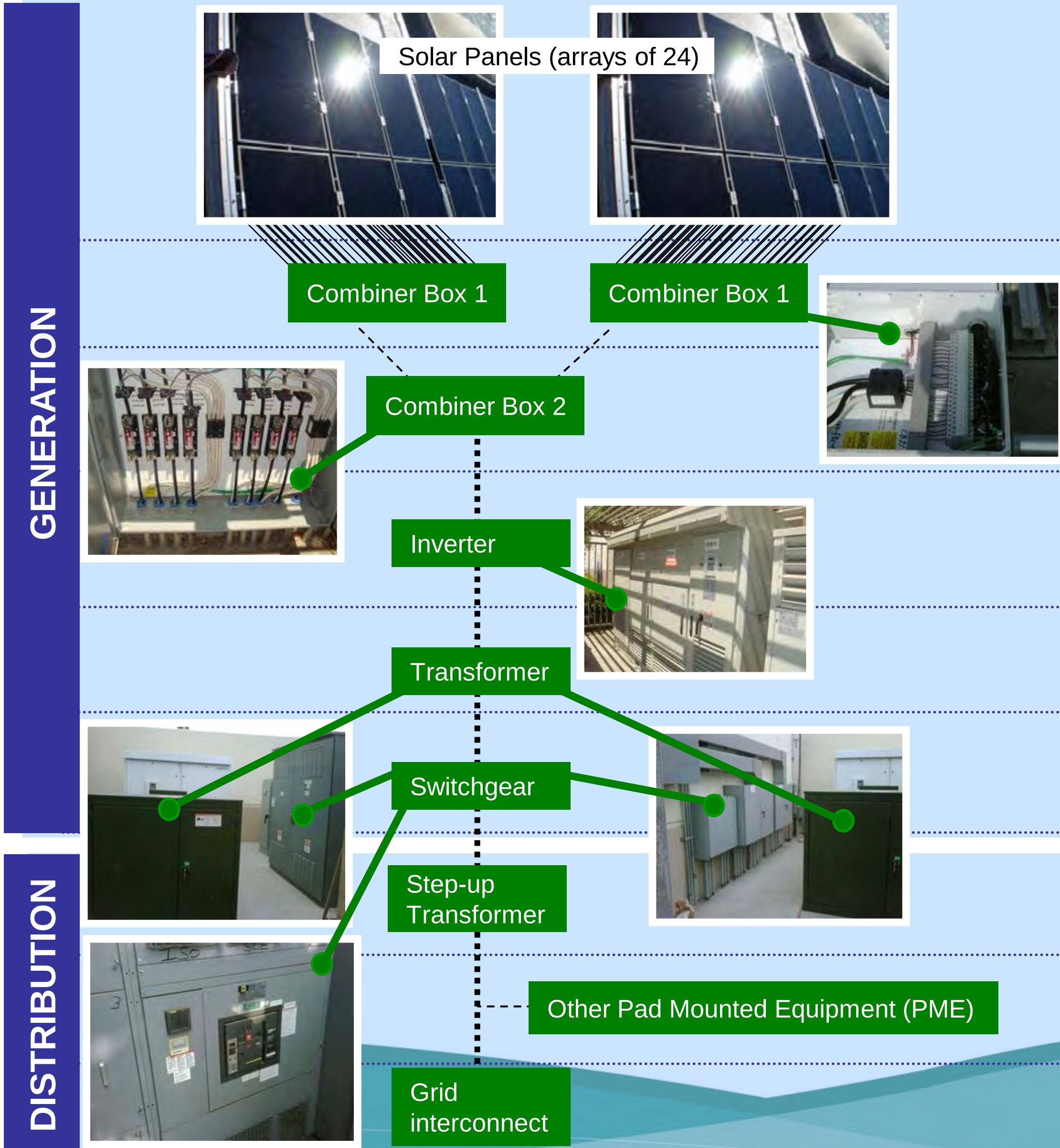
# Current SPVP Status

- UOG SPVP has 71 MW of projects completed and interconnected
  - 23 sites – 22 rooftops and 1 ground-mount
  - There is one project under construction, Dexus in Perris a 10 MW rooftop – largest single rooftop in the US.
  - Future plans call for 3 additional rooftops and 2 ground mounts totaling 30 MW
  - Total Program expected to be 111 MW
- IPP SPVP awarded 29 contracts. 50.8 MW in 2010 solicitation
  - 24 rooftop contracts for 28.4 MW
  - 5 ground sites for 22.4 MW
  - Projects must be on-line within 18 months of approval by CPUC
    - Two Projects to come on-line in April, 2012 (2 MW total)

# Interconnection Experience

- ☐SCE SPVP projects are "Merchant Plants" interconnected under WDAT Process through direct connections to SCE's distribution grid. (Not NEM - Not connected to Host building's load)
- ☐Interconnection costs vary with location and state of existing system. Costs have ranged from $100K – $500K per facility.
- ☐No Fast Track Sites (9 to 12 months). Most sites Independent Study (12 to 18 months). One site was cluster study (3 years plus upgrade time).
- ☐Ongoing Research includes:
  - ☐SCE / NREL Hi Penetration of PV Study
  - ☐FSU Inverter Study
  - ☐Site "Trip Tests" found high voltage concerns
  - ☐AT Inverter Study using PV and Grid Simulator
- ☐EPRI Lessons Learned Report in progress, publically available 6/12

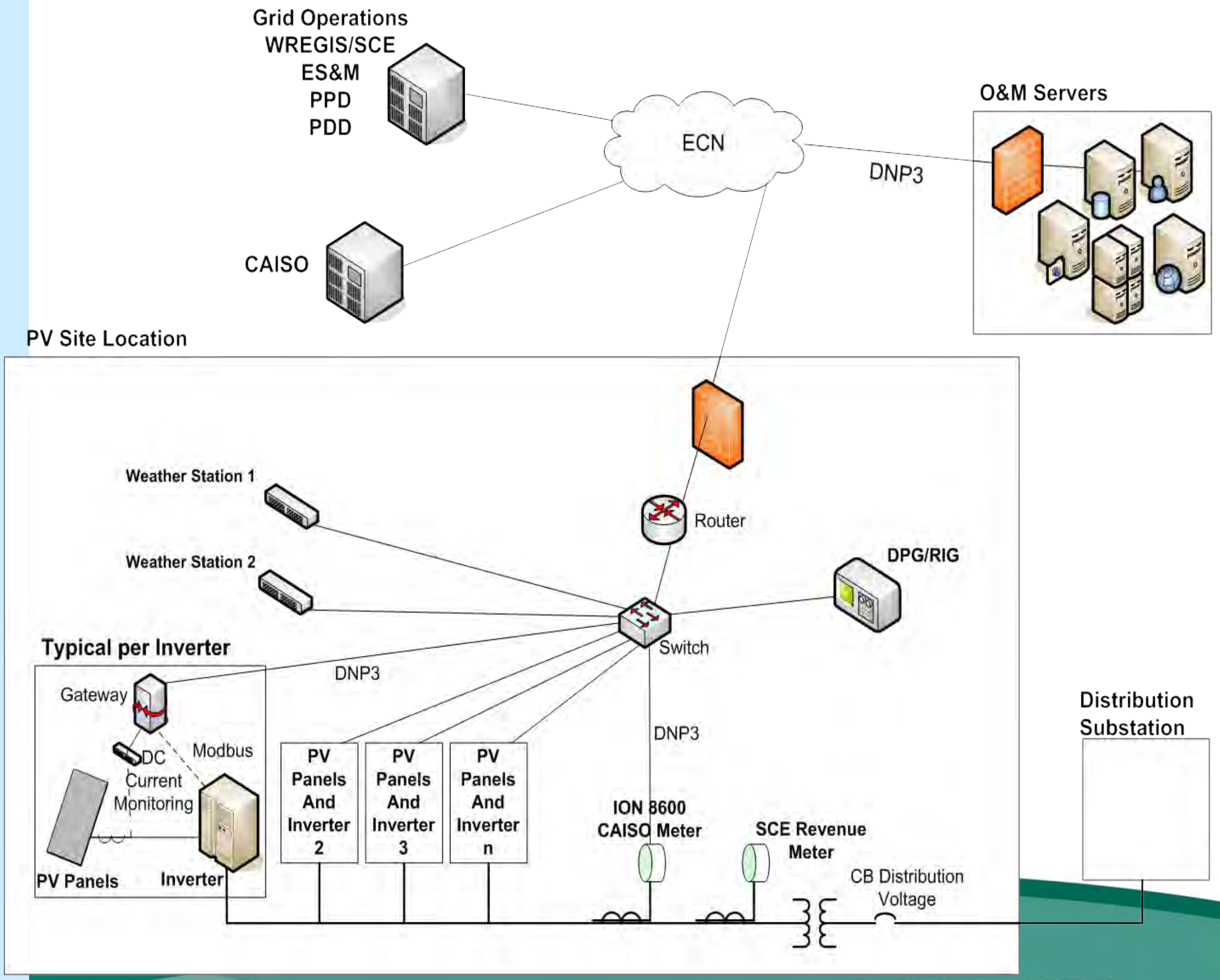
# PV SITE SPECIFICATIONS




| Quantity (at Fontana 2MW AC site) | Description | |
|---|---|---|
| 30,472 panels | Complete solar module including cells, casing, bracketing, wiring | On roof |
| 256 | Combines DC output for 24 panels | On roof |
| 12 | Master Fuse box | On roof |
| 4 | 500kW DC/AC inverter | On roof |
| 4 | 208/408 Volt KVA transformer | On ground |
| 1 | 408 Volt switchgear, breakers, metering, relay protection | On ground |
| 1 | 480/12,000 Volt 1,000 kVA transformer | On ground |
| 1 | Includes CAISO connection, data measuring, weather, etc. | On ground |
| 1 | Distribution system interconnection | On ground |

# SPVP Data Acquisition System

- Approximately 400 data points gathered in near real-time:
  - Generation data
  - Meteorological information
  - System status and monitoring
- Data Customers are ISO, GCC, ES&M, O&M and R&D
- Costs are $50K in Capital and $2K/Mo in O&M per site. Considerably Reduced.
- Scheduled outside PIRP as manual intervention in real time results in less imbalance charges.
- Monitoring is only to Inverter Level – benefit for string monitoring not cost effective.
- Possible Cost Reductions
  - Aggregation of Data has produced considerable cost savings
  - Redundant T-1 line requirements for ISO and Power System Controls results in additional $1,000/mo O&M expense
  - Corporate Pi Data Base License.

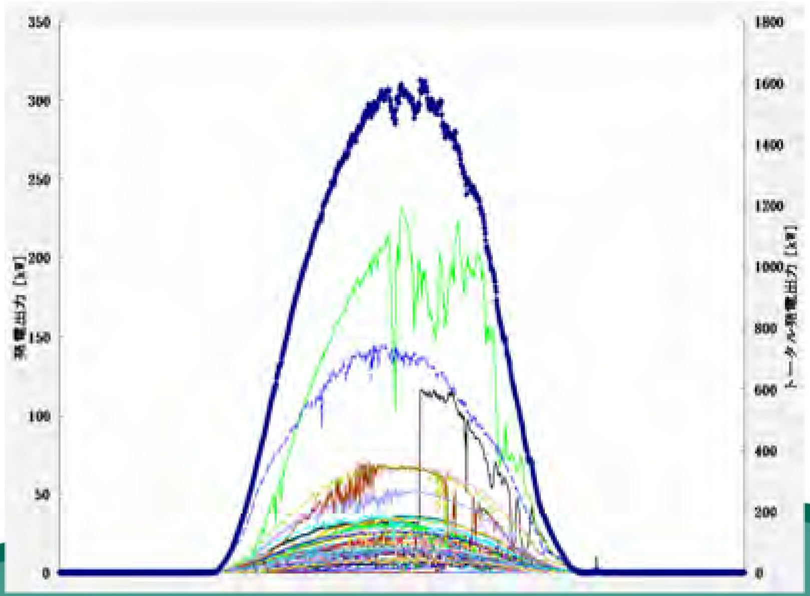


# Possible Interconnection Changes to Improve SPVP Integration

- Penetration Level
  - Originally 15 % circuit rule would have limited SPVP to 1-2 MW per circuit
  - Latest studies allow for up to 8 MW on a circuit if near the substation
  - Dedicated circuits needed if PV exceeds circuit capacity.
  - Costly ($100K/site) Remote Controlled Disconnect Switches current requirement. Inverters can be controlled via internet if deemed reliable
- Active Voltage Regulation –
  - Rule 21, Para D2a – prohibits the generator from any active voltage regulation –
  - Utilities don't want DG units to control voltage is because our "not smart" grid has no way to monitor & control customer generation.
  - Customers will want to be paid for their services and we have no CPUC approved way to do this.
  - Possible solution is to have utility owned generation - even DG- to be treated and considered differently from customer or IPP units.
- System Disturbance Ride-through
  - Rule 21, Para D2b3 – has tight voltage limits which basically prevent any ride thru of a distribution system disturbance.
  - PV systems may have value during disturbances that we want to keep them on-line

- Harmonics – Concerns over harmonics from PV Inverters seemed to have allayed, Further study may be needed to guarantee this concern.
- Intermittency – SCE / NREL Study may allay concerns.
  - Overall distributed PV "smoothing effect" reduces impact

Smoothing Effect of Multiple PV



# DER Technology Integration Issues and Concerns

**Safety and Reliability**

- Impact of generation on the ability to transfer load between distribution circuits/substations
- Real power control to curtail excessive generation
- Unintentional "Islanding" (unintentionally isolated systems)
- Lack of "low voltage ride through" (LVRT) where temporary faults can shut down large amounts of generation
- Line management and service

**Voltage**

- Steady state voltage regulation, and or insufficient voltage support
- Transient over-voltages caused by connecting generation to systems with little or no load
- Short circuit duty (the amount of energy produced during fault conditions that may exceed circuit breaker duty ratings)

**Power Quality, including high/low transient voltages, harmonics**

- Harmonics, or power line distortion due to electronic loads, can interfere with utility protection and equipment; in addition to causing damage to equipment.
- Transient voltages can interfere and interrupt sensitive equipment; problems typically are seen at customer facilities.

**Intermittency**

- The output of renewable generation varies with the energy source. Examples include variable solar production during cloud cover, or intermittent wind speeds.
- Produces challenges with managing demand on specific parts of the grid and ensuring adequate capacity.

**Integration**

- Increasing difficulties to regulate voltage with significant penetration of variable and intermittent generation.

**Protection**

- Requirements will need to be revised to accommodate increasing generation on utility systems that were not designed to serve local generation in large quantities.

# SCE Advanced Technology (AT) Group Research & Testing Program

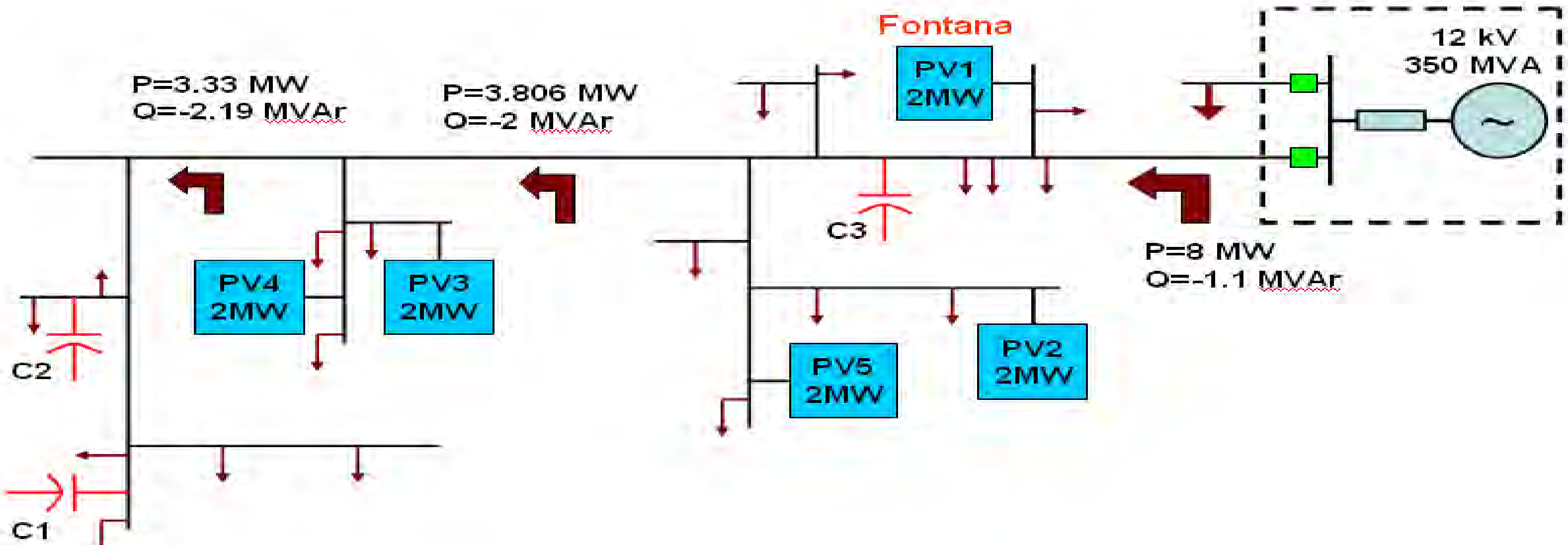
- **Models have not properly being developed or validated**
  - Short Circuit Duty Models
  - Voltage Characteristics Models
  - Harmonic Models
  - Load flow Models

- **SCE's Advanced Technology (AT) group is working with NREL, WECC, Sandia NL, and others to:**
  - Help develop/validate computer models for PV impact studies
  - Assist with testing of large inverters

- **AT has begun laboratory testing and evaluation of inverters**

# High Penetration of PV Systems

***SCE Feeder Transient Studies are being conducted***




***Scenario 1:*** Change in solar radiations sudden drop from 100% to 0% change with pre-specified ramp up/down rates

***Scenario 2:*** Load rejection Disconnecting adjacent feeder load

Target studies:

- Impact on feeder flow (P & Q)
- Impact on feeder voltage
- Impact on short circuit capacity of the feeder
- Interaction with capacitor banks

# Modeling and Testing of Inverters to Address Integration Issues at the Distribution Circuit Level

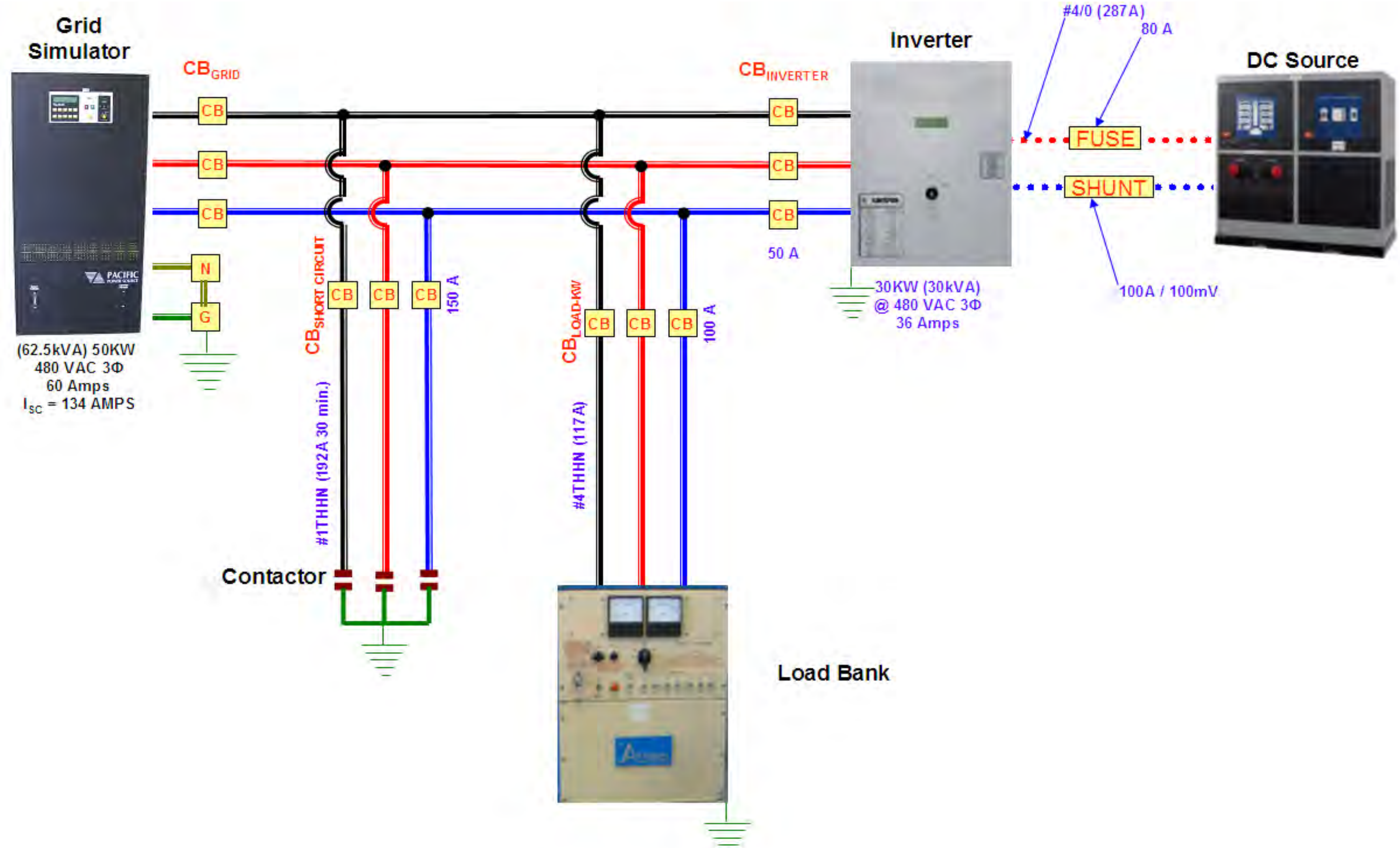
- Tested three 3-Phase commercial inverters in the AT Labs at the EVTC in Pomona. The inverters were tested for:
  - Fault current
  - Transient overvoltage
  - Harmonic levels
  - Response to voltage/frequency transients of various depths and durations
  - Response to voltage and frequency oscillations
- Constructed inverter models for PSLF and PSCAD programs
- Modeled selected circuits with high penetrations of inverters using the models built based on the testing to date
- Identified a list of grid integration questions that needed to be answered to allow high penetration of inverter-based generation and storage.
- Tested 14 single phase residential inverters in the lab using the same tests specified for the 3-phase inverters
- Worked with Distribution Engineering to identify information needed from inverter manufacturers so that proper interconnection studies can be accomplished.
- Arrangements are being made to test a 500 kW inverter at Florida State where the team will perform the same tests done on the 3-phase inverters. The results will help validate inverter models and allow proper interconnection studies to be performed by Distribution Engineering

# SCE's Advanced Technologies Research

- Developed Inverter Test procedure
  - Shared with NREL, SANDIA, EPRI, WECC, etc
  - NREL, SANDIA, EPRI testing 1-phase inverters
- Tested 4 three-phase 30KW 480V inverters and one parallel combination of three-phase inverters
- Tested 1 three-phase 500KW 208V inverter at laboratory
- Testing 1-phase USA (~20) inverters (including XMRLESS)
- Testing German 1-phase and 3-phase inverters with advance features (LVRT and VAR support)

| Inverter # | Manuf. | Ratings | | | | | Comments |
|---|---|---|---|---|---|---|---|
| | | $V_{AC}$ | Φ | $P_{GEN}$ (KW) | $V_{DC}$ | Pf | |
| 1 | 1 | 480 | 3 | 30 | 300-600 | ±0.8 | Old controls |
| 2 | 1 | 480 | 3 | 30 | 300-600 | ±0.8 | New Controls |
| 3 | 2 | 480 | 3 | 30 | 300-600 | 1.0 | No pf setting |
| 2//3 | 1&2 | 480 | 3 | 30 + 30 | 300-600 | ±0.8 & 1.0 | Paralleled |

# Short Circuit Test Diagram



# Short Circuit Duty Behavior (Source – Inverter Manufacturers)

| Type | SCD Contribuiton (P.U) |
|---|---|
| **Inverter Manufacturer 1** | **1.11** |
| **Inverter Manufacturer 2** | **1.2** |
| **Inverter Manufacturer 3** | **1.25** |
| **Inverter Manufacturer 4** | **1.2** |
| **Inverter Manufacturer 5** | **1.06** |

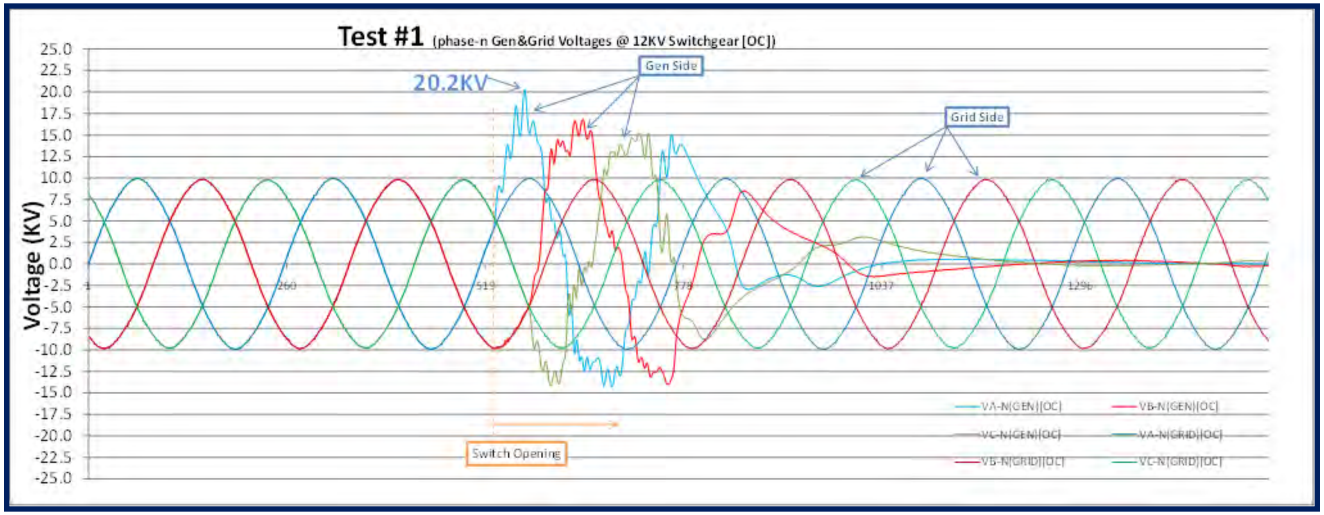
- Short Circuit Testing Results for various inverters
- Based on data provided from inverter manufacturers
- Testing based on UL testing procedures 47.3

# Temporary Overvoltage

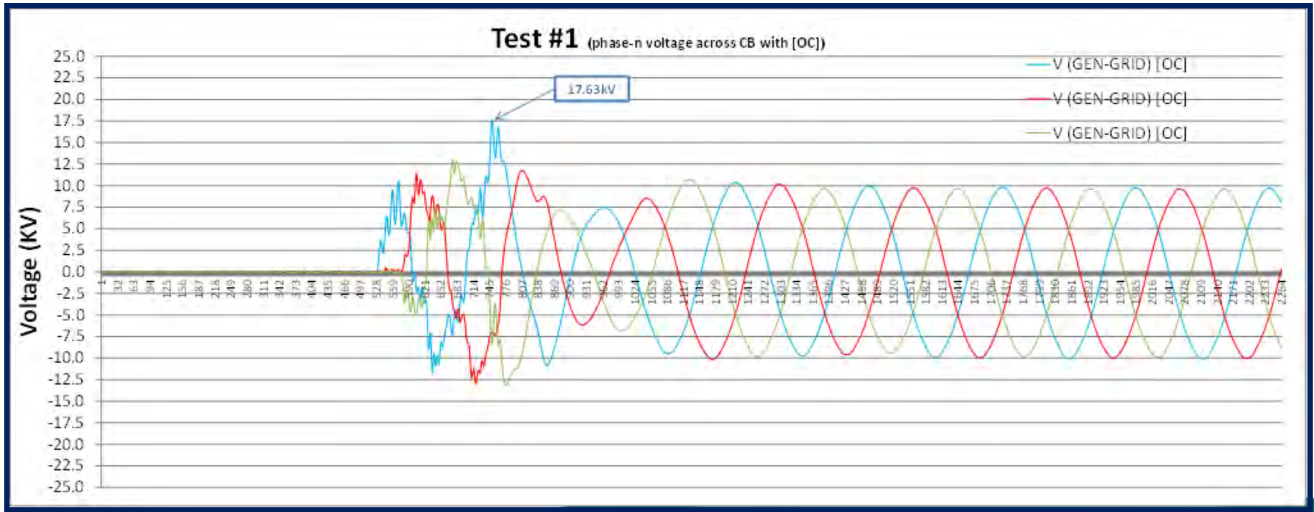


- ❑ Impacts to
  - ❑ customers
  - ❑ Operations
- ❑ Tested 5 SPV plants
  - ❑ 480V
  - ❑ 12KV
- ❑ Plant sizes 1.5MW ~ 6.5MW

Voltage phase-ground (both sides of the switch)




Voltage Across the Switch



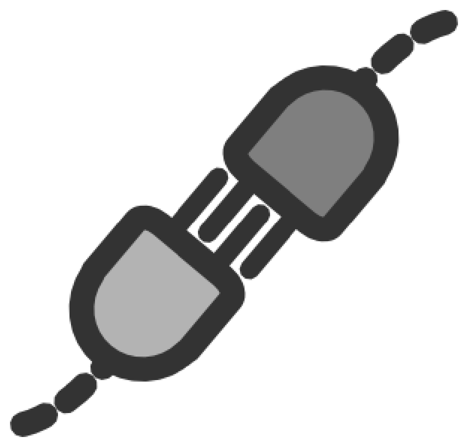
# DER Integration – Enabling Infrastructure & Technologies

| |
|---|
| **Advanced Load Control System (ALCS)** - Release 3 is planned for 2014 to support future concepts such as integration with the DMS for event dispatch, distributed energy resources and electric vehicles. |
| **DMS -** The main management system required to enable SCE's distribution and substation automation capabilities. A DMS is required to configure and coordinate operation of the field equipment deployed to support DER integration and advanced outage management. A DMS also includes the software required for SCE to deliver advanced volt/var control. |
| **Smart Inverters –** Intelligent control systems incorporated into inverter connected devices, as PVs, to address circuit overloading and voltage fluctuation at the distribution level |
| **Geographical Information System (GIS)** - Will serve as a comprehensive data repository that stores information regarding the physical, electrical, and spatial attributes of all transmission and distribution assets. GIS will contribute to the development of smart grid capabilities such as integrating renewable energy resources and distributed energy resources. |
| **Distributed Energy Storage –** Has the potential to resolve issues related to the integration of intermittent generation and transmission congestion. SCE is conducting 2 major DOE co-funded pilots or demonstration projects incorporating energy storage: the Irvine Smart Grid Demonstration (ISGD) and the Tehachapi Wind Energy Storage Project (TSP). |
| **FACTS Devices** - DSVCs |
| **Advanced Protective (4-Quadrant) Relays –** Relays designed to adjust dynamically to grid conditions in any power flow direction. |

# Thank You !

George D Rodriguez
Consulting Engineer

# 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

# Pepco Holdings, Inc.

## 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

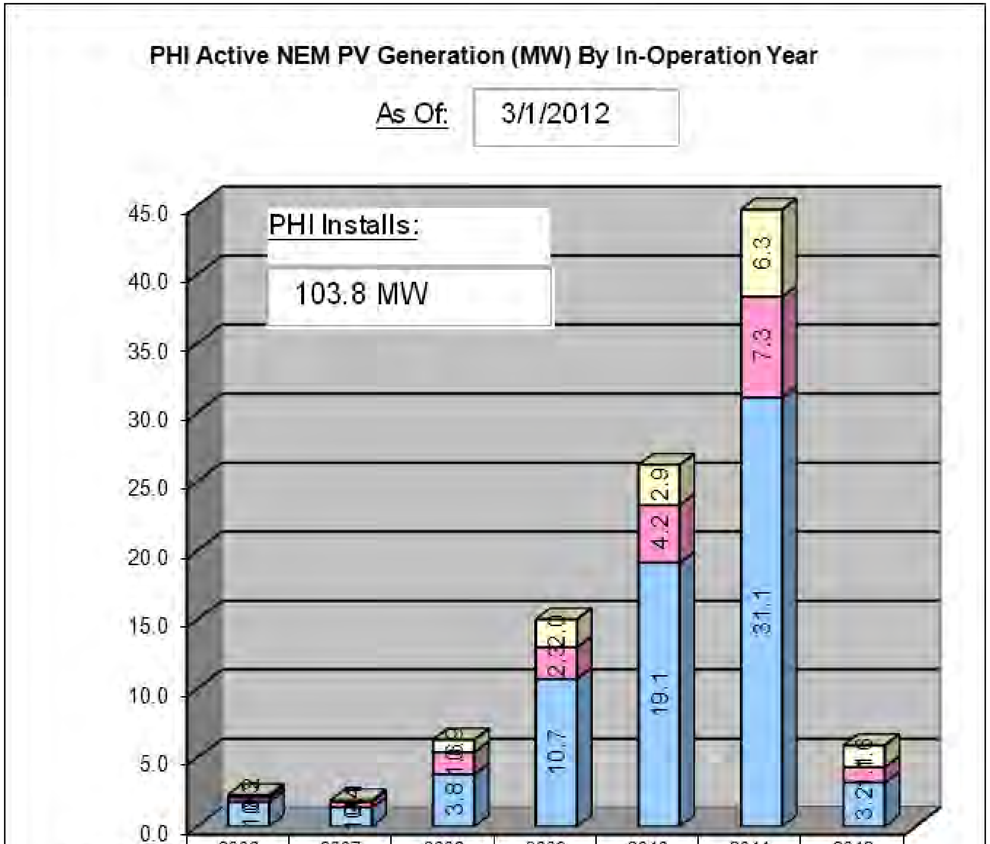
**5,400 sq mi (*3,500 in MD)***
**498,000 cust (*199,000 in MD)***
**4, 12, 25 and 34kV distribution**

**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




| | 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**

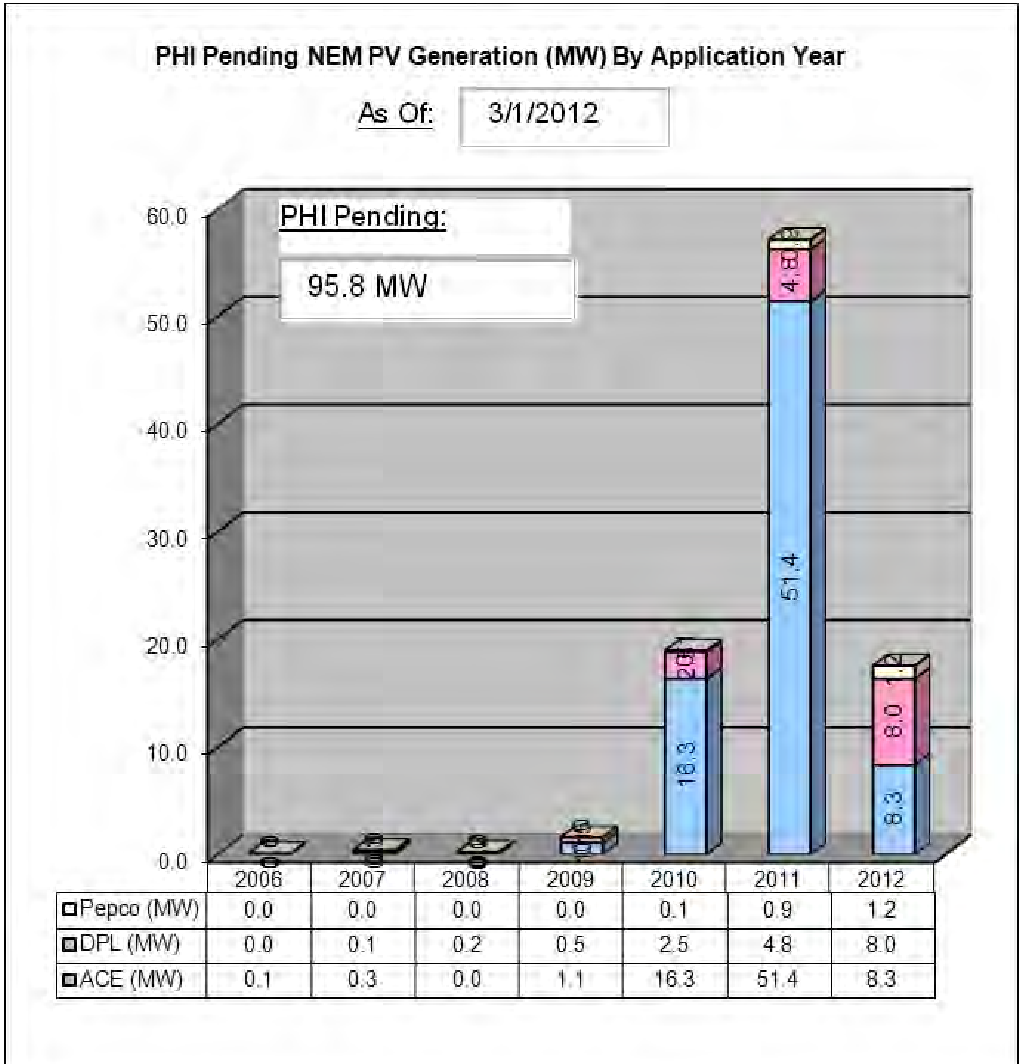
**DPL**
**17.5 MW**

**PEPCO**
**14.0 MW**

**TOTAL**
**103.8 MW**

Pepco Holdings, Inc

# 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**

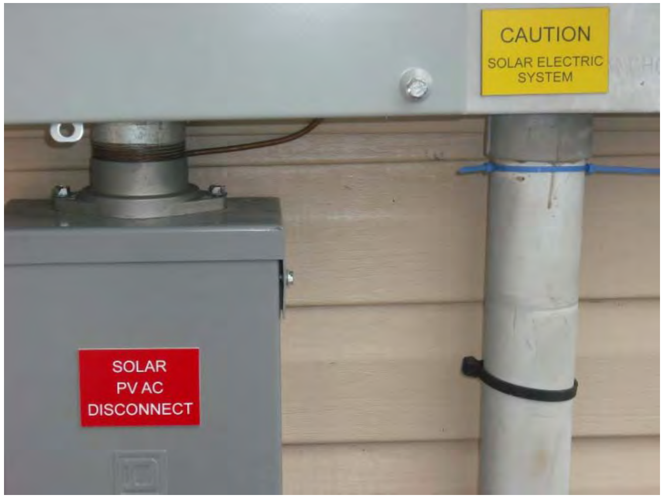
**TOTAL**
**95.8 MW**

Pepco Holdings, Inc

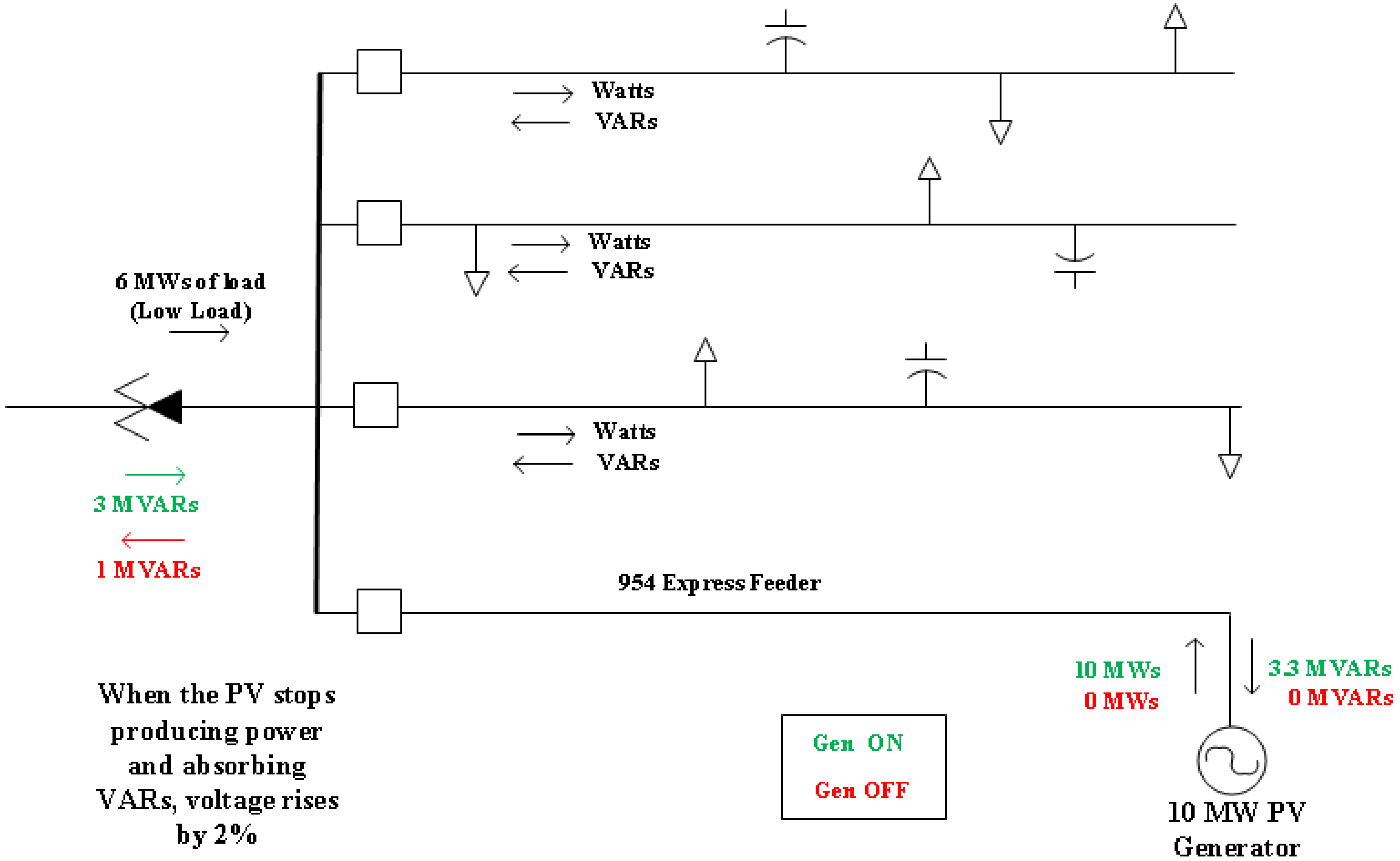
# Solar PV on Express Feeders

# Solar PV on Radial Load Serving Feeders

# Small Solar – 250 kW or less



# Substation Bus Voltage Regulation and Impact of VAR Fluctuation



# *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.

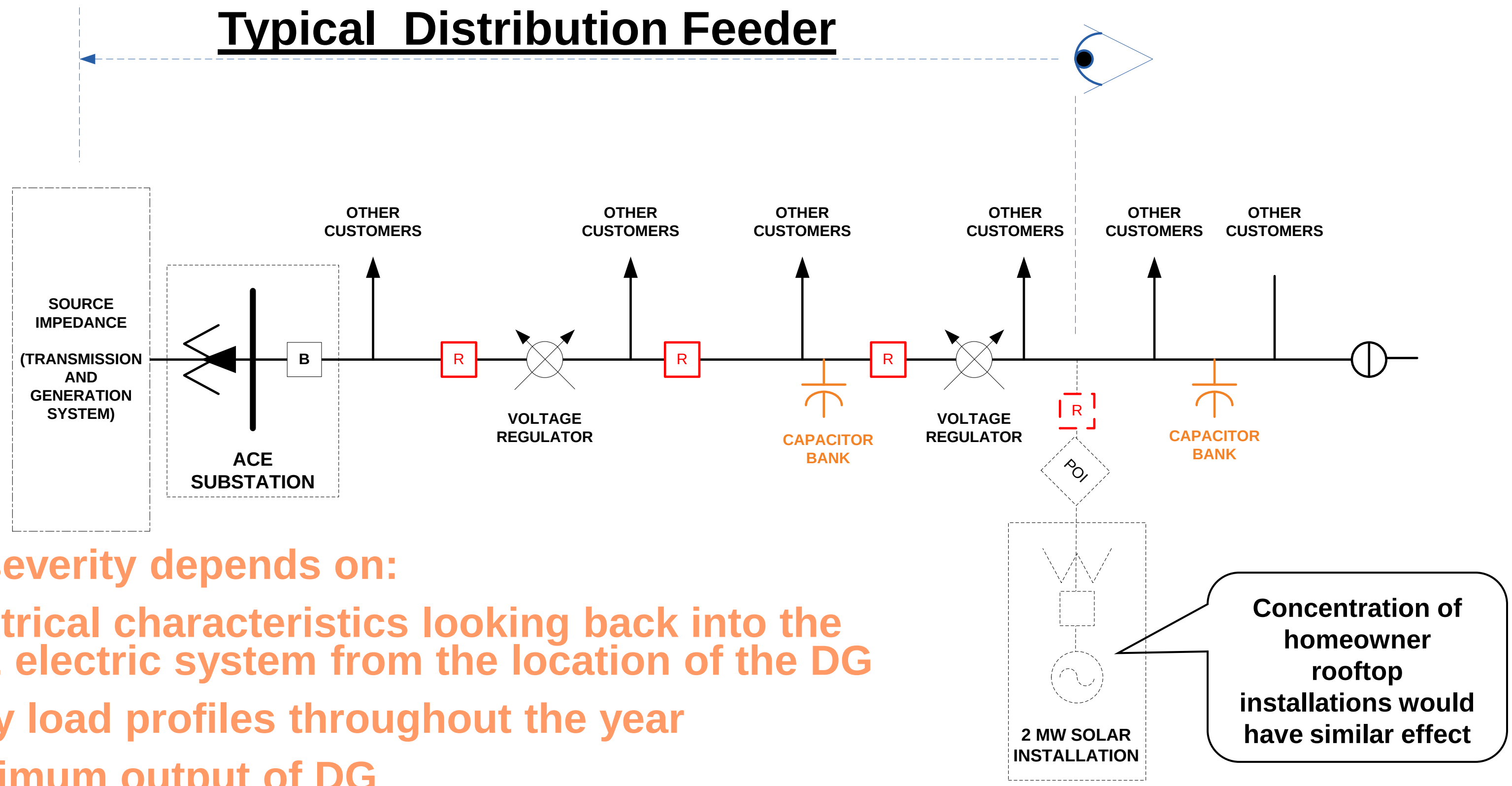
# *Potential Voltage Rise and Fluctuations*

- 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*

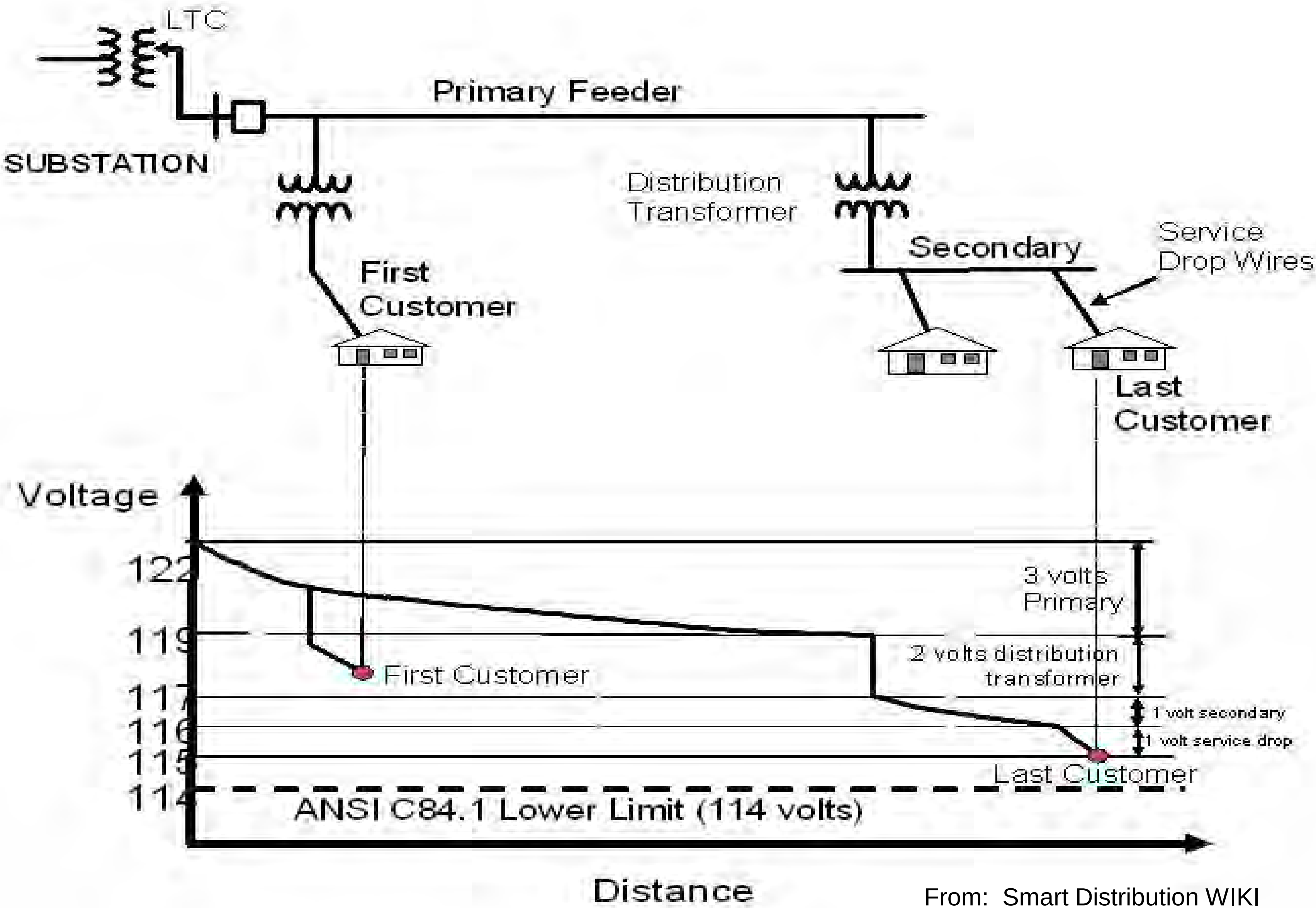
- 10 MW Solar System
- Resonant with utility system
- Several times per day it caused some over voltages and unexpected tripping
- Capacitance was added to the inverters to resolve the situation

# Impacts to a Distribution Feeder



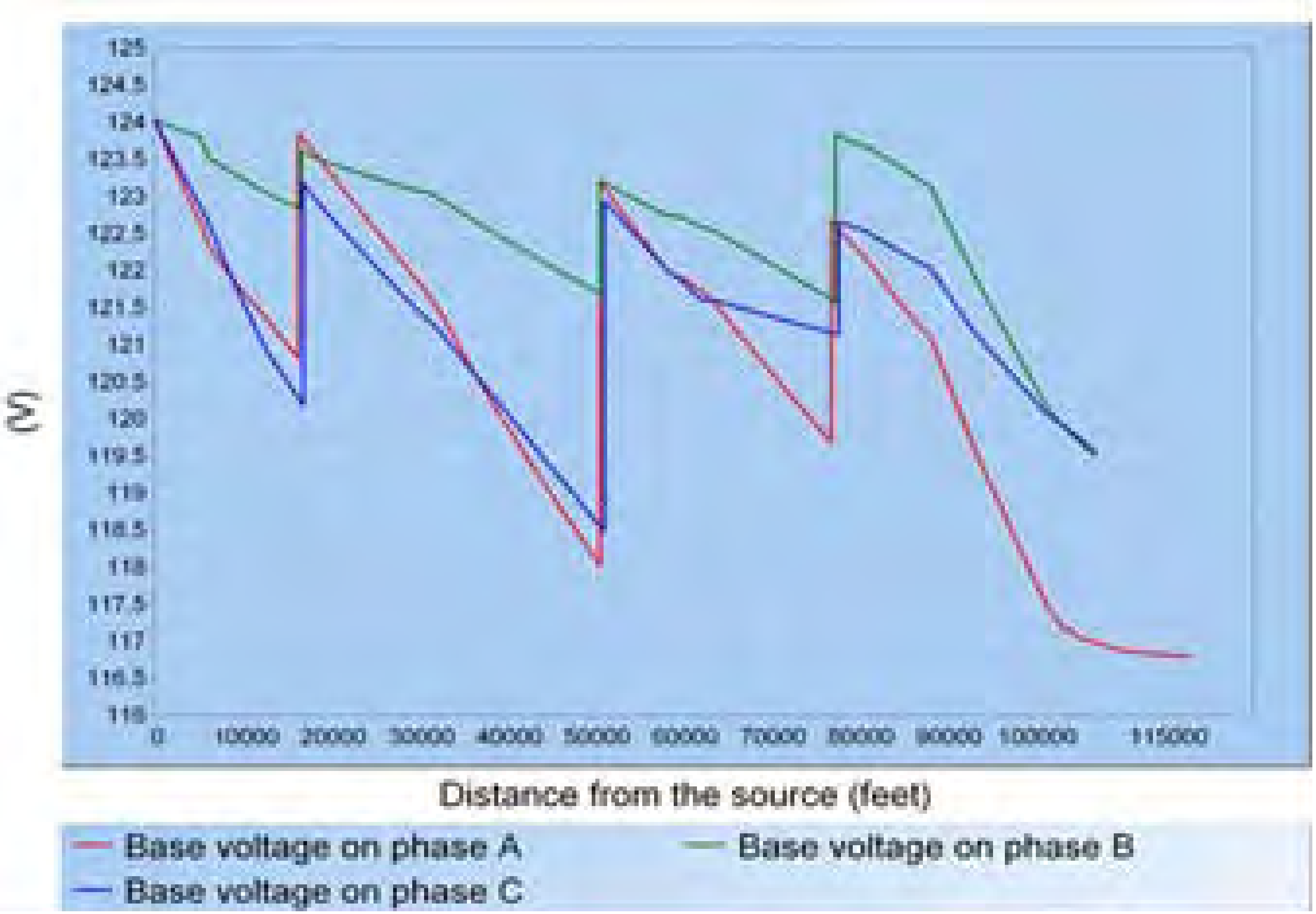

- **Impact severity depends on:**
  - **Electrical characteristics looking back into the ACE electric system from the location of the DG**
  - **Daily load profiles throughout the year**
  - **Maximum output of DG**
  - **Substation transformer settings**
  - **Location and settings of regulators, capacitors,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

adapted from actual DG customer application




From: Smart Distribution WIKI

# Plot of Feeder Voltage over Distance



# *Feedes 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%* |

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

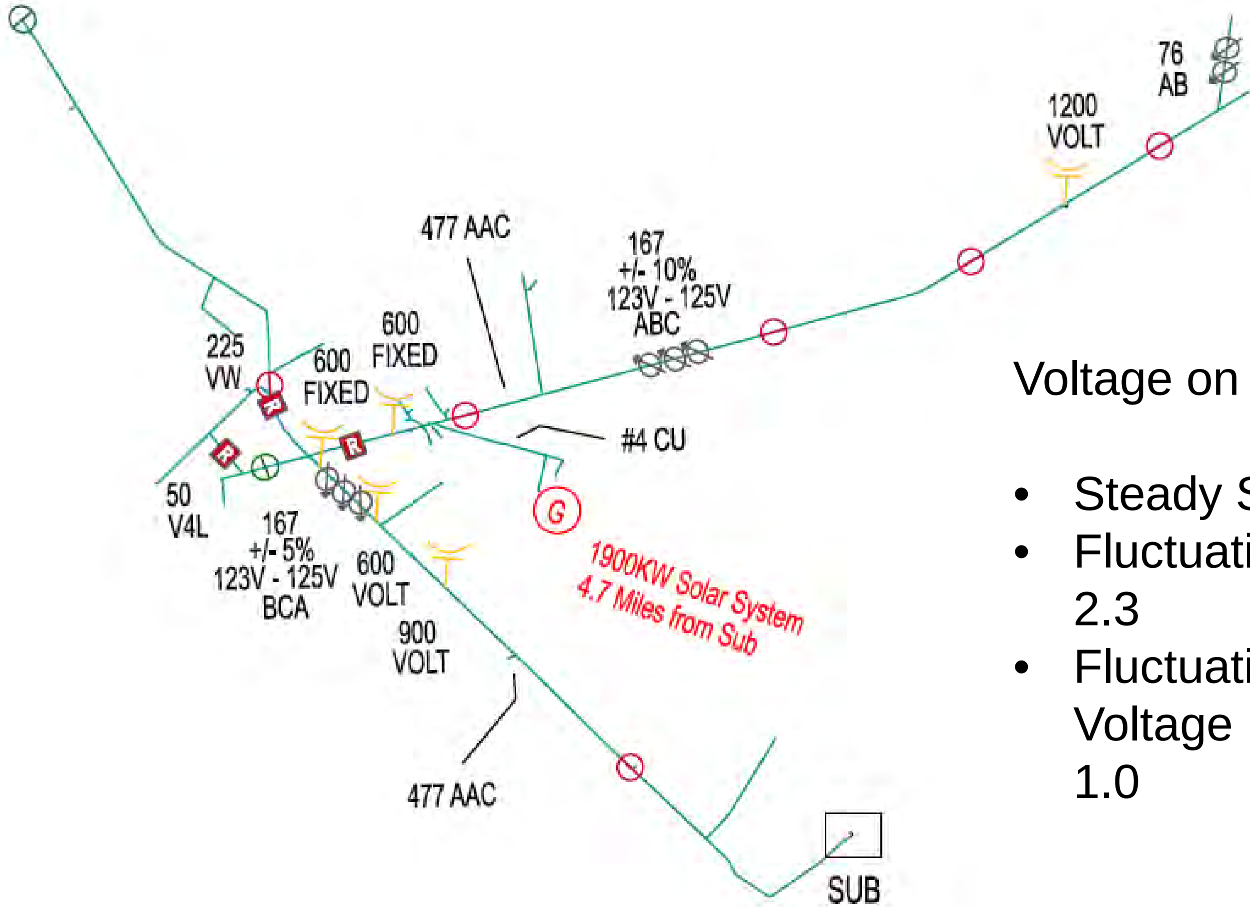
Fdr 2

| 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

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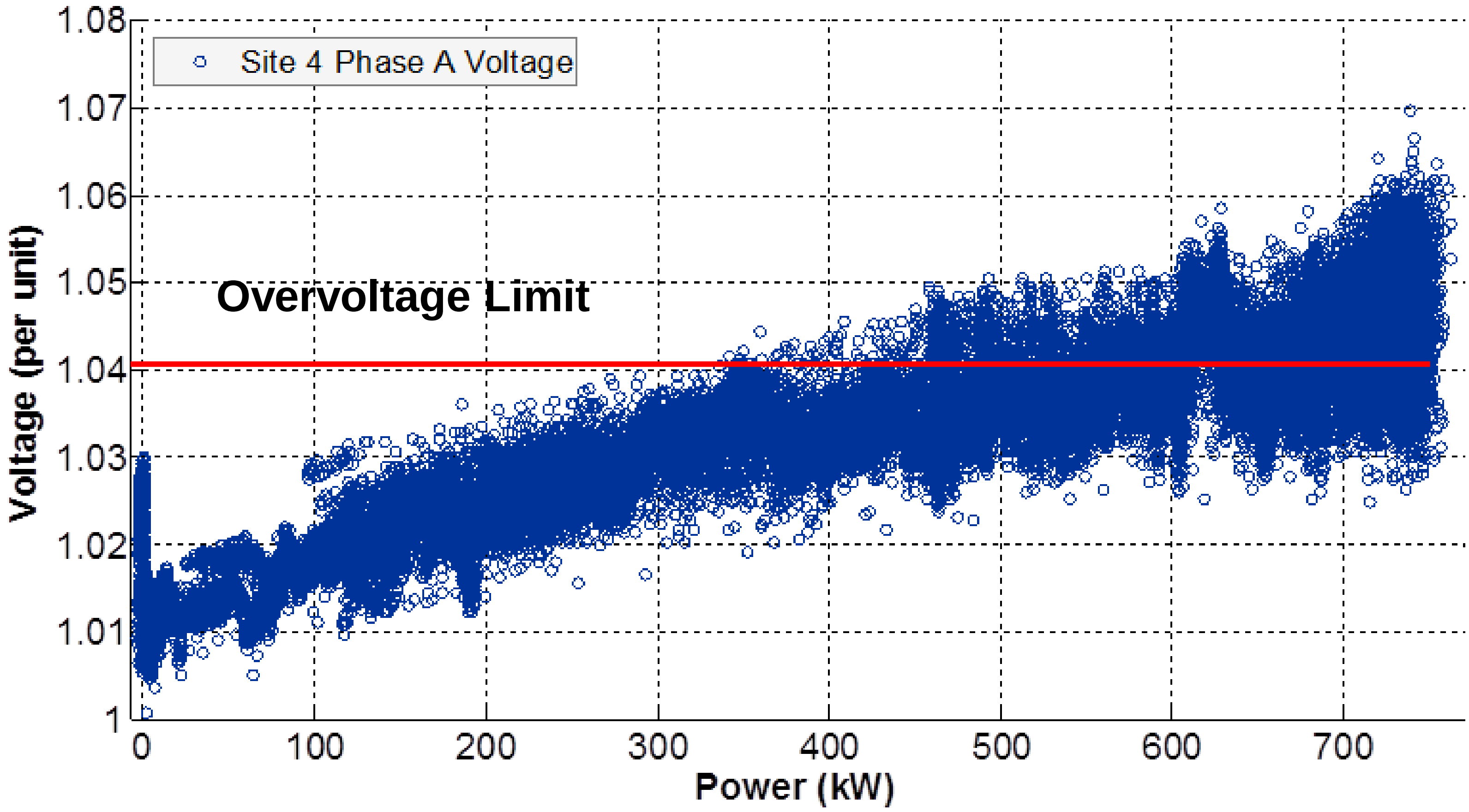
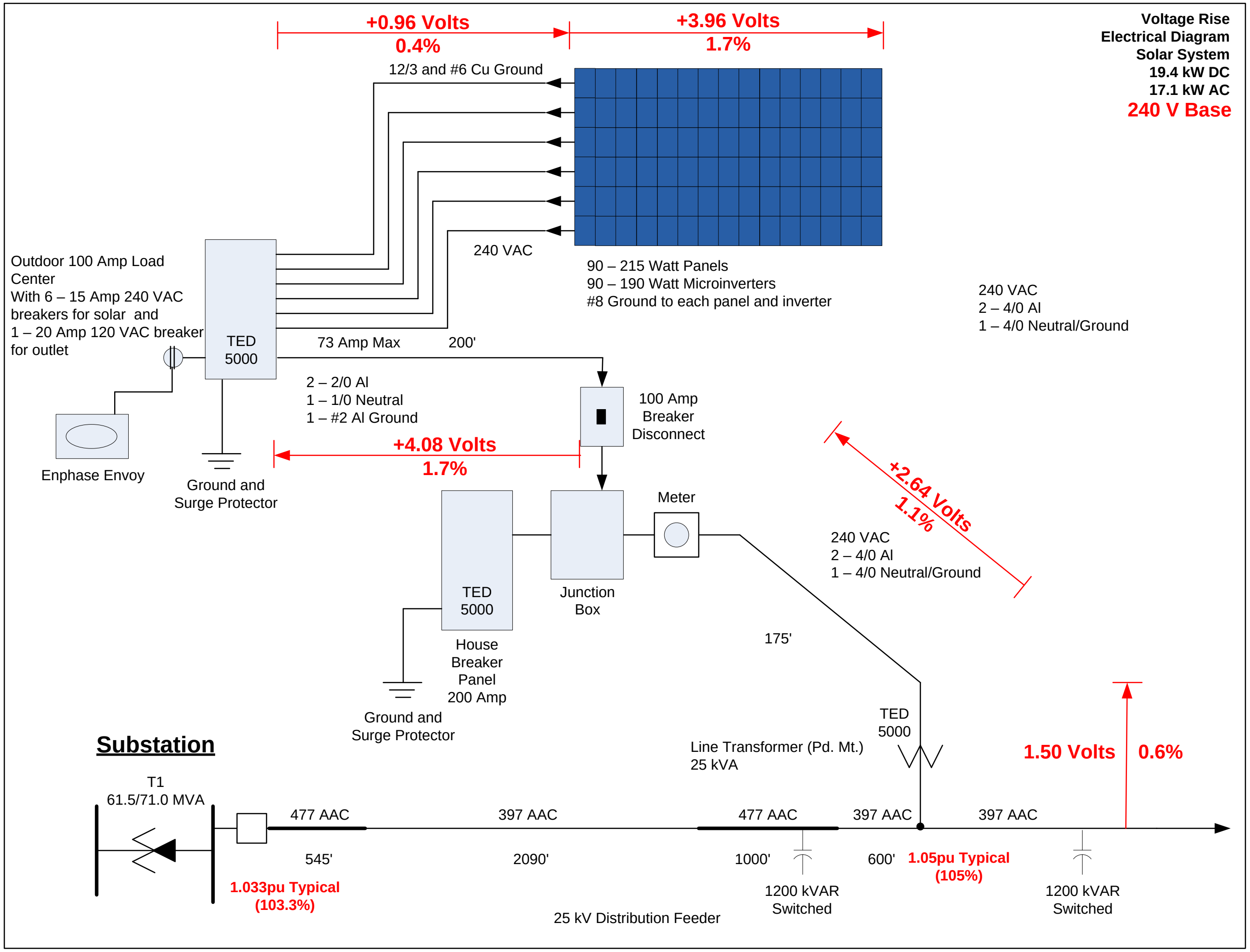
# *Overvoltage at the Inverter*




Source: EPRI Monitoring

# Voltage Rise



# Voltage Rise Chart
## (at max gen and no load)

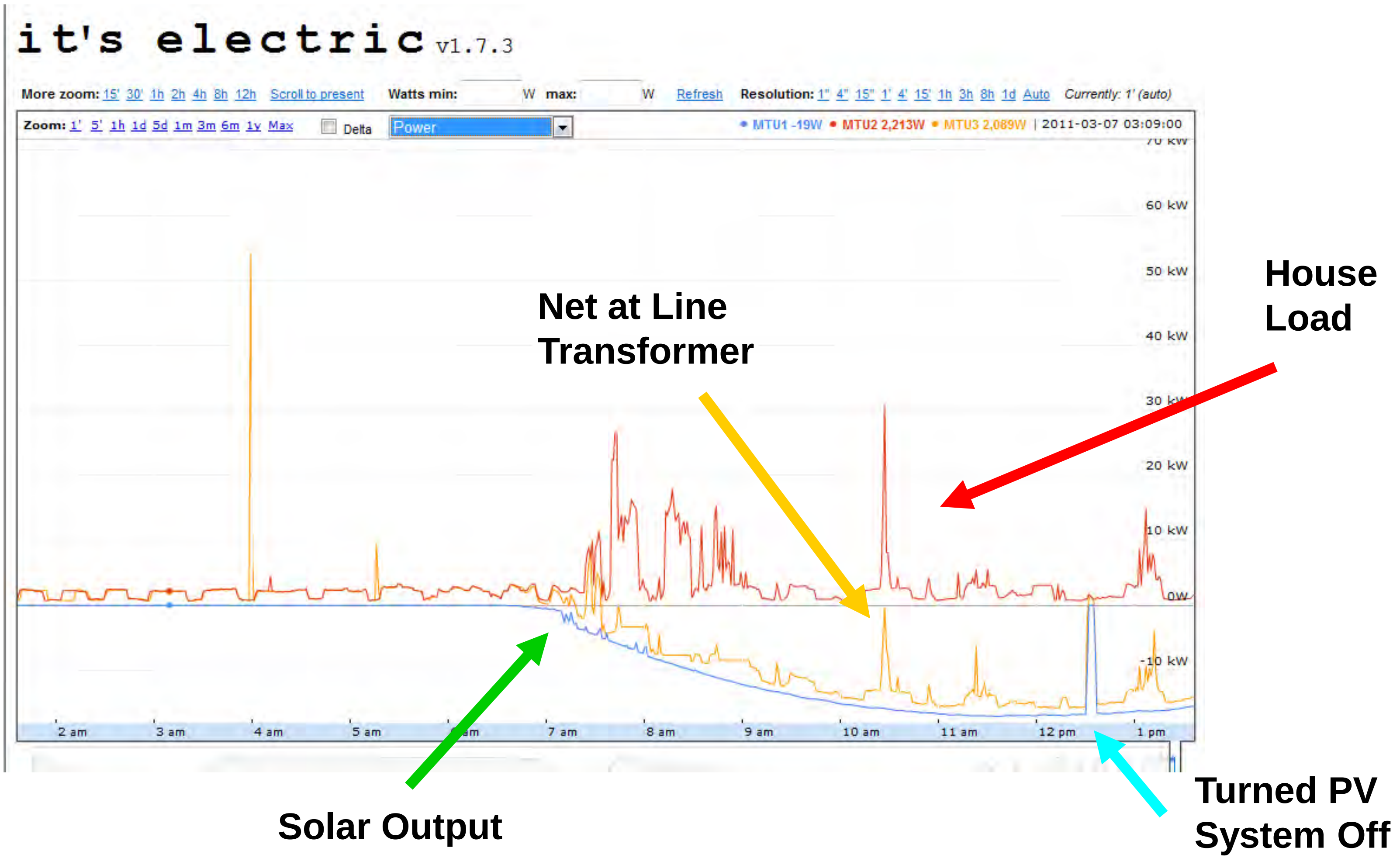
Nominal Voltages: 120V or 240V

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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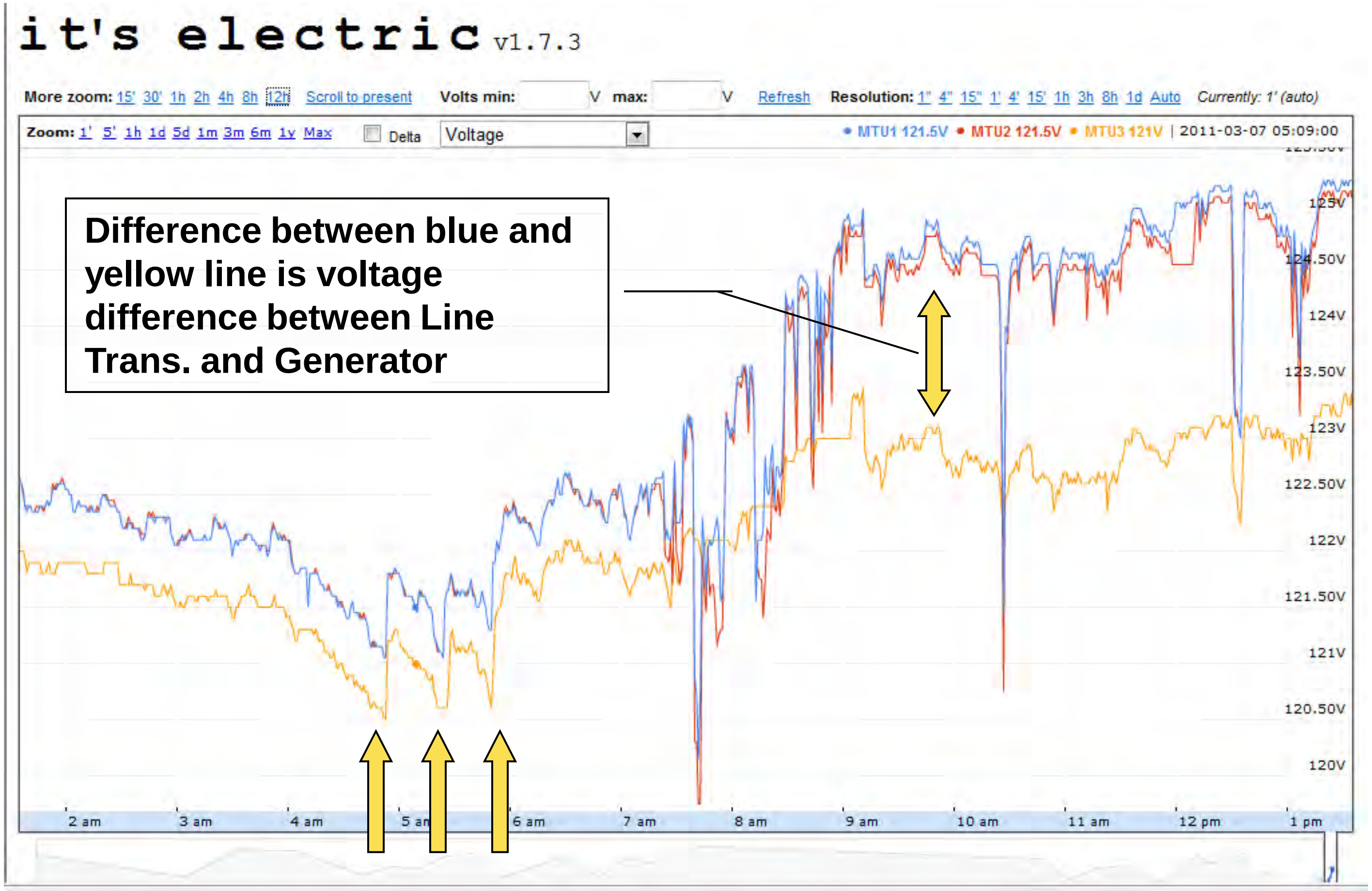
# Voltage vs. Time




**Substation transformer adjusting voltage**

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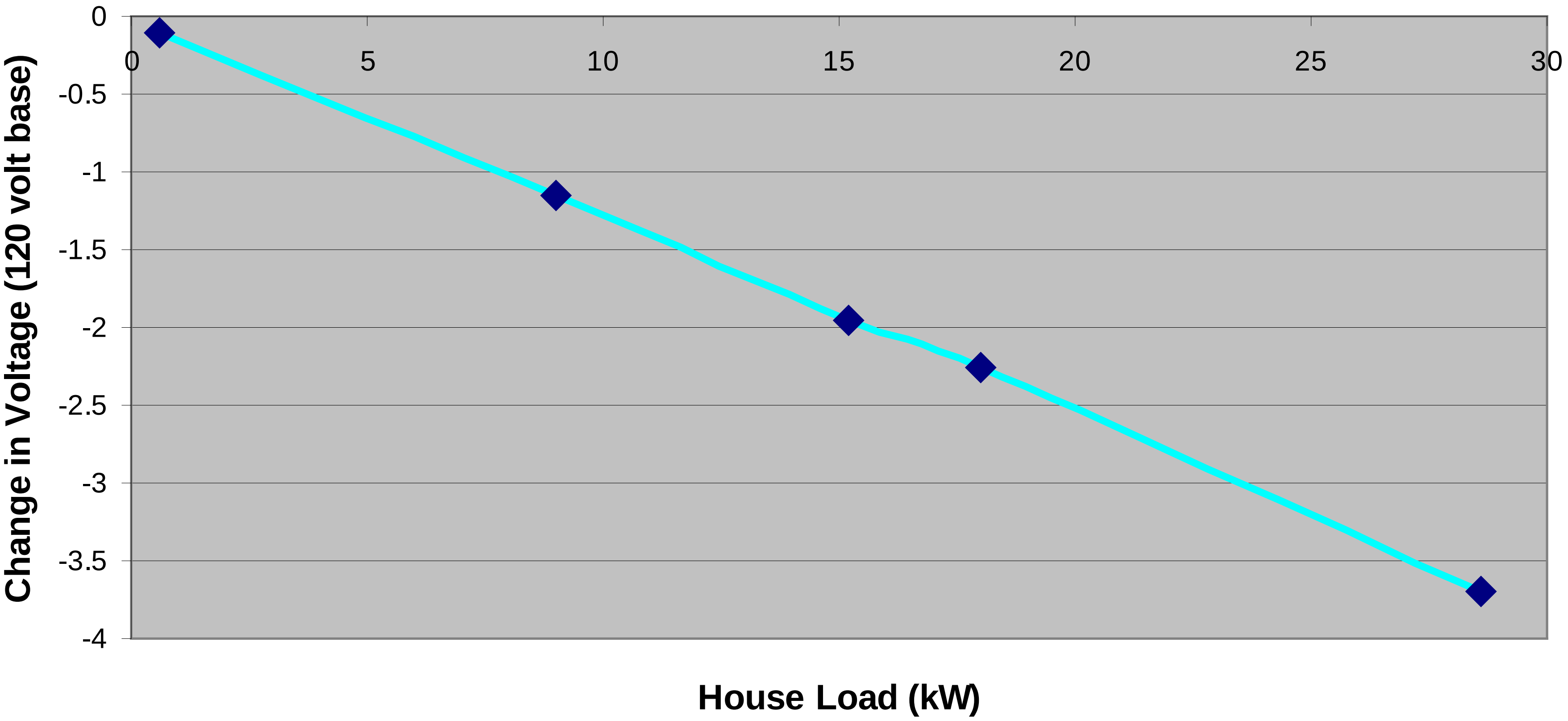
# Voltage Drop vs. House Load

## Unity Power Factor

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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

atlantic city electric
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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

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# Thank You!