Revised IEEE 1547 Standard for Interconnecting Distributed Energy Resources with Electric Power Systems- National Grid Solar Program



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- What is IEEE 1547?
- Voltage regulation
- Power Quality
- Interoperability
- National Grid Solar Program

IEEE 1547 Uses

IEEE 1547 is:

- A technical standard—functional requirements for the interconnection itself and interconnection testing
- A single (whole) document of mandatory, uniform, universal, requirements that apply at the point of common coupling (PCC) or point of DER connection (PoC)
- Technology neutral—i.e., it does not specify particular equipment or type
- Should be sufficient for most installations

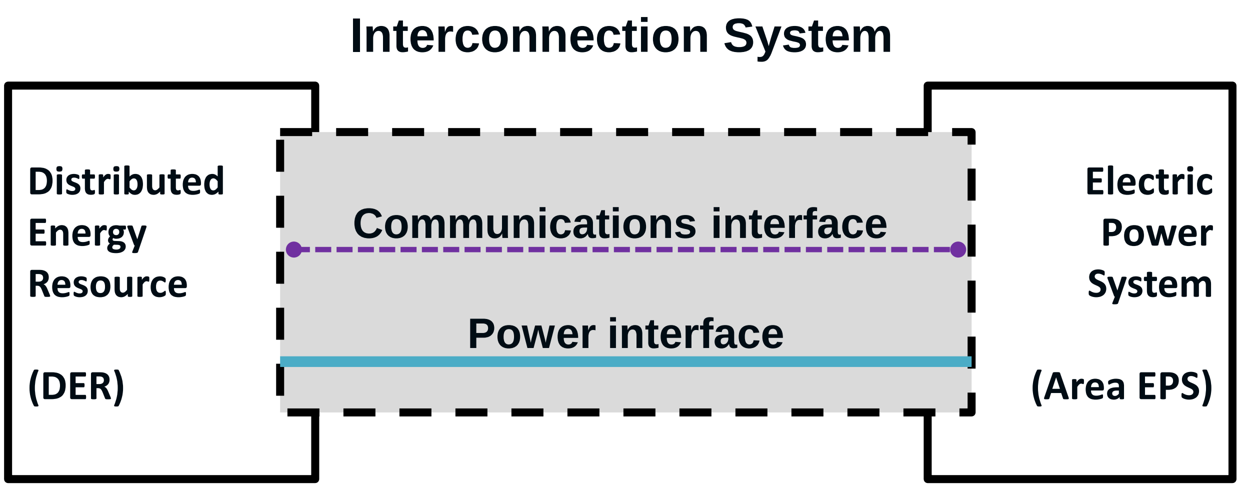
IEEE 1547 is not:

- A design handbook
- An application guide (see IEEE 1547.2)
- An interconnection agreement
- Prescriptive—i.e., it does not prescribe other important functions and requirements such as cyber-physical security, planning, designing, operating, or maintaining the area EPS with DER

IEEE 1547 Scope and Purpose, P1547 Revision

Title: *Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces*

Scope: *This standard establishes criteria and requirements for interconnection of distributed energy resources (DER) with electric power systems (EPS), and associated interfaces.*



Purpose*: This document provides a uniform standard for the interconnection and interoperability of distributed energy resources (DER) with electric power systems (EPS). It provides requirements relevant to the interconnection and interoperability performance, operation, and testing, and, safety, maintenance and security considerations.*

Interconnection system: The collection of all interconnection equipment and functions, taken as a group, used to interconnect DERs to an area EPS. Note: In addition to the power interface, DERs should have a communications interface.

Interface: A logical interconnection from one entity to another that supports one or more data flows implemented with one or more data links.

Image based on IEEE 1547-2018

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IEEE 1547 Document Outline (Clauses)

1. Overview
2. Normative references
3. Definitions and acronyms
4. General specifications and requirements
5. *[normal grid]* Reactive power, voltage/power control
6. Response to Area EPS abnormal conditions
7. Power quality
8. Islanding
9. Distribution secondary grid and spot networks
10. Interoperability
11. Test and verification

12. Seven new annexes (Informative)

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1547 Voltage regulation

Two performance categories are defined for DERs with voltage regulation capabilities:

a) Category A covers minimum performance capabilities needed for Area EPS voltage regulation and are reasonably attainable by all DER technologies as of the publication of this standard. This level of performance is deemed adequate for applications where the DER penetration in the distribution system is lower, and where the overall DER power output is not subject to frequent large variations

b) Category B covers all requirements within Category A and specifies supplemental capabilities needed to adequately integrate DERs in local Area EPSs where the aggregated DER penetration is higher or where the overall DER power output is subject to frequent large variations

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1547 Example New Reactive Power Requirements

5.2 Reactive power capability of the DER

The DER shall be capable of injecting reactive power (over-excited) and absorbing reactive power (under-excited) for active power output levels greater than or equal to the minimum steady-state active power capability (P_{min}), or 5% of rated active power, P_{rated} (kW) of the DER, whichever is greater.

When operating at active power output greater than 5% and less than 20% of rated active power, the DER shall be capable of exchanging reactive power up to the minimum reactive power value given in Table 7 multiplied by the active power output divided by 20% of rated active power.

Operation at any active power output above 20% of rated active power shall not constrain the delivery of reactive power injection or absorption, up to the capability specified in Table 7, as required by the active control function at the time, as defined in 5.3. Curtailment of active power to meet apparent power constraints is permissible. These reactive power requirements are illustrated in informative Figure H.3.[60]

Table 7—Minimum reactive power injection and absorption capability

Category	Injection capability as % of nameplate apparent power (kVA) rating	Absorption capability as % of nameplate apparent power (kVa) rating
A (at DER rated voltage)	44	25
B (over the full extent of ANSI C84.1 range A)	44	44

Voltage and Reactive Power Control

The DER shall provide voltage regulation capability by changes of reactive power. The approval of the Area EPS Operator shall be required for the DER to actively participate in voltage regulation.

The voltage and reactive power control functions do not create a requirement for the DER to operate at points outside of the minimum reactive power capabilities specified in of 5.2.

The DER shall, as specified in Table 6, provide the capabilities of the following mutually exclusive modes of reactive power control functions:

- Constant power factor
- Voltage-reactive power
- Active power-reactive power
- Constant reactive power

DER category	Category A	Category B
Voltage regulation by reactive power control		
Constant power factor mode	Mandatory	Mandatory
Voltage—reactive power mode[a]	Mandatory	Mandatory
Active power—reactive power mode[b]	Not required	Mandatory
Constant reactive power mode	Mandatory	Mandatory
Voltage and active power control		
Voltage—active power (volt-watt) mode	Not required	Mandatory

[a]Voltage-reactive power mode may also be commonly referred to as "volt-var" mode.
[b]Active power-reactive power mode may be commonly referred to as "watt-var" mode.

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Constant Power factor mode

When in this mode, the DER shall operate at a constant power factor. The target power factor shall be specified by the Area EPS operator and shall not require reactive power exceeding the reactive capability requirements specified in 5.2. The power factor settings are allowed to be adjusted locally and/or remotely as specified by the Area EPS operator. The maximum DER response time to maintain constant power factor shall be 10 s or less.

Volt-Reactive Power Capability (Volt/Var Mode– Section 5.3.3)

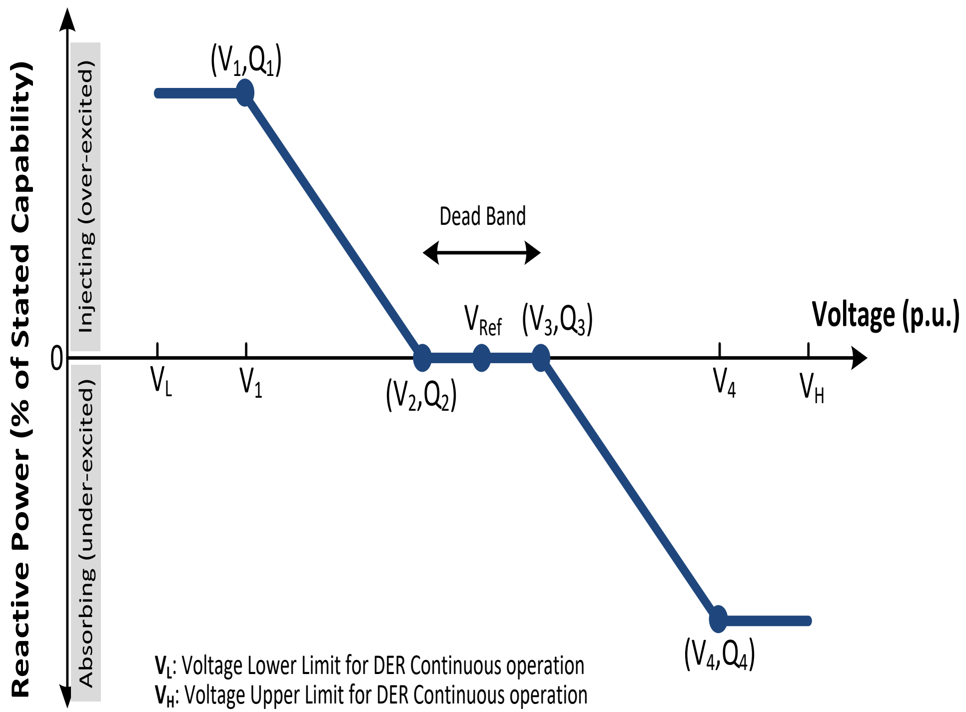

Figure 5—Example voltage-reactive power characteristic

The Volt/VAR characteristics curve is adjustable

Volt-var parameters	Definitions	Default Settings for Cat A DER	Default Settings for Cat B DER	Range of Allowable settings	
				Minimum	Maximum
V_{Ref}	Reference voltage	Nominal voltage (V_N)	Nominal voltage (V_N)	0.95 V_N	1.05 V_N
V_2	Dead band lower voltage limit	Nominal voltage (V_N)	V_{Ref} – 0.02 V_N	Cat A: V_{ref} Cat B; V_{Ref} – 0.03 V_N	V_{Ref} [c]
Q_2	Reactive power injection or absorption at voltage V_2	0	0	0	100% of stated reactive capability
V_3	Dead band upper voltage limit	Nominal voltage (V_N)	V_{Ref} + 0.02 V_N	V_{Ref}[c]	Cat A: V_{ref} Cat B: V_{Ref} + 0.03 V_N
Q_3	Reactive power injection or absorption at voltage V_3	0	0	0	100% of stated reactive capability
V_1	Voltage at which DER shall inject Q_1 reactive power	0.9 V_N	V_{Ref} – 0.08 V_N	V_{Ref} - 0.18 V_N	V_2 [c]-0.02 V_N

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Active Power – Reactive Power Capability (Watt-Var or P - Q Section 5.3.4)

When in this mode, the DER shall actively control the reactive power output as a function of the active power output following a target piecewise linear active power–reactive power characteristic, without intentional time delay. In no case shall the response time be greater than 10s. The target characteristics shall be configured in accordance with the default parameter values shown in Table 9. The characteristics shall be allowed to be configured as specified by the Area EPS Operator using the values specified in the optional adjustable range .

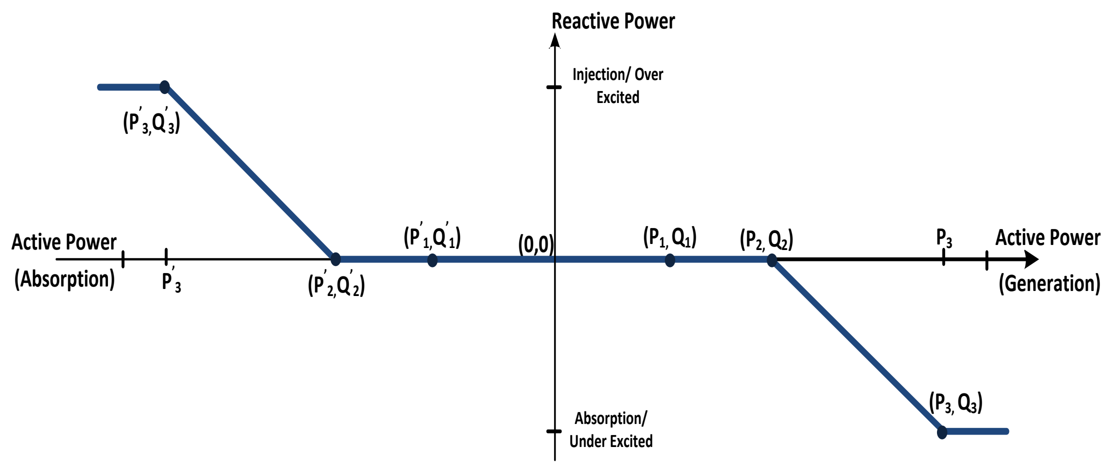

Figure 6—Example active power-reactive power characteristic

Watt-Var settings for Category A and Category B types of DER

Point/ Parameter	Default	Range of allowable settings	
	Cat A and B	Min	Max
P_3	P_{rated}	P_2+0.1P_{rated}	P_{rated}
P_2	0.5P_{rated}	0.4P_{rated}	0.8P_{rated}
P_1	The greater of 0.2P_{rated} and P_{min}	P_{min}	P_2- 0.1P_{rated}
P'_1	The lesser of 0.2P'_{rated} and P'_{min}	P'_2- 0.1P'_{rated}	P'_{min}
P'_2	0.5P'_{rated}	0.8P'_{rated}	0.4P'_{rated}
P'_3	P'_{rated}	P'rated	P'_2+0.1P'_{rated}
Q_3	40% of Nameplate Apparent Power (kVA) absorption or $Qmin_s$	100% of nameplate reactive power absorption capability	100% of nameplate reactive power injection capability
Q_2	0		
Q_1	0		
Q'_1	0		
Q'_2	0		
Q'_3	44% of		

Constant Reactive Power Capability

When in this mode, the DER shall maintain a constant reactive power. The target reactive power level and mode (injection or absorption) shall be specified by the Area EPS operator and shall be within the range specified in 5.2. The reactive power settings are allowed to be adjusted locally and/or remotely as specified by the Area EPS operator. The maximum DER response time to maintain constant reactive power shall be 10 s or less.

Voltage Active Power Capability

When in this mode, the DER shall actively limit the active power output as a function of the voltage following a Volt-Watt piecewise linear characteristic. Two example Volt-Watt characteristics are shown in Figure 7. The characteristic shall be configured in accordance with the default parameter values specified in Table 10 for the given DER *normal operating performance category*. The characteristic may be configured as specified by the Area EPS Operator using the values in the adjustable range.

If enabled, the Volt-Watt function shall remain active while any of the voltage-reactive power modes are enabled.

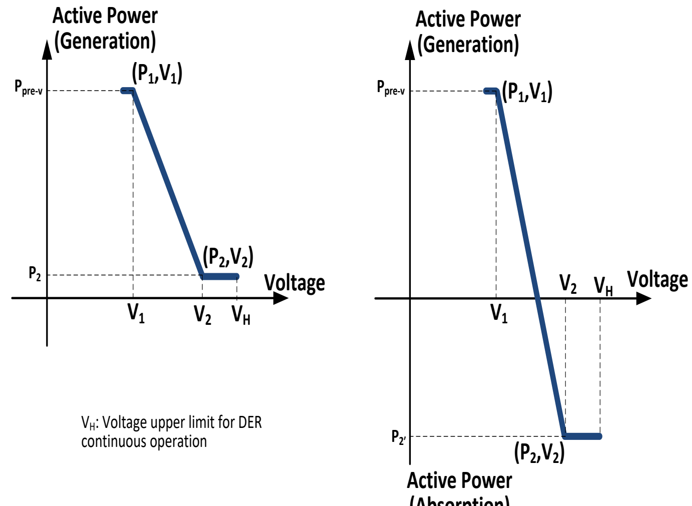

Figure 7—Example voltage-active power characteristic

Are the voltage regulation requirements proposed to be mandatory?

Voltage regulation capability is mandatory but the performance is proposed to be at the utility's discretion (The DER will provide this capability and the utility will decide to enable/disable it and choose the proper operating modes).

Impacts of IEEE 1547 on Interconnection Screens used by some utilities

- System protection (Supplemental review and full impact studies)
- Anti-islanding protection screens may need to be revised
- System DER hosting capacity
- Modeling the Advanced DER. Lack of modeling tools that are widely used by the utilities for protection and load flow studies
- ✓ Interconnection study time and cost

New Power Quality Requirements
Flicker (section 7.2.3)

Flicker- Flicker is the subjective impression of fluctuating luminance caused by voltage fluctuations.

Assessment and measurement methods for flicker are defined in IEEE1453and IEC 61000-3-7.

- EPst –Emission limit for the short-term flicker severity. If not specified differently, the Pst evaluation time is 600 s.
- EPlt – Emission limit for long-term flicker severity. If not specified differently, the Plt evaluation time is 2 h.

Table 25—Minimum Individual DER Flicker Emission Limits[a]

E_{Pst}	E_{Plt}
0.35	0.25

[a] 95% probability value should not exceed the emission limit based on a one week measurement period.

New Power Quality Requirements
Limitation of Current Distortion (section 7.3)

- Harmonic current distortion and total rated-current distortion (TRD) at the *reference point of applicability* (RPA) shall not exceed the limits stated inTable 26 and Table 27.
- The harmonic current injections shall be exclusive of any harmonic currents due to harmonic voltage distortion present in the Area EPS without the DER connected.

Table 26—Maximum odd harmonic current distortion in percent of rated current (I_{rated}) [a]

Individual odd harmonic order h	$h < 11$	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h < 50$[120]	Total rated current distortion (TRD)
Percent (%)	4.0	2.0	1.5	0.6	0.3	5.0

[a] I_{rated} = the DER unit rated current capacity (transformed to the RPA when a transformer exists between the DER unit and the RPA).

Table 27—Maximum even harmonic current distortion in percent of rated current (I_{rated}) [a]

Individual even harmonic order h	h=2	h=4	h=6	$8 \le h < 50$
Percent (%)	1.0	2.0	3.0	Associated range specified in Table 26

[a] I_{rated} = the DER unit rated current capacity (transformed to the RPA when a transformer exists between the DER unit and the RPA).

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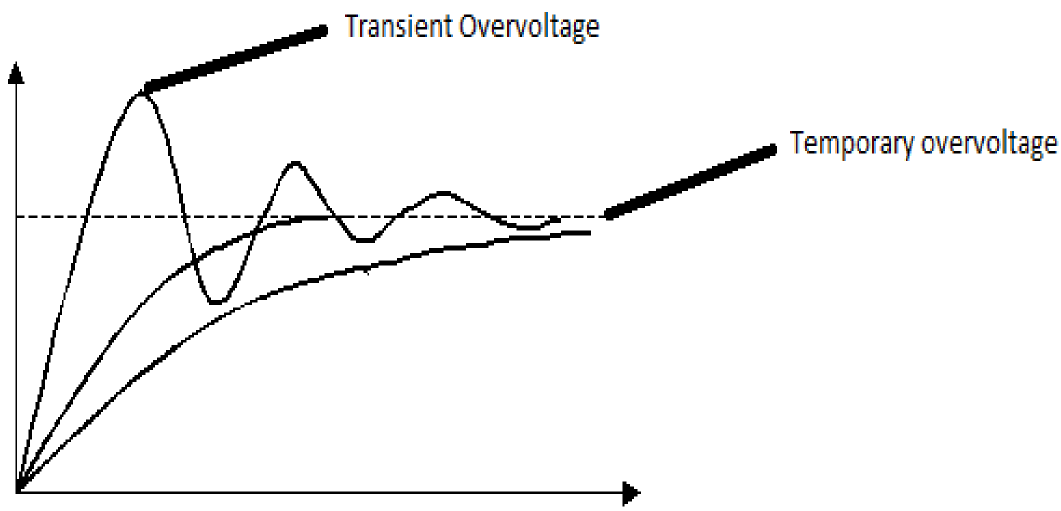
Transient vs Temporary overvoltage



New Power Quality Requirements
Limitation of Over Voltage Contribution- (section 7.4)

Limitation of over-voltage over one fundamental frequency period

The DER shall not contribute to instantaneous or RMS over voltages with the following limits:

a) The DER shall not cause the fundamental frequency line-to-ground voltage on any portion of the Area EPS that is designed to operate effectively grounded, as defined by IEEE Std C62.92.1, to exceed 138% of its nominal line-to-ground fundamental frequency voltage for a duration exceeding one fundamental frequency period.

b) The DER shall not cause the line-to-line fundamental frequency voltage on any portion of the Area EPS to exceed 138% of its nominal line-to-line fundamental frequency voltage for a duration exceeding one fundamental frequency period.

Limitation of cumulative instantaneous over-voltage

The DER shall not cause the instantaneous voltage on any portion of the Area EPS to exceed the magnitudes and cumulative durations shown in Figure 13. The cumulative duration shall only include the sum of durations for which the instantaneous voltage exceeds the respective threshold over a one-minute time window

P1547 Example New Power Quality Requirements
Over Voltage Contribution-Transient Over-voltage (TOV)

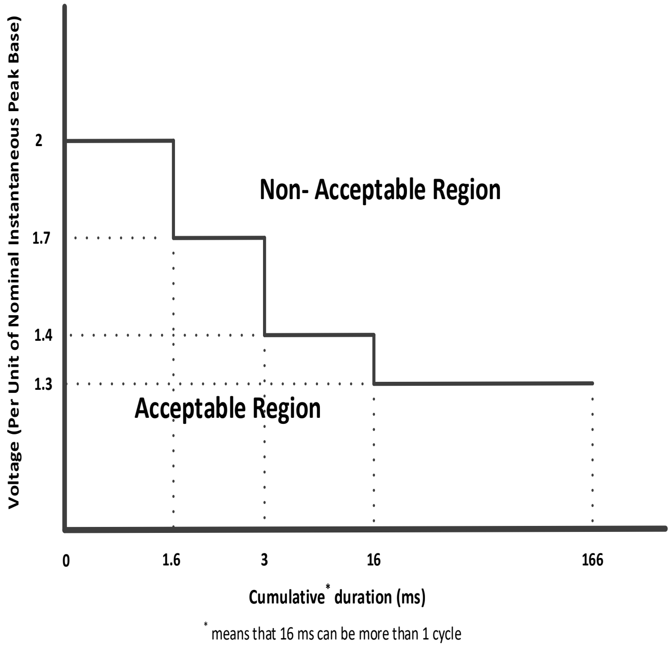
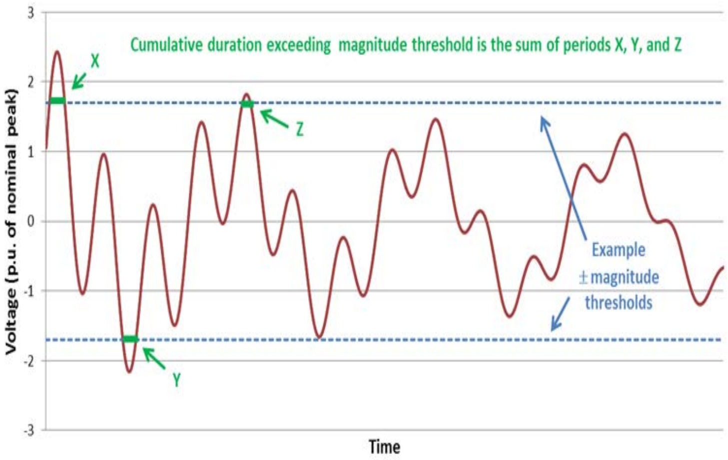


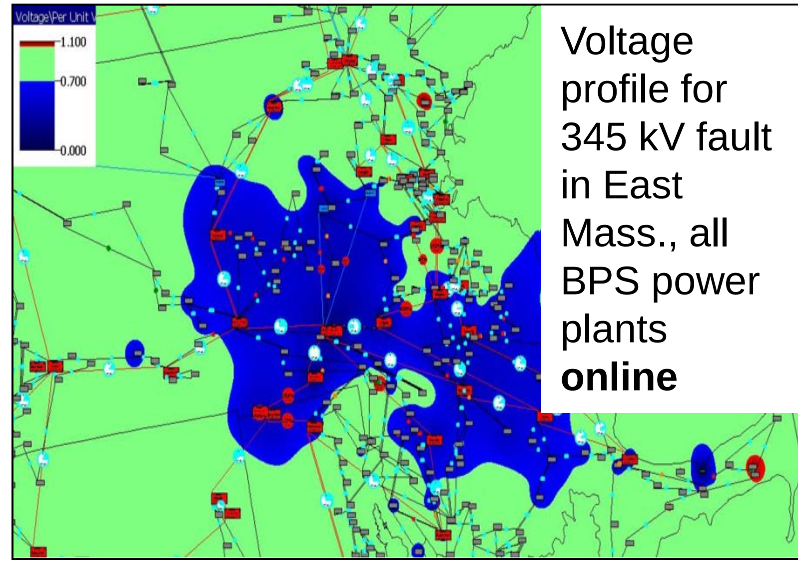
Figure 13—Transient overvoltage limits



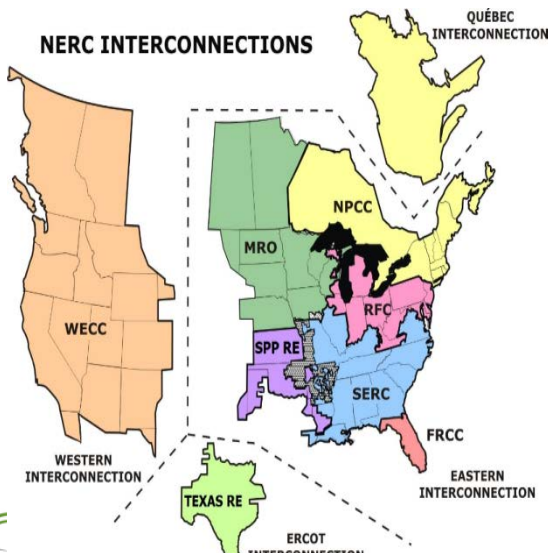
An example of the cumulative duration is provided in this figure

Driver for new ride-through requirements: Potential for widespread DER tripping

- System frequency is defined by balance between load and generation
- Frequency is similar across entire interconnection; all DER can trip simultaneously during disturbance
- Impact the same whether or not DER is on a high-penetration feeder



Source: ISO-New England



- Transmission faults can depress distribution voltage over very large areas
- Sensitive voltage tripping (i.e., 1547-2003) can cause massive loss of DER generation
- Resulting BPS event may be greatly aggravated

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Abnormal Performance Categories

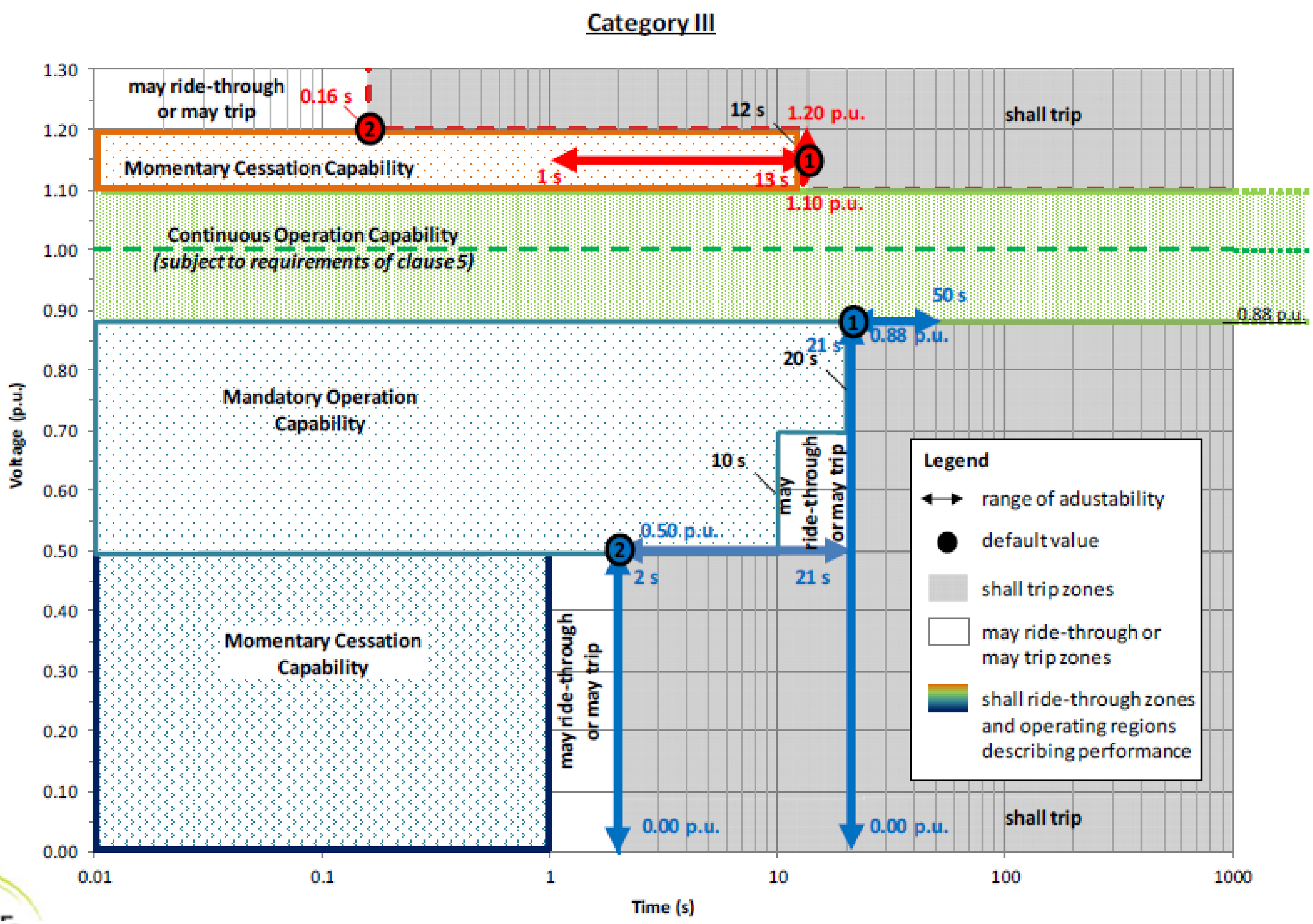
Category	Objective	Foundation
I	Essential bulk system needs and reasonably achievable by all current state-of-art DER technologies	German grid code for synchronous generator DER
II	Full coordination with bulk power system needs	Based on NERC PRC-024, adjusted for distribution voltage differences (delayed voltage recovery)

Category II and III are sufficient for bulk system reliability.

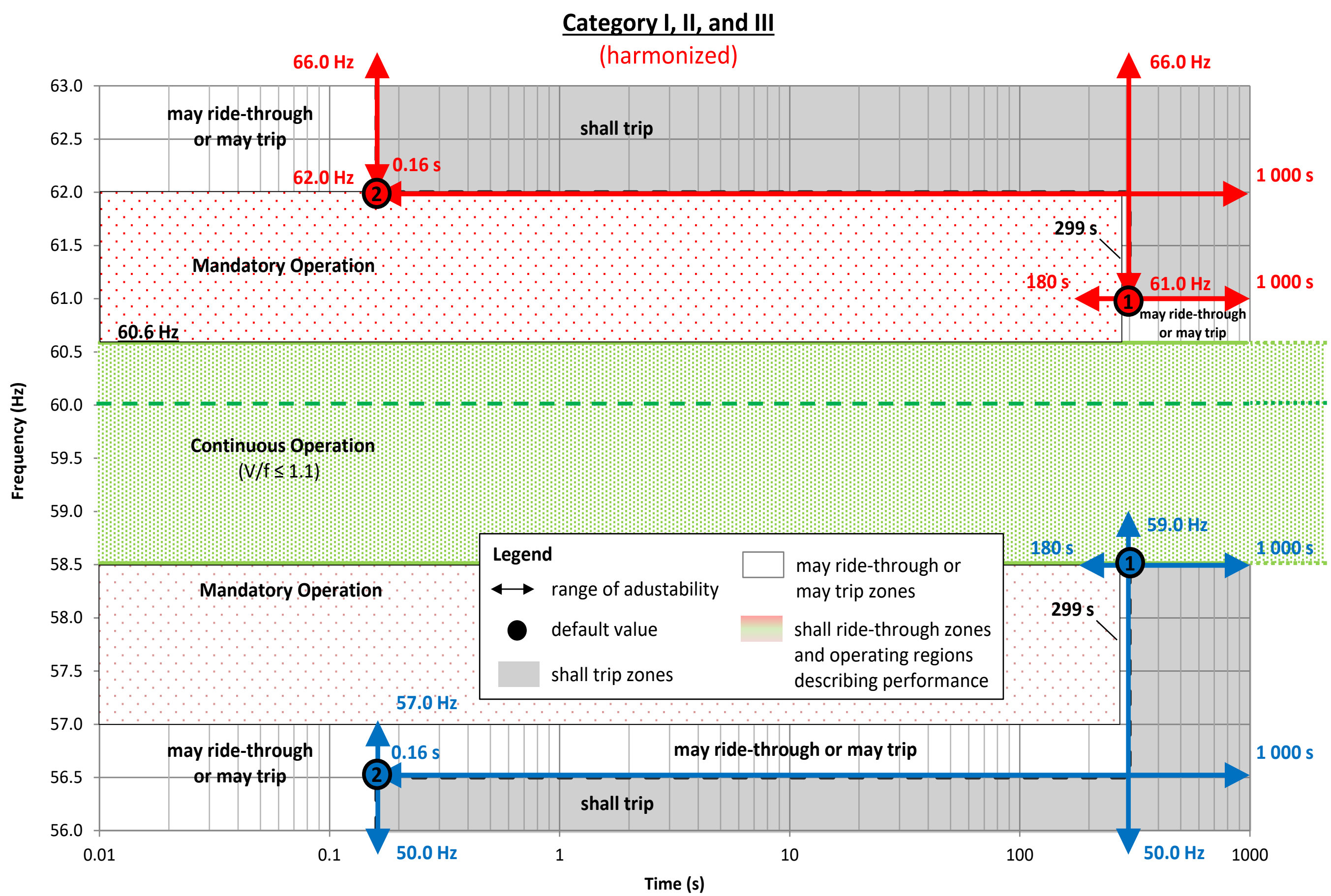
Clarification of “Cease to Energize”

- **Cease to energize**
  - Refers to Point of DER Connection (PoC) of individual DER unit(s)
  - No active power delivery
  - Limitations to reactive power exchange
  - Does not necessarily mean physical disconnection
  - Used either for *momentary cessation* or *trip*

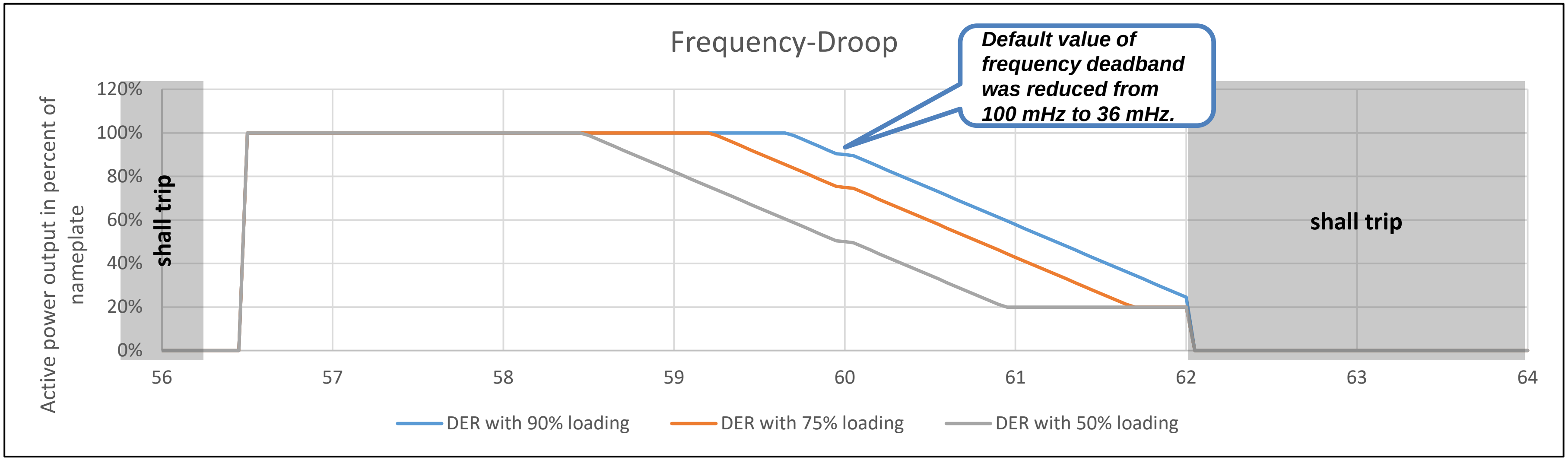
1547 Example of New Requirements for Voltage Ride- Through



1547 Example New Requirements for frequency Ride Through



Frequency Support

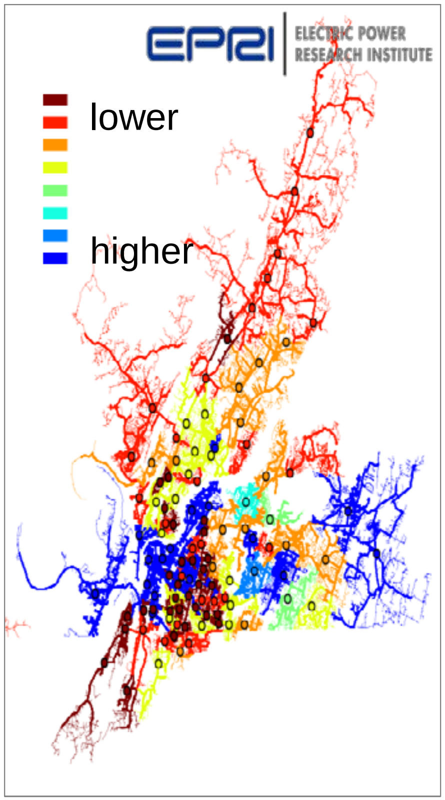


- Overfrequency: all DERs required to provide droop response
- Underfrequency: Cat II and III DERs required to provide droop response *if power is available*
- Only a functional capability requirement
  - Utilization remains outside the scope of IEEE 1547-2018
- Adjustable dead bands and droop
- Response time requirements (not “as fast as technically possible”)

Application of revised IEEE P1547

Example: Specify grid-specific voltage control settings to increase "hosting capacity".

Hosting Capacity



Factors impacting hosting capacity:

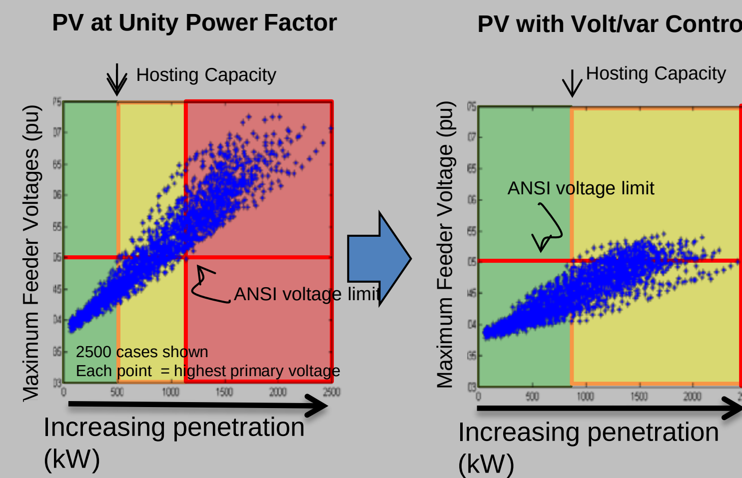
- Feeder Design and Operation
- DER Location
- DER Technology
  - Variable vs. non-variable generation
  - Synchronous vs. inverter-based
  - Traditional vs. advanced inverters

Criteria evaluating hosting capacity:

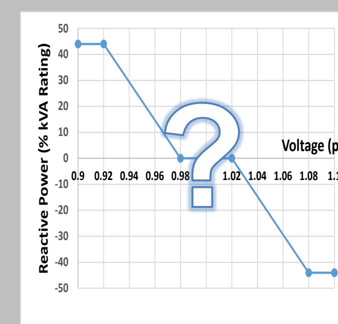
- Power quality/voltage
- Thermal overload
- Protection
- Reliability/Safety

Refer to 3002008848 for more info.

Voltage-Reactive Power Control



- Increase hosting capacity
  - by addressing voltage issues with exchange of reactive power.
  - may require feeder-specific settings.



TOP 5 concerns of distribution grid planners, operators, and line workers

- "Cease to energize" with or without galvanic separation?
- Unintentional islanding risk with DERs that ride through disturbances and regulate voltage and/or frequency.
- DER coordination with Area EPS automatic reclosing.
- DER coordination with Area EPS protection.
- DER impact on line workers' safety during hot-line maintenance.

Specify **tests** in IEEE P1547.1

Address in DER interconnection practices via **screening**

➢ ***Feel free to share your own questions and concerns now…***

Communication Requirements

- A DER shall have provisions for an interface capable of communicating (local DER communication interface) to support the information exchange requirements specified in this standard for all applicable functions that are supported in the DER.
- Under mutual agreement between the Area EPS Operator and DER Operator additional communication capabilities are allowed.
- The decision to use the *local DER communication interface* or to deploy a communication system shall be determined by the Area EPS operator.

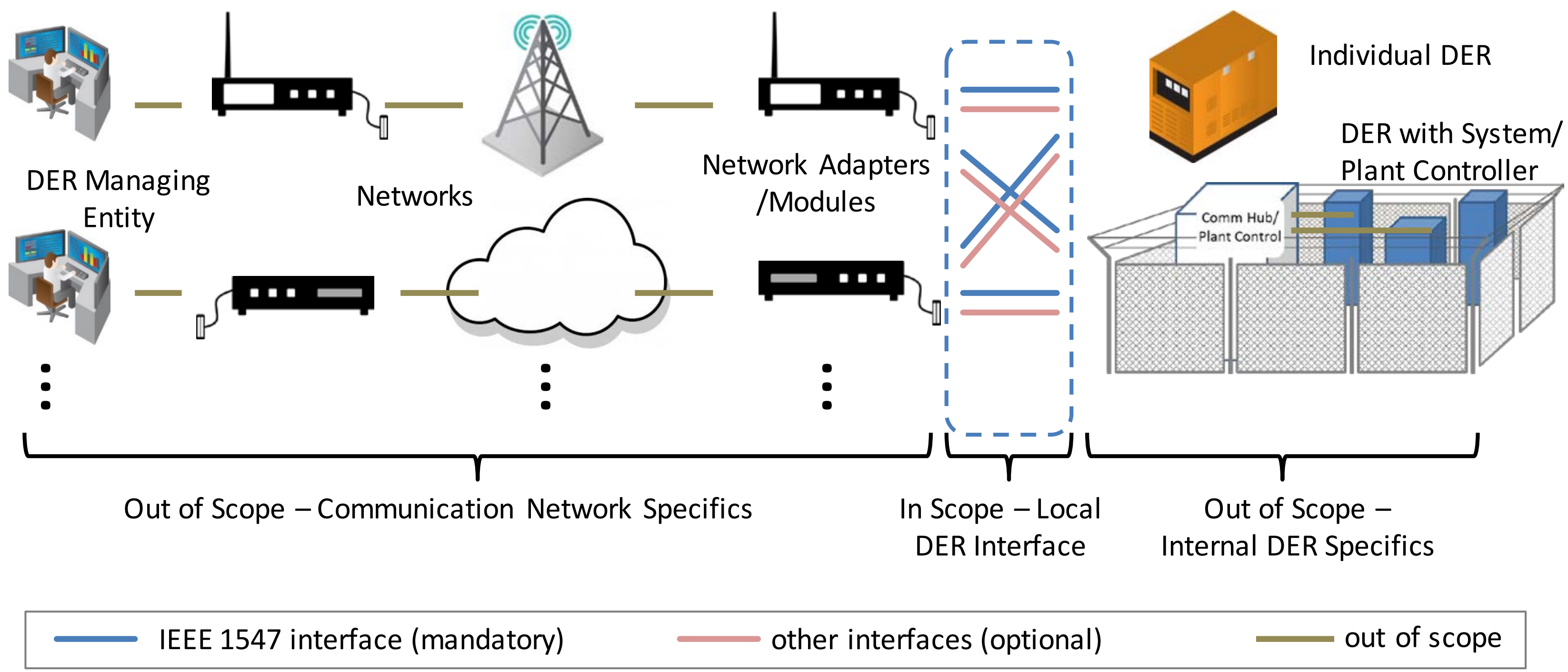
Information Categories

- Information to be exchanged:
  - Nameplate Data – As-built characteristics of the DER.
  - Configuration Information – Each rating in Nameplate Data may have a configuration setting.
  - Monitoring Information – Latest value measured.
  - Management information – This information is used to update functional and mode settings for the DER.

Management Information

- Constant power factor mode parameters
- Voltage-Reactive power mode parameters
- Active power-reactive power mode parameters
- Constant reactive power mode parameters
- Voltage-active power mode parameters
- Voltage trip and momentary cessation parameters
- Frequency trip parameters
- Frequency droop parameters
- Enter service parameters
- Cease to energize and trip
- Limit Maximum active power

Scope of Interoperability Requirements



List of Eligible Protocols

Protocol	Transport	Physical Layer
IEEE Std 2030.5™ (SEP2)	TCP/IP	Ethernet
IEEE Std 1815™ (DNP3)	TCP/IP	Ethernet
SunSpec Modbus	TCP/IP	Ethernet
	N/A	RS-485

Massachusetts Solar Phase II

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Background – Solar Phase I

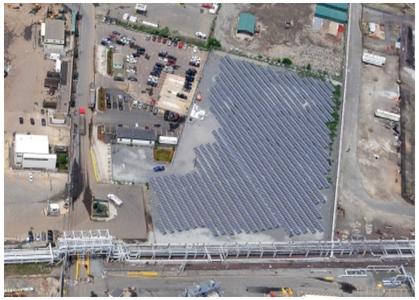
- Received approval from Department of Public Utilities (DPU) in 2009 to <u>own and operate Solar</u>
- Six separate sites for a total of approximately five megawatts of solar generation.
  - Dorchester 1250kW
  - Everett 605kW
  - Haverhill 1016 kW
  - Revere 750 kW
  - Sutton 983 kW
  - Waltham 225 kW
- Cost recovery mechanism to allow recovery when unit goes into service

Background – Solar Phase I

Additional Site Information : https://www.nationalgridus.com/masselectric/solar/

Waltham – 225 kW

Sutton – 983 kW



Everett – 605 kW

Revere – 750 kW

Dorchester – 1250 kW

Haverhill – 1016 kW

Background – Solar Phase II Proposal

- Phase II – Up to 20 MW of Company-owned solar,
  - Company or third party-owned property (NG still owns solar)
  - Estimated Capital Cost U$85M (mid-point) - $4.2 / W
  - **Company to retain SRECs** to meet its RPS requirements
  - Begin construction on Spring 2015
  - Introduce the concept of targeted deployment for system improvement
  - Includes "Advanced" Inverter Functionality (R&D)

- Active/Reactive Power Control (Voltage and frequency regulation)
- Power Factor Control
- Ramp Rate Control
- Under/Over Voltage and Frequency ride through
- The inverter must be capable of remote start/stop

Solar goal in MA: Increase levels of PV penetration

1.6 GW of PV by 2020

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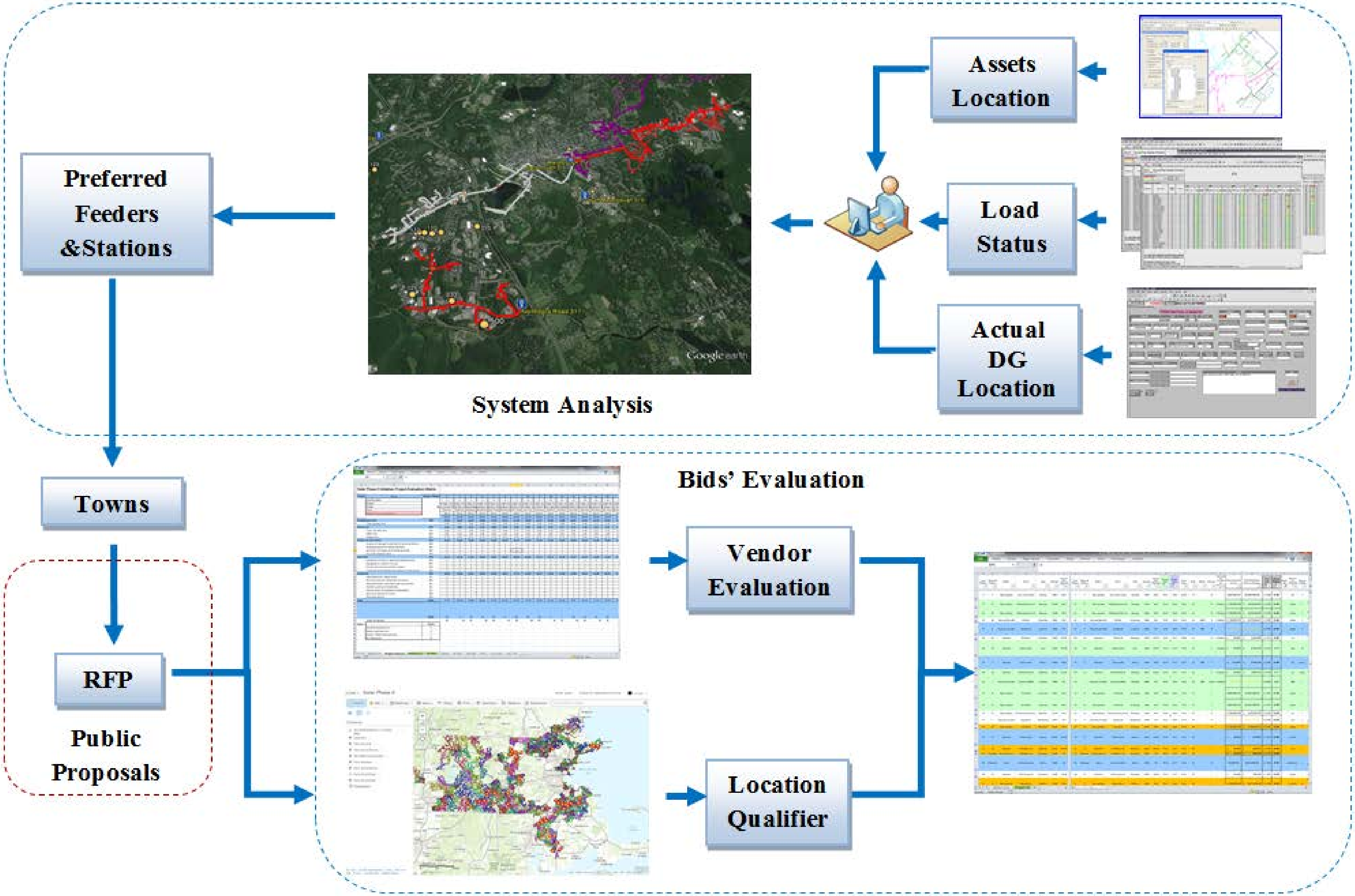
Background – Solar Phase II - DPU Approval

DPU found the Solar Phase II program consistent with MA energy policy and is in the public interest

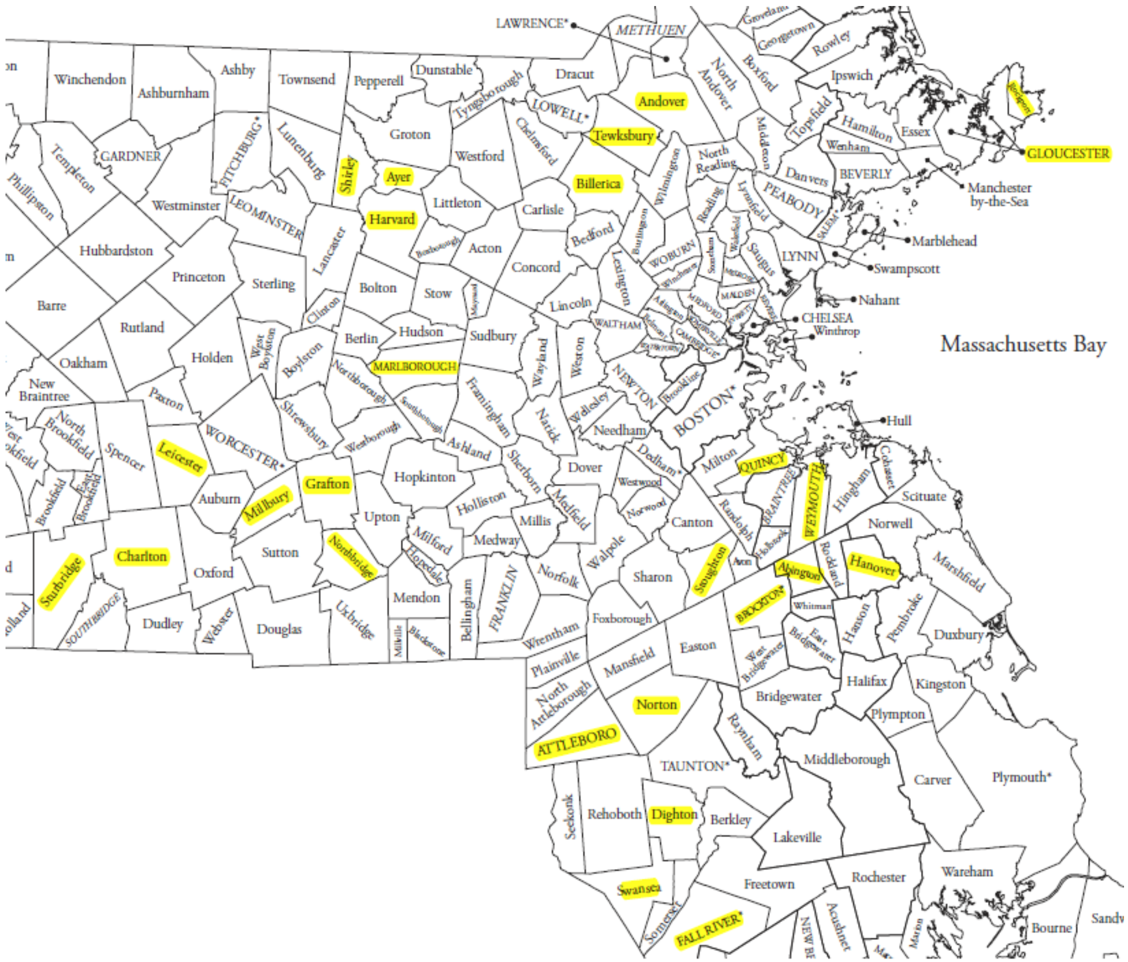
- DPU imposed a Cost Cap of $97.6M
  - $84.86M Capital
  - $12.74M (for Lease & Property Taxes)
  - Equal to $4.2M per MW
  - Annual O&M is independent of the cost cap

- Cost recovery filing once projects are in-service

Selection Methodology – Targeted Deployment Process



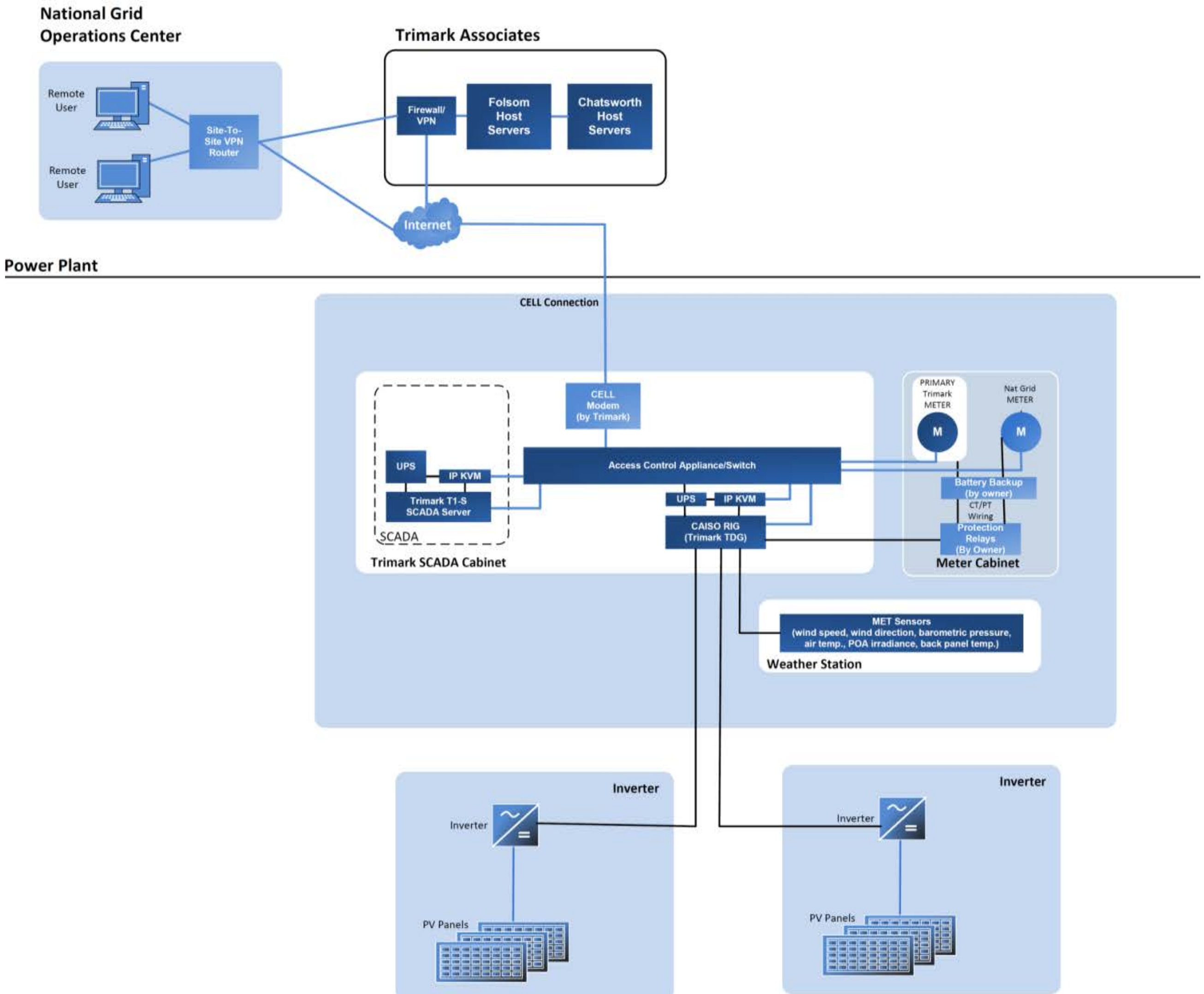
Selection Methodology – Targeted Deployment - Towns



Equipment – Inverters' "Advanced" functions

Functionality	Modes	Description
Active Power Control	Real Power Curtailment	Ability to limit the active power production of the PV site to a value below its potential
	Ramp Rate Control	Ability to limit the rate of change in magnitude of active power supplied
	Frequency Droop Response	Ability to curtail Active Power during higher than normal frequency at the PCC
	Power factor compensation - Power factor/active power characteristic curve PF(P)	Ability to establish a Power Factor level at the PCC based on actual Active Power production
Reactive Power Control	Fixed Power Factor: PF_{fixed}	Ability to maintain a power factor at the PV site's PCC by changing reactive power injection (under the right conditions)
	Fixed Reactive Setpoint: Q_{Fixed}	Ability to inject a fixed amount of reactive power (percentage of nameplate) at the PCC (under the right conditions)
	Voltage Compensation - Reactive power/voltage characteristic curve Q(U)	Ability to inject Reactive Power at the PCC based on actual Voltage level

Equipment – Control and Communication System

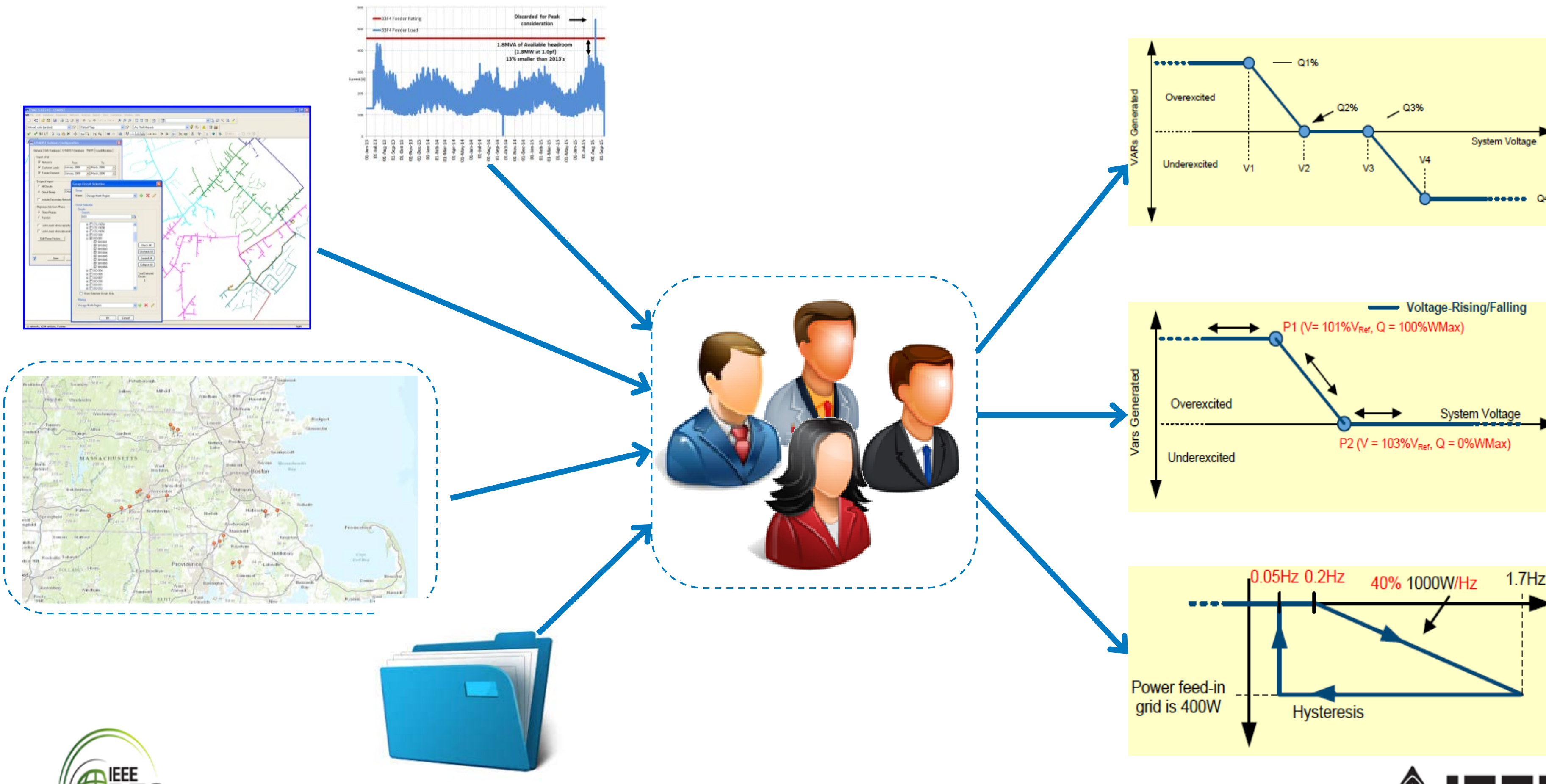


Characteristics:

- Not integrated into NG EMS (for now)
- Uses secure cellular communication
- Provides full remote control (including scheduling of parameters change)
- Provides flexibility for integration of external devices
- Easy to use interface with different levels of access

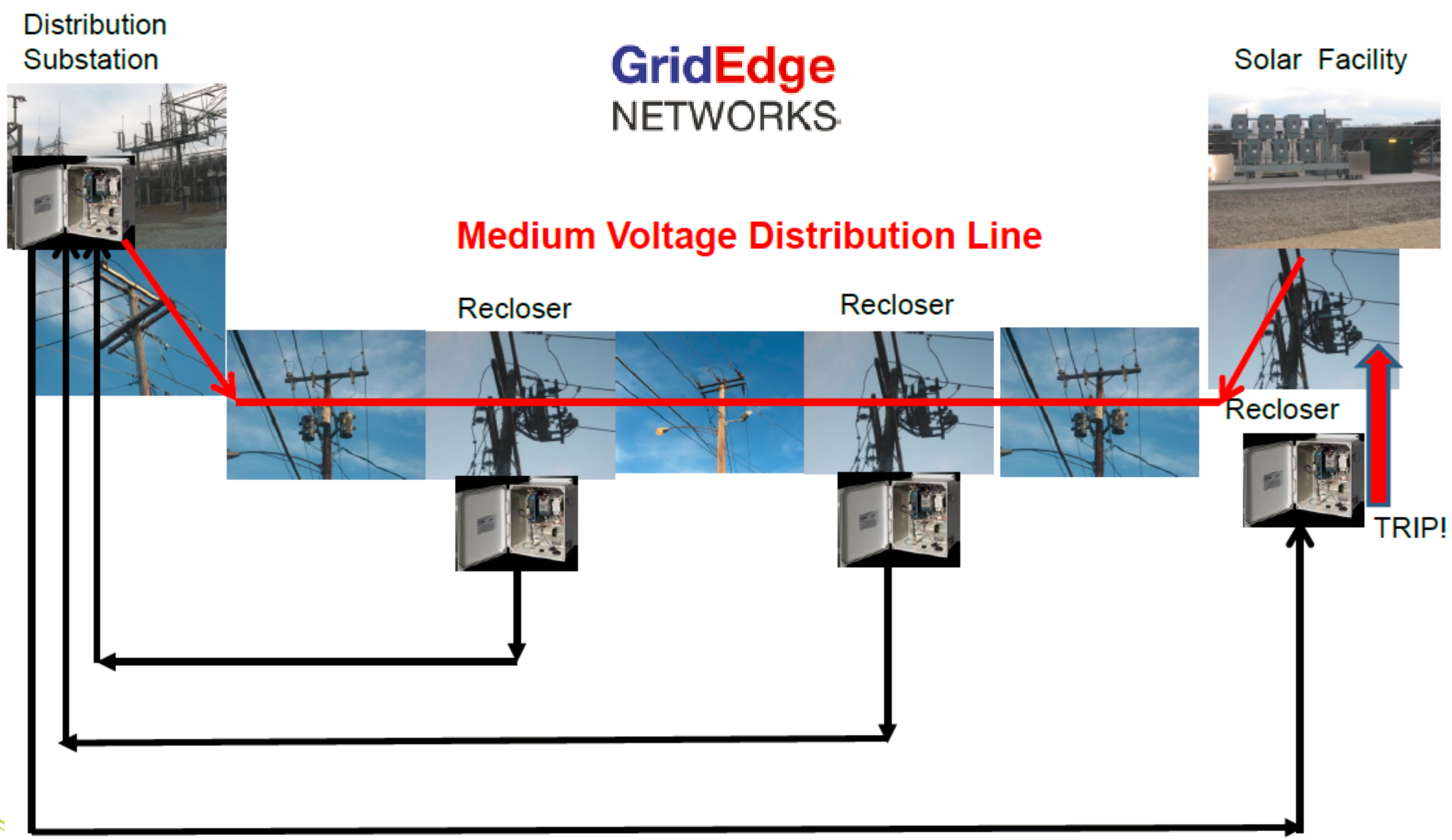
Set up Methodology – Configuration

- Each site will require specific configuration settings based on the operational conditions in the area and the “purpose” of the site



Testing Methodology - Additional technology

- Power Line Carrier as an alternative to conventional DTT scheme for Anti-Islanding protection



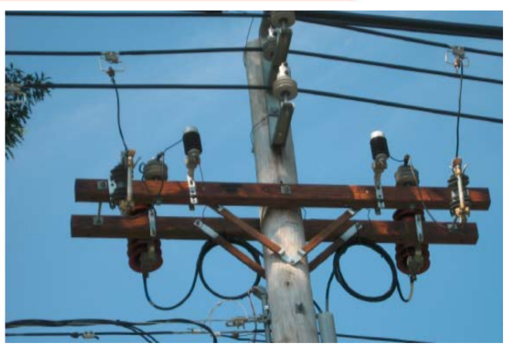
Testing Methodology - Additional technology

- 2 Feeders selected (3 sites) – Snow St 413L2 and 413L4

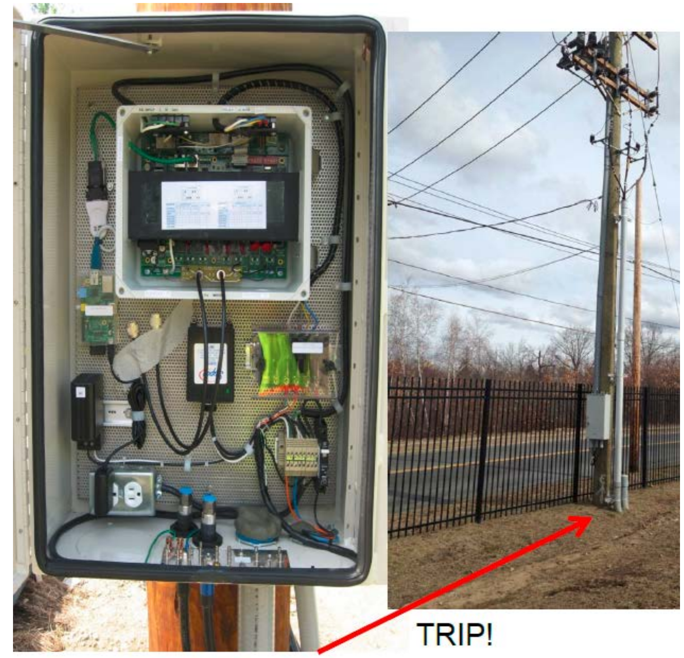
Recloser control cable can be shielded copper or fiber

Transmitter

Underground control cable



Signal Regenerator

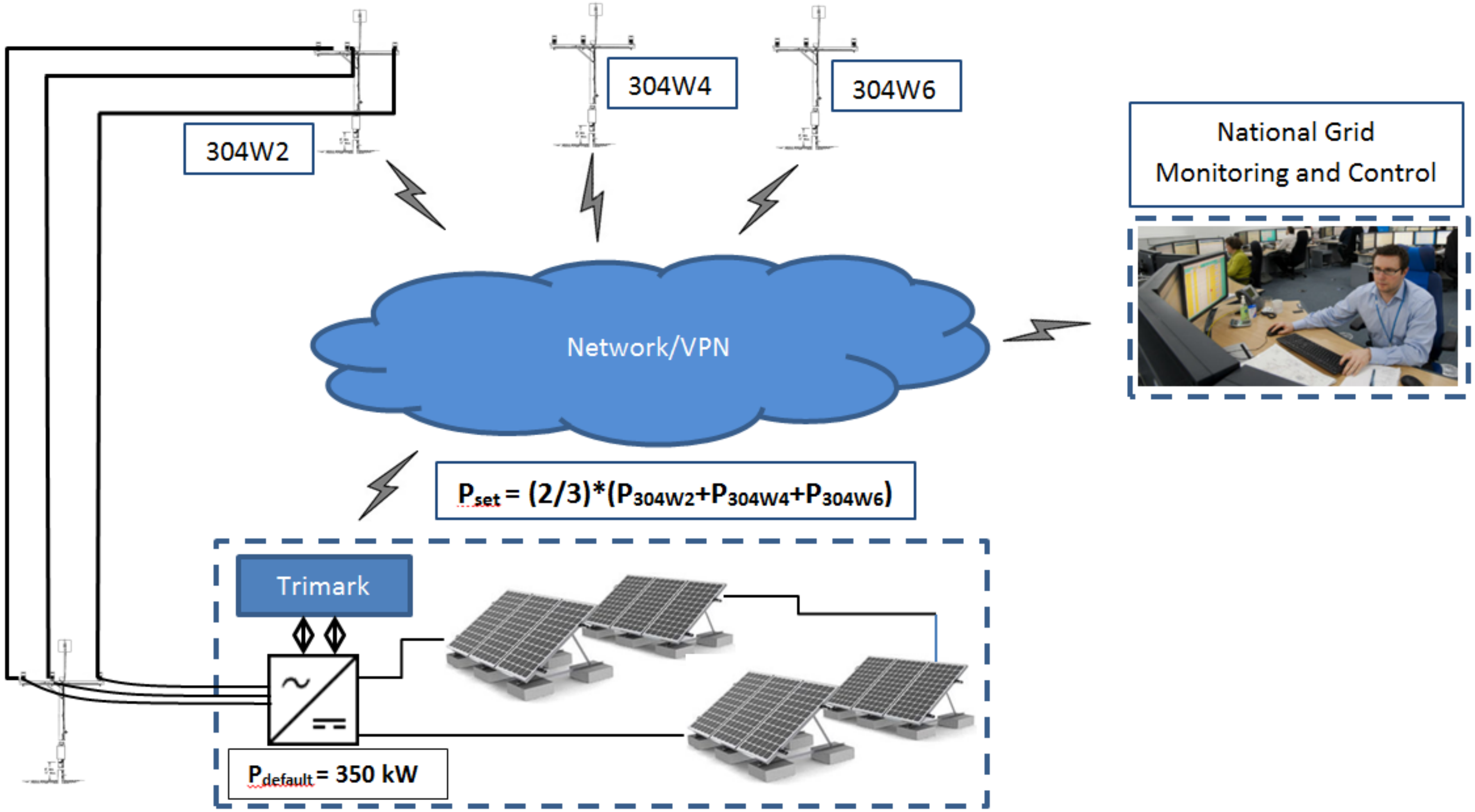


TRIP!

Receiver

Testing Methodology - Additional technology

Dynamic Active Power curtailment to avoid reverse power flow at the station, if the generator owner does not pay for the station upgrades due to station backfeed.



Testing Methodology - Additional technology

- Battery Storage
  - Used to further reduce the impact of variable or intermittent generation
  - Has the potential to be used to intentionally de-rate systems to avoid interconnection costs (already proposed by a developer)
  - Provide support to the system during certain scenarios

500kW/1MWh	Phase II Solar
Initial Cost	$900k
Partnership with DOE	Yes – 50/50 cost share
ITC	Yes – 30%
Town Interaction	Yes – Town of Shirely
Added Value	Yes – Ties in with Solar
Other Offers	Responded to FOA w/ DOE & MA CEC
Risk	Medium - (Was not in original

Above: [illegible] Stationary Storage System

Smart inverter setting levels

Methods to determine smart inverter settings

Level	Complexity	Power Factor	Volt-Var
0	None	Unity Power Factor	Disabled, Unity Power Factor
1	Low	Based on Feeder X/R Ratio	Generic Setting
2	Medium	Based on Feeder Model and PV Location	Based on Feeder Model and PC Location
3	High	Based on Feeder Model, PV Location and Service Transformer Impedance	Based on Feeder Model, PV Location, and Service Transformer Impedance

Power factory setting-level 3

1. Conduct a short-circuit analysis to determine resistance (R) and reactance (X) to the primary node of the PV site point of interconnection.
2. Adjust the X/R ratio for the PV site interconnect transformer resistance (Rxfmr) and reactance (Xxfmr):

$$\left(\frac{X}{R}\right)_{adjusted} = \frac{X}{R} + [(\mathrm{R}_{xfmr}) + \frac{X}{R}(X_{xfmr})]\sqrt{1 + \left(\frac{X}{R}\right)^2}$$

3. Calculate the PV site power factor using the adjusted X/R

$$Powerfactor = \frac{\left(\frac{X}{R}\right)_{adjusted}}{\sqrt{\left(\left(\frac{X}{R}\right)_{adjusted}\right)^2 + 1}}$$

4. Adjust PV site power factor for additional DER on the feeder:

a. Use the full power flow model with DER interconnection transformers to simulate and observe the potential voltage change at the proposed PV site

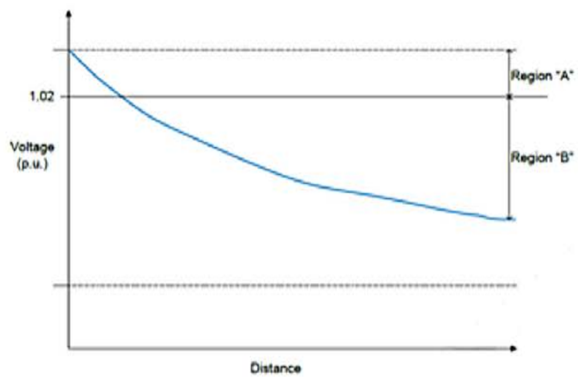
b. Calculate the reactive power needed to mitigate the voltage change at the PV site.

c. The additional amount of reactive power needed is used to adjust the PV site power factor setting.

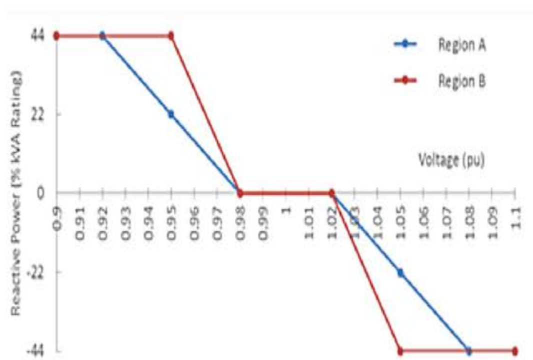
5. If the power factor calculated in step 3 is less than 0.9, limit it to 0.9.

Volt-VAR setting

- Procedure A: If the maximum feeder voltage without DER during all load conditions is greater than 1.02 Vpu, the site-specific volt-var settings are based on the voltage at the DER site and the corresponding regions shown in Figure below. The idea is that nodes with high voltages may be near the head of the feeder, where benefit from reactive power is minimal, while the locations with lower voltage usually have higher impedance and can benefit more from additional reactive power.
- Procedure B: If the maximum feeder voltage without DER during all load conditions is less than 1.02 Vpu, the site-specific volt-var settings are adjusted such that the upper deadband voltage (VUDB) is reduced to the maximum feeder voltage but limited to 1.0 Vpu to maintain a minimum 2% volt-var deadband.



Voltage Profile



Volt-var Setting

Volt-VAR settings

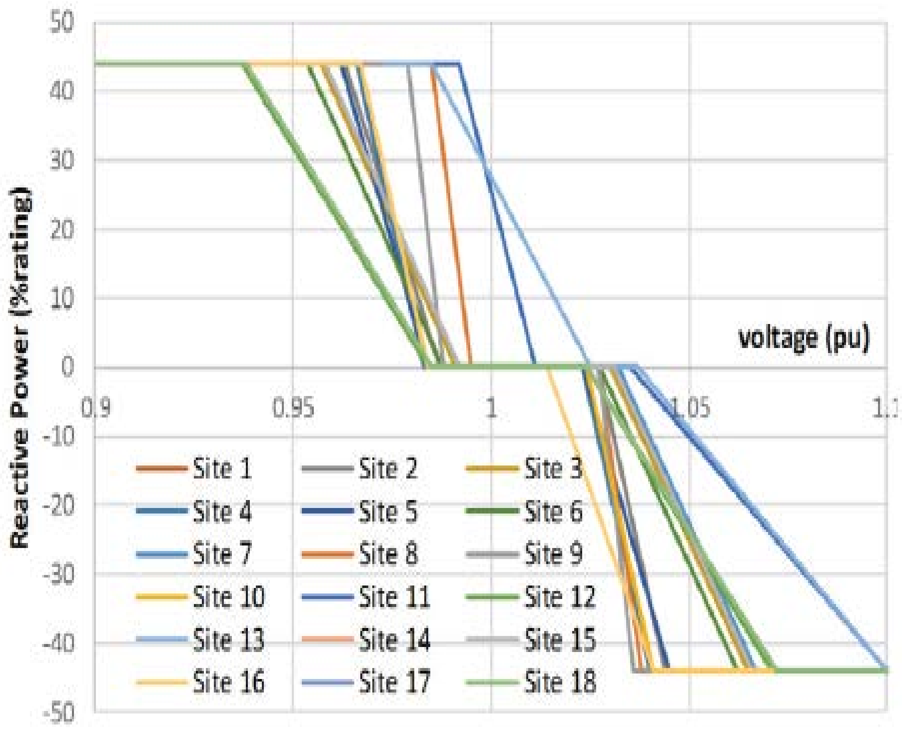
The final adjustment to the Level 3 volt-var settings is applied to consider the interconnect transformer. The primary voltage level volt-var setting is transferred over the interconnection transformer resistance (Rxfmr) and reactance (Xxfmr) by modifying each of the volt-var points considering full PV active power (Pgen) and the voltage/reactive power (V/Qgen) shown at each volt-var point using:

$$V_{new} = \mathrm{V} + \frac{P_{gen}}{V} * R_{xfmr} + \frac{Q_{gen}}{V} * X_{xfmr}$$

Volt/VAR settings of all PV sites

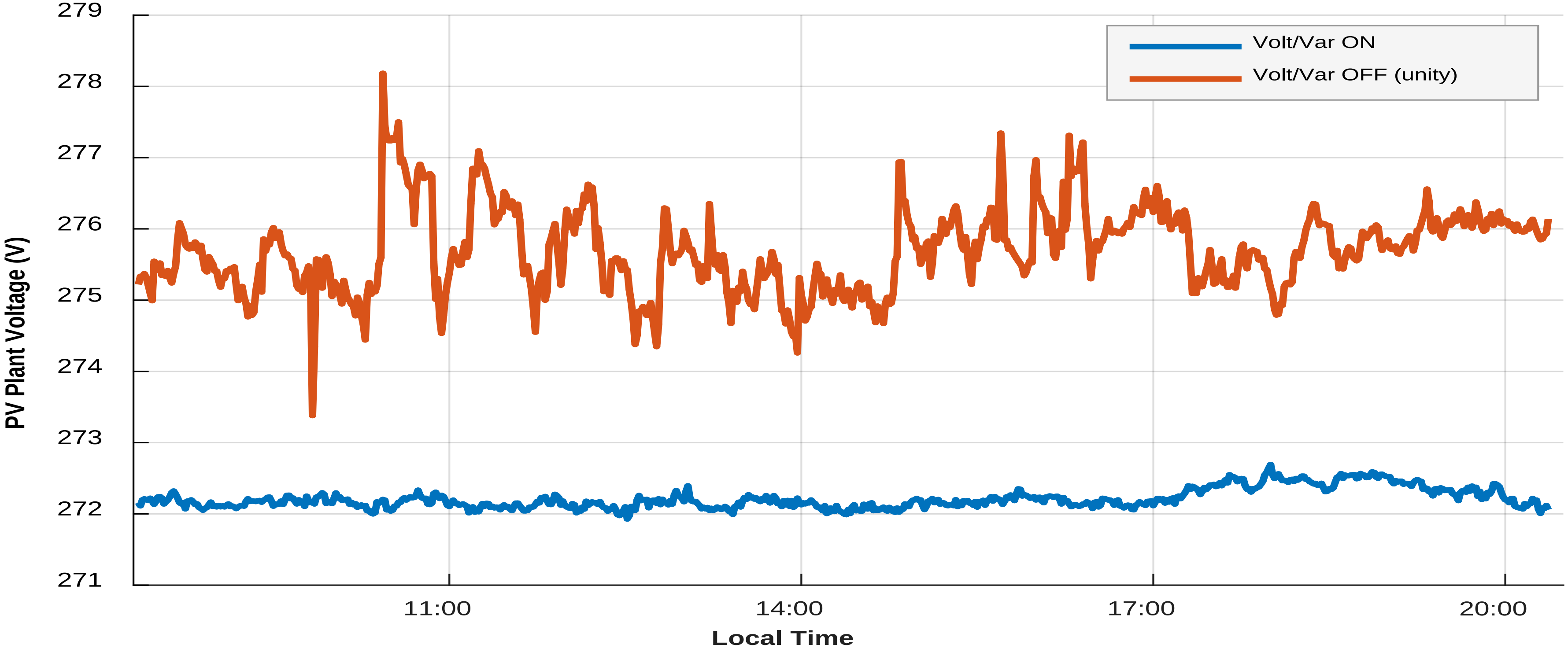
Site #	Power Factor
1	0.94
2	0.94
3	0.90*
4	0.90*
5	0.90*
6	0.99
7	0.99
8	0.95
9	0.97
10	0.98
11	0.99
12	0.94
13	0.90*
14	0.98
15	0.90*
16	0.95
17	0.98
18	0.98

b)



Value of Volt/VAR

- Demonstrated the benefits that smart Inverters can provide to the distribution grid.



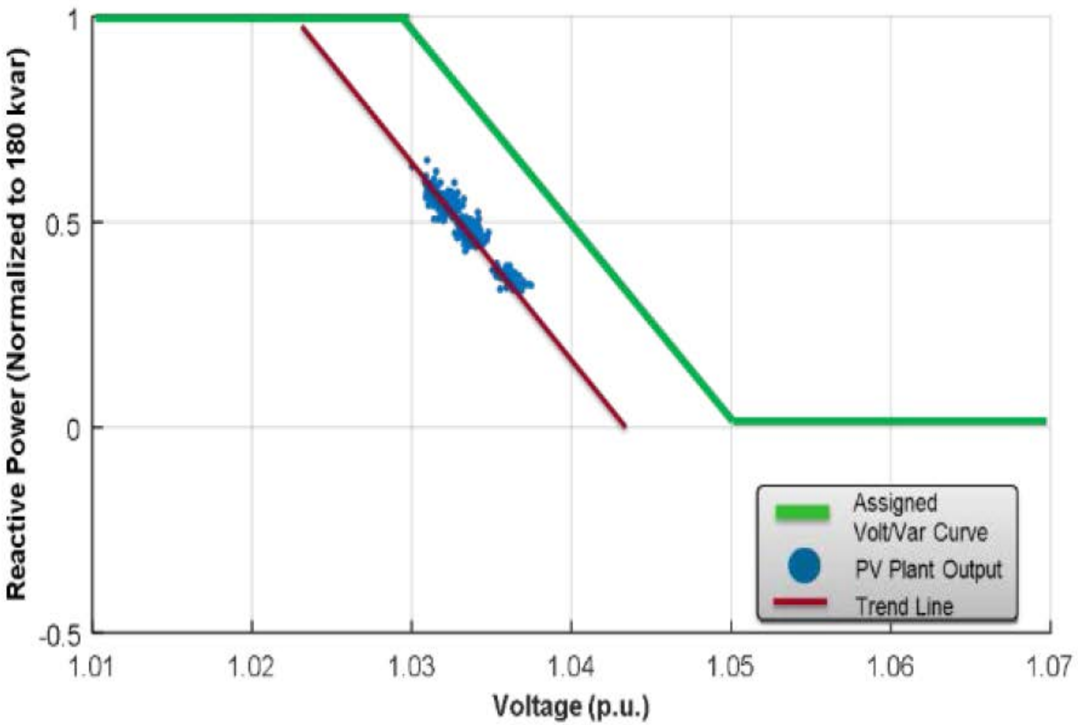
Smart Grid Ready PV Inverters with Utility Communication: Results from Field Demonstrations, EPRI 2016

http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002008557

Voltage at the Point of Common Coupling (PCC)

- Inverters react to the output voltage at their terminals.

- For utilities the Voltage at the PCC is of higher value.

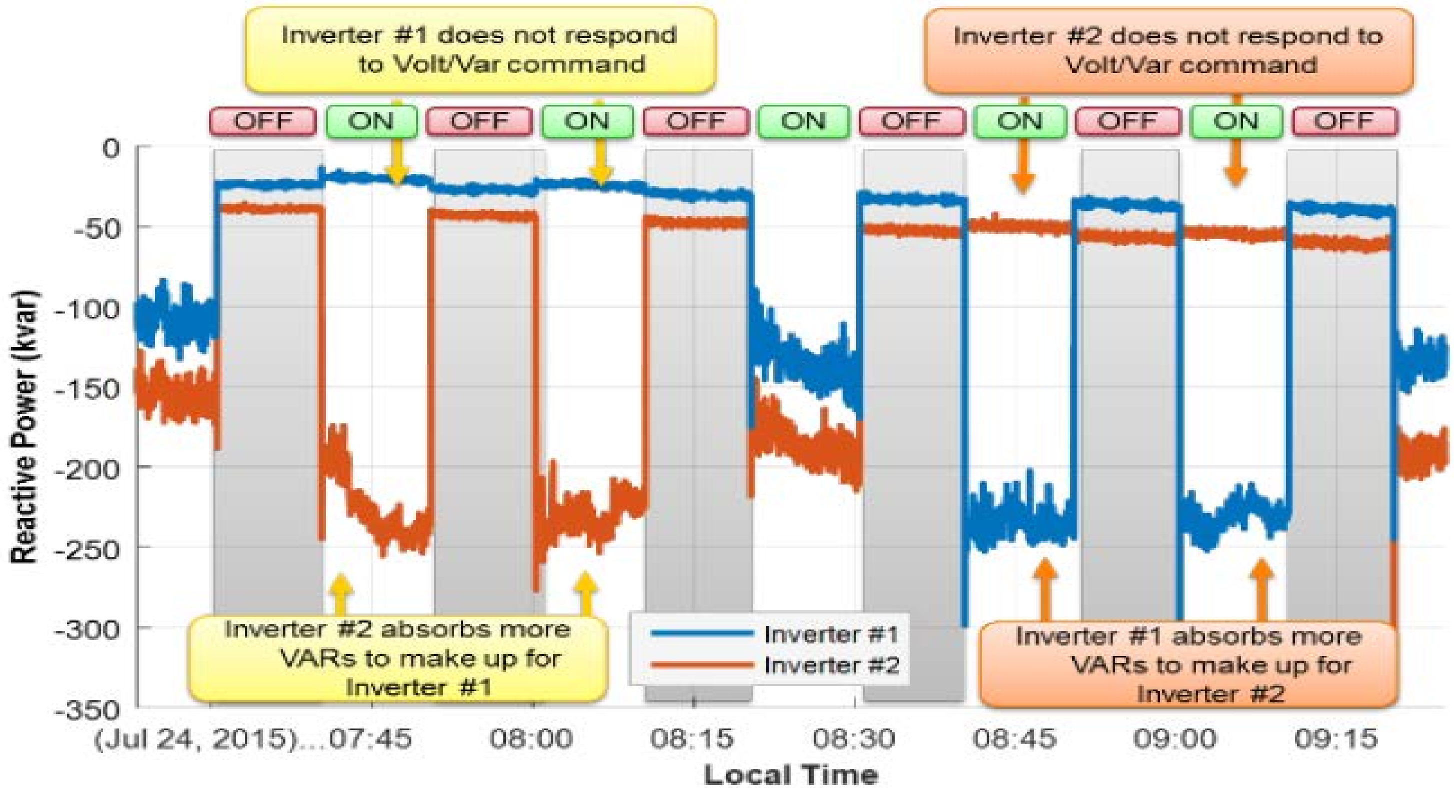


Smart Grid Ready PV Inverters with Utility Communication: Results from Field Demonstrations, EPRI 2016

http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002008557

Expect Communication Issues

- New projects require that in the case of a communication fault that the system revert to a default command set.



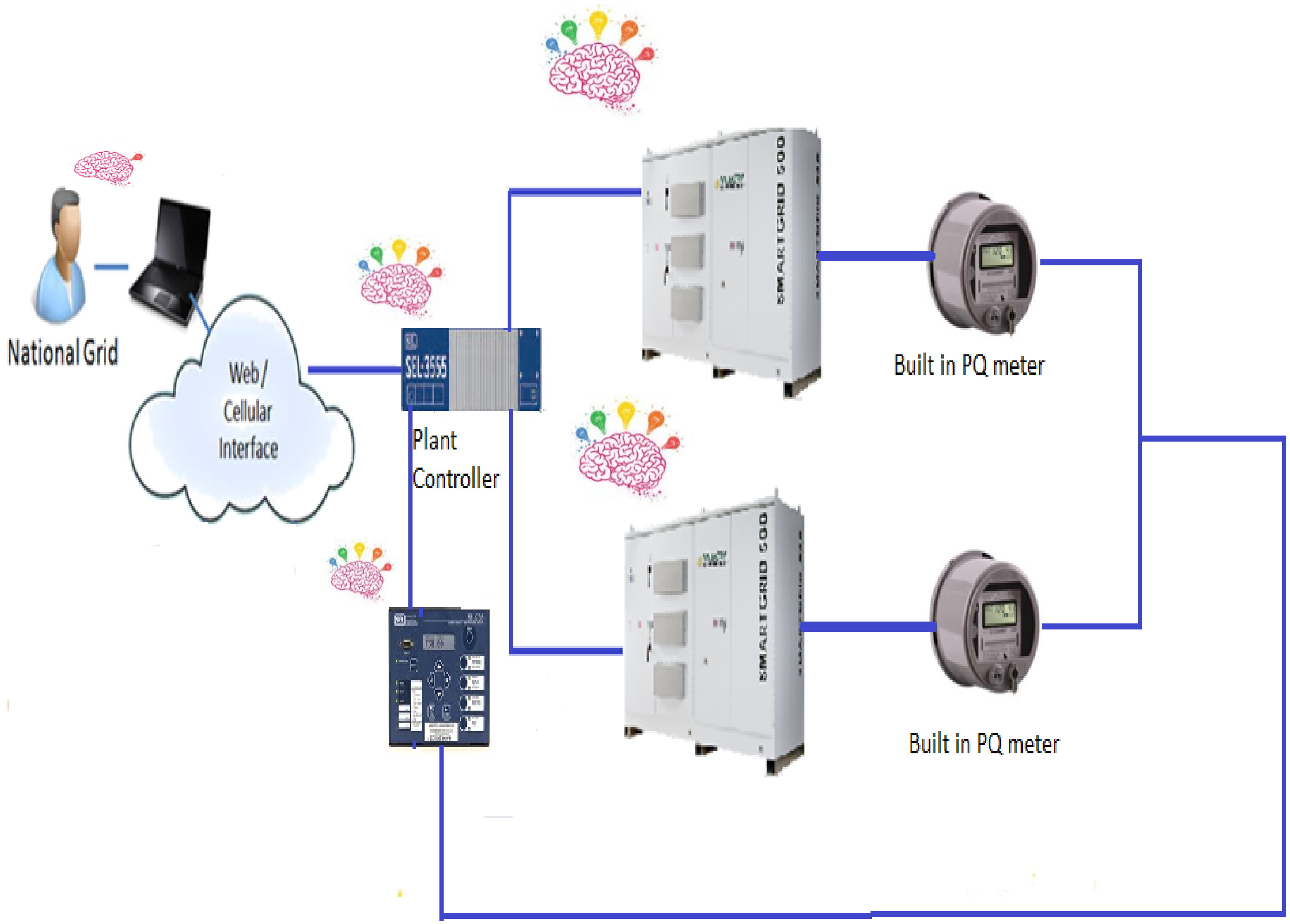
Smart Grid Ready PV Inverters with Utility Communication: Results from Field Demonstrations, EPRI 2016

http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002008557

Never Test in the New England Winter

National Grid Haverhill PV site

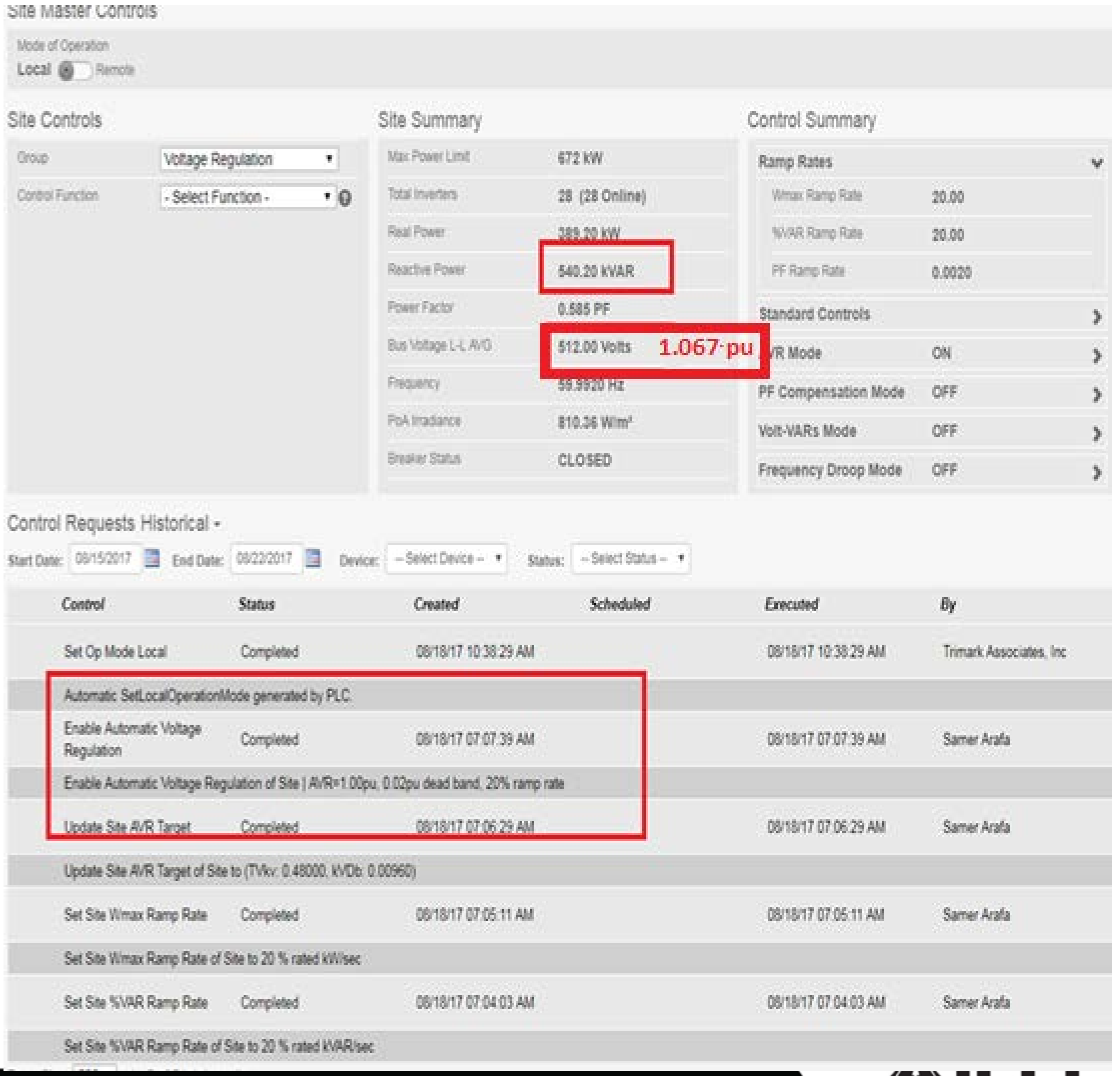
Solar Phase II



- Plant Controller continuously talking to PQ meter and PV inverter.
- Plant Controller translates grid conditions into fixed VAR, Fixed Watt or Fixed PF commands.
- PQ meter connected to Plant Controller Voltage accuracy $\pm$ 1%.

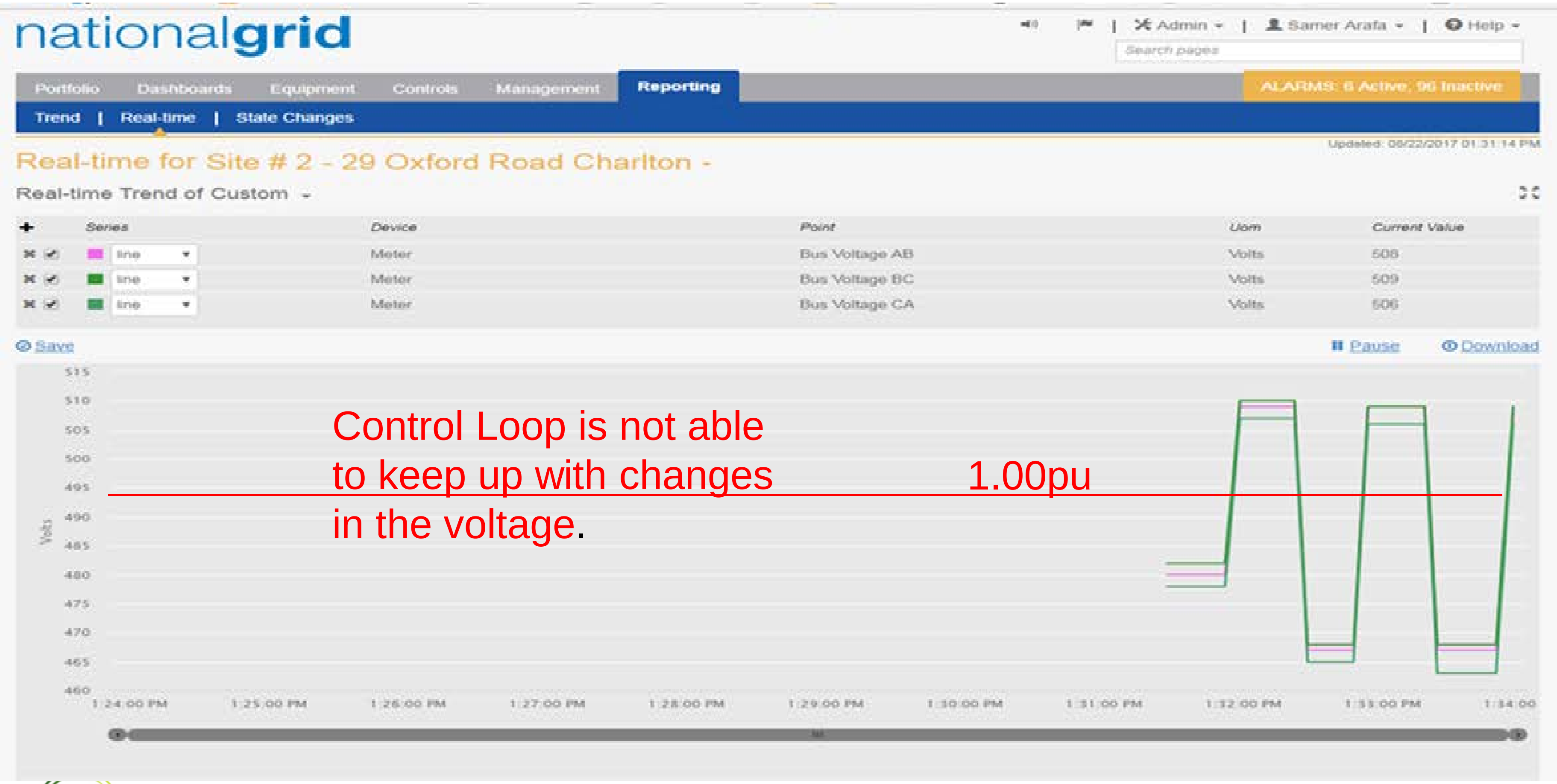
What Can Go Wrong?

- On the right is an example of a controller that is attempting to regulate the voltage at 1.00 pu.
- The end result is the Inverter injecting VAR and further bringing up the voltage despite the Voltage being above 1.00pu at the time.

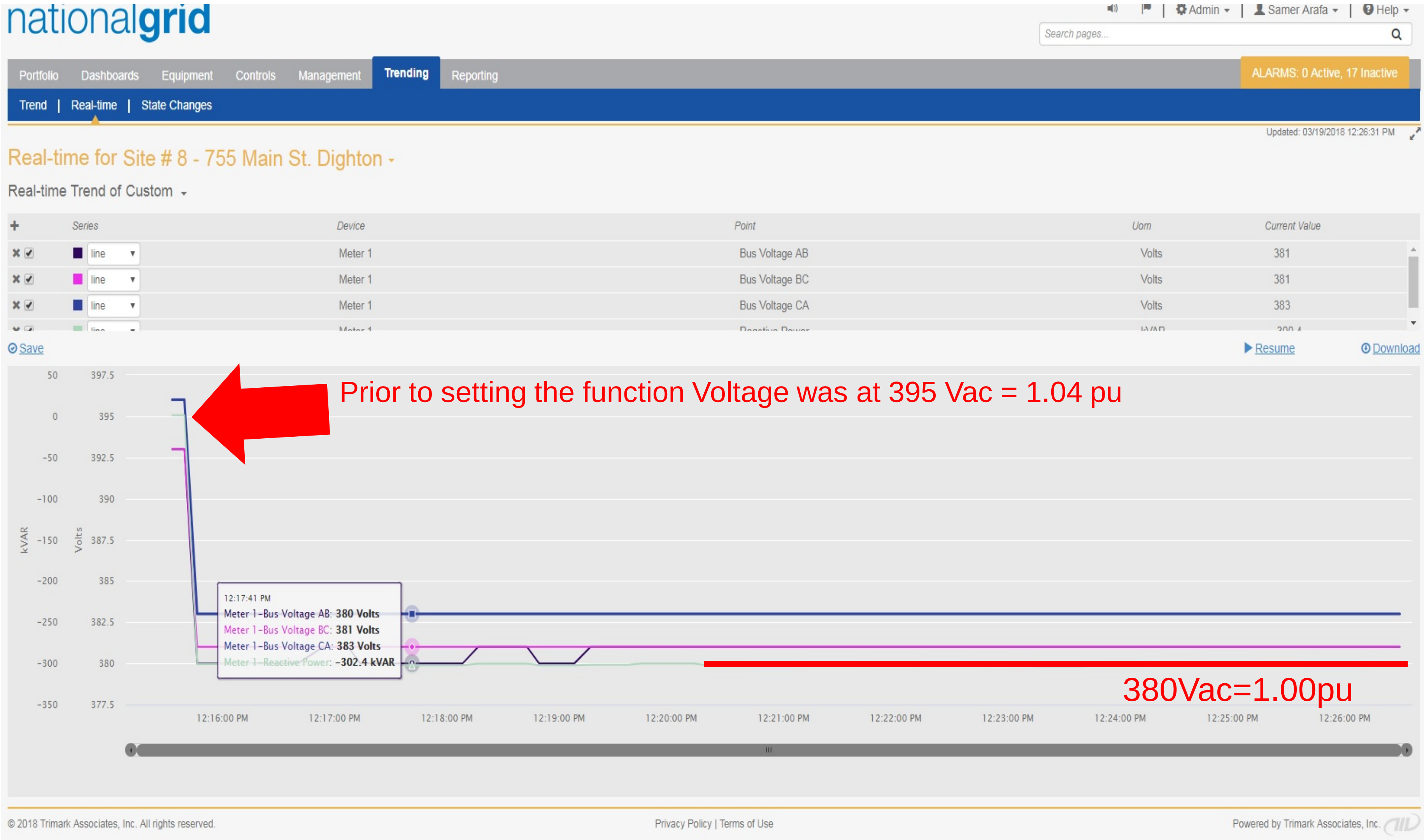


Closed Loop Voltage Regulation

- Ramp Rates will need to be adjusted to better match control loops speed



After Some Tweaking



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