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Beneficial Applications of Smart Inverter Technology- Project Update

Massachusetts Technical Standards Review Group (MA-TSRG)– 11/28/17

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Program Stages

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1. Interconnection
   Sites placed into service, running full power at unity power factor
2. Advanced Inverter Plant Control
   Test to confirm advanced Inverter functionality and plant control capability
3. Theoretical Settings
   Calculate the theoretical ideal voltage regulation settings
4. Feature Testing
   Compare proposed ideal settings to variations
5. Lessons Learned
   Share lessons learned with the industry
6. Implement Recommendations!

Stage 1. Interconnection

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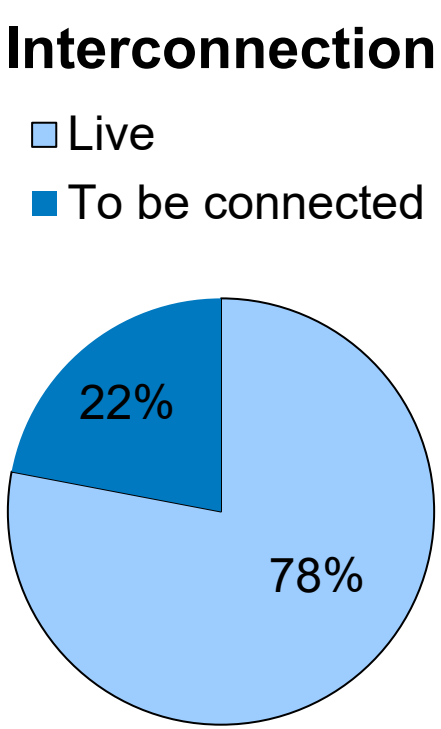
- Live sites are sites capable of running at full kW and at unity power factor.



Site Order	Site Address	Feeder	Town	Site Live
1	17 Kelly Rd.	413L2	Sturbridge	Yes
2	26 Kelly Rd.			
3	Blossom Rd. 1	05-115W52	Fall River	Q1, 2018
4	Blossom Rd. 2			
5	76 Groton Rd.	227W3	Shirley	Yes
6	Cape Cod Lumber	93W42	Abington	Yes
7	438 Richardson Ave.	05-8L3	Attleboro	Yes
8	79 Old Upton Rd.	304W2	Grafton	Yes
9	24 Boutilier Rd.	21W2	Leicester	Yes
10	755 Main St.	19W73	Dighton	Yes
11	380 Frank Mossberg Dr.	05-9L2	Attleboro	Yes
12	29 Oxford Rd.	406L3	Charlton	Yes
13	19 Groton School Rd.	201W4/W1	Ayer	Yes
14	40 Auburn Rd.	26W2/W4	Millbury	Yes
15	430 Stafford St.	406L1	Leicester	Yes
16	29Snake Hill Rd/ Carpenter	413L4	Charlton	Yes
17	Patterson Rd. 1	227W3	Shirley	Q1, 2018
18	Patterson Rd. 2			

Stage 2. Plant Controller Integration

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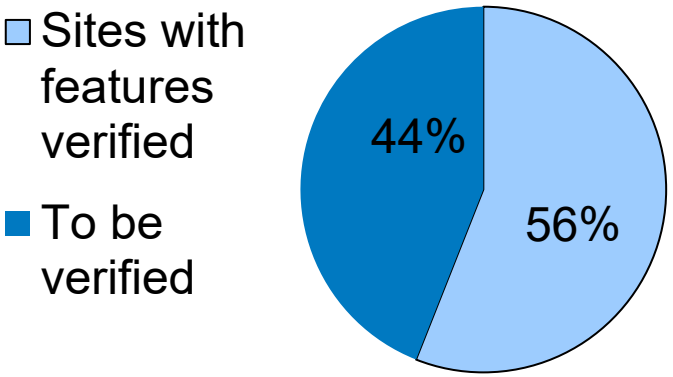
- This stage intends to confirm that the advanced inverter and plant controller features when combined intended functionality of the program.

Plant Controller Integration



Site Order	Site Address	Town	ETA for Integration
1	17 Kelly Rd.	Sturbridge	Complete
2	26 Kelly Rd.		Complete
3	Blossom Rd. 1	Fall River	Mar. 2018
4	Blossom Rd. 2		Mar. 2018
5	76 Groton Rd.	Shirley	Complete
6	Cape Cod Lumber	Abington	Complete
7	438 Richardson Ave.	Attleboro	Complete
8	79 Old Upton Rd.	Grafton	Dec. 2017
9	24 Boutilier Rd.	Leicester	Complete
10	755 Main St.	Dighton	Dec. 2017
11	380 Frank Mossberg Dr.	Attleboro	Complete
12	29 Oxford Rd.	Charlton	Complete
13	19 Groton School Rd.	Ayer	Complete
14	40 Auburn Rd.	Millbury	Complete
15	430 Stafford St.	Leicester	Jan. 2018
16	29Snake Hill Rd/ Carpenter	Charlton	Jan. 2018
17	Patterson Rd. 1	Shirley	Mar. 2018
18	Patterson Rd. 2		Mar. 2018

Stage 3. Theoretical Settings

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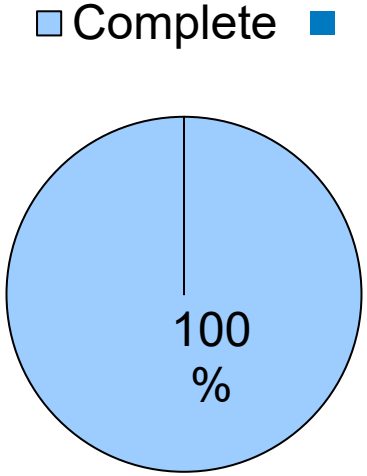
- In this stage we work to calculate the theoretical ideal settings, which will later be used in our test plan and compared to several variations.

Recommended Test Settings



Site Order	Site Address	Feeder	Town	EPRI Suggested Settings
1	17 Kelly Rd.	413L2	Sturbridge	Yes
2	26 Kelly Rd.			Yes
3	Blossom Rd. 1	05-115W52	Fall River	Yes
4	Blossom Rd. 2			Yes
5	76 Groton Rd.	227W3	Shirley	Yes
6	Cape Cod Lumber	93W42	Abington	Yes
7	438 Richardson Ave.	05-8L3	Attleboro	Yes
8	79 Old Upton Rd.	304W2	Grafton	Yes
9	24 Boutilier Rd.	21W2	Leicester	Yes
10	755 Main St.	19W73	Dighton	Yes
11	380 Frank Mossberg Dr.	05-9L2	Attleboro	Yes
12	29 Oxford Rd.	406L3	Charlton	Yes
13	19 Groton School Rd.	201W4/W1	Ayer	Yes
14	40 Auburn Rd.	26W2/W4	Millbury	Yes
15	430 Stafford St.	406L1	Leicester	Yes
16	29Snake Hill Rd/ Carpenter	413L4	Charlton	Yes
17	Patterson Rd. 1	227W3	Shirley	Yes
18	Patterson Rd. 2			Yes

Stage 4. Feature Testing-ON Hold

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- The following is our proposed detailed testing to measure quantifiable Power Quality impacts advanced PV facilities can bring to the grid.
- Began preliminary testing at 8 sites.
- Results indicate further work is needed to adjust calculated settings to better match plant controller limitation.
- National Grid is also working to improve its power quality data collection from 1 minute to 1 second.

Week	Adv. Function	Day #	Setting
1	PF	1,3,5,7	Site Recommended PF
		2,4,6	Off
2	Volt-VAR	1,3,5,7	Site Recommended Vol-VAR curve
		2,4,6	Off
3	Constant Voltage Regulation	1,3,5,7	Volt-VAR Dead band center
		2,4,6	Off
4	PF	1,3,5,7	Site Recommended PF-0.3 (more VARS absorbed)
		2,4,6	Off
5	Volt-VAR	1,3,5,7	Volt-VAR curve not Chosen
		2,4,6	Off
6	Constant Voltage Regulation	1,3,5,7	Volt-VAR Dead band center- 0.03PU
		2,4,6	Off
7	PF	1,3,5,7	Site Recommended PF+0.2 (less VARS absorbed)
		2,4,6	Off
		49 Days	

Stage 5. Lessons Learned

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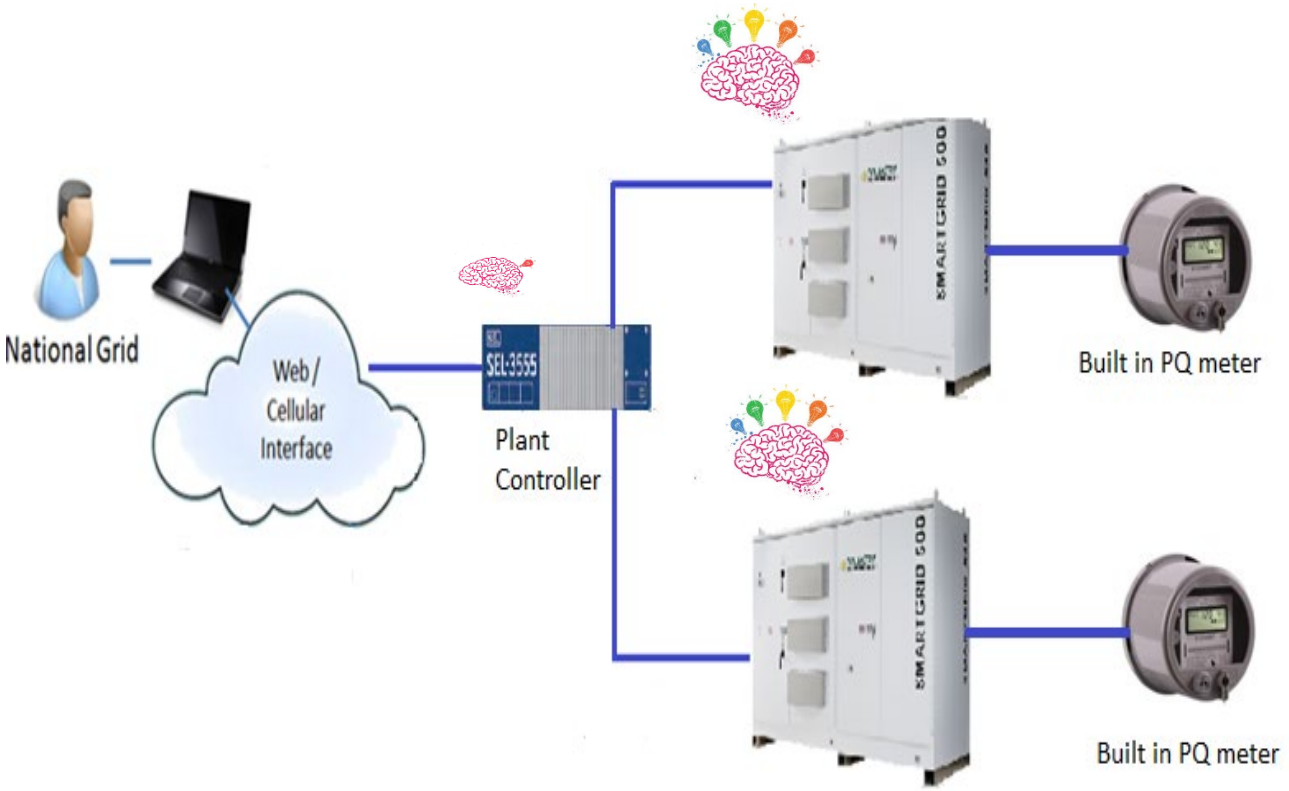
Solar Phase 1:



- The plant controller gets a command remotely and passes it forward.
- Plant Control is not closed loop.
- Inverter measurement Voltage accuracy ± 5%

Volt/VAR

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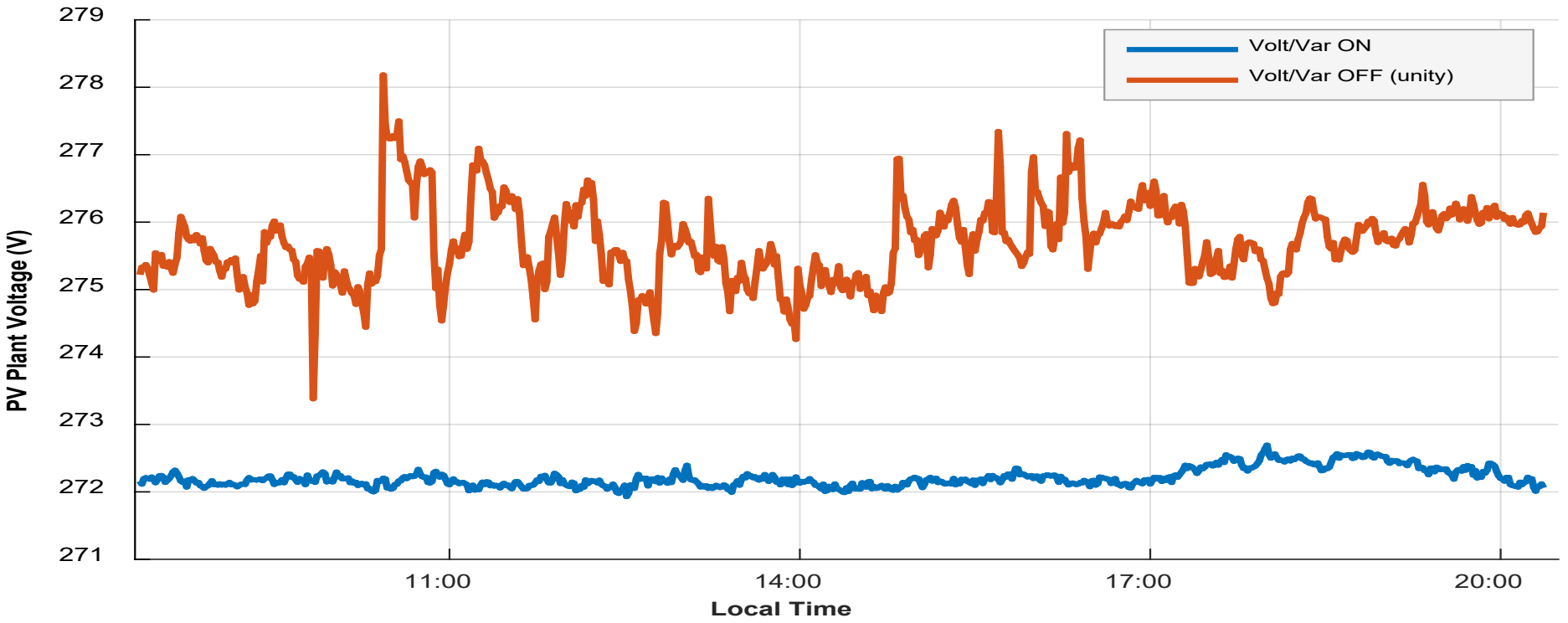

Smart Grid Ready PV Inverters with Utility Communication: Results from Field Demonstrations, EPRI 2016

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

Volt/VAR

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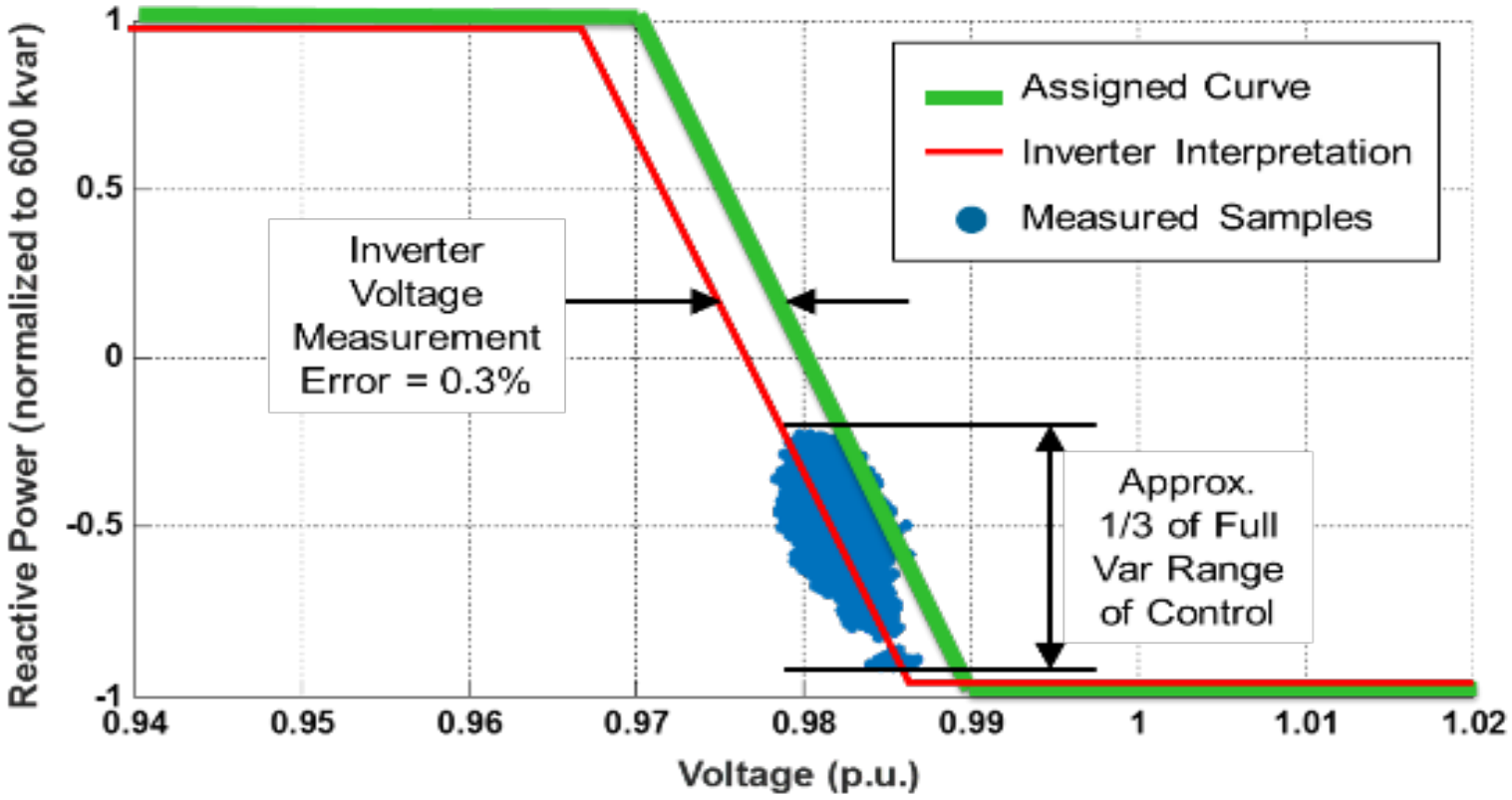

Smart Grid Ready PV Inverters with Utility Communication: Results from Field Demonstrations, EPRI 2016
http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002008557

Stage 5. Lessons Learned

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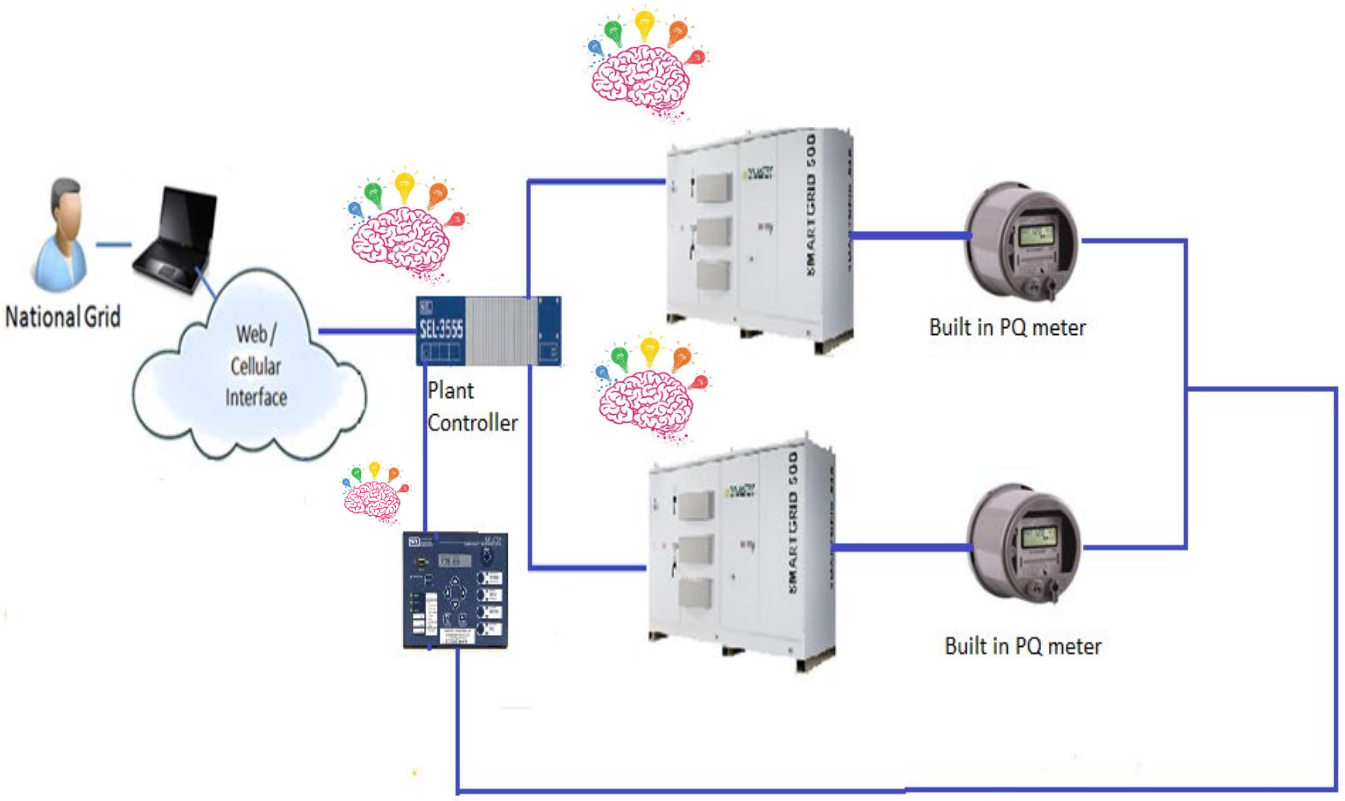
Solar Phase 2:



- 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 ± 1%

Benefits of closed loop

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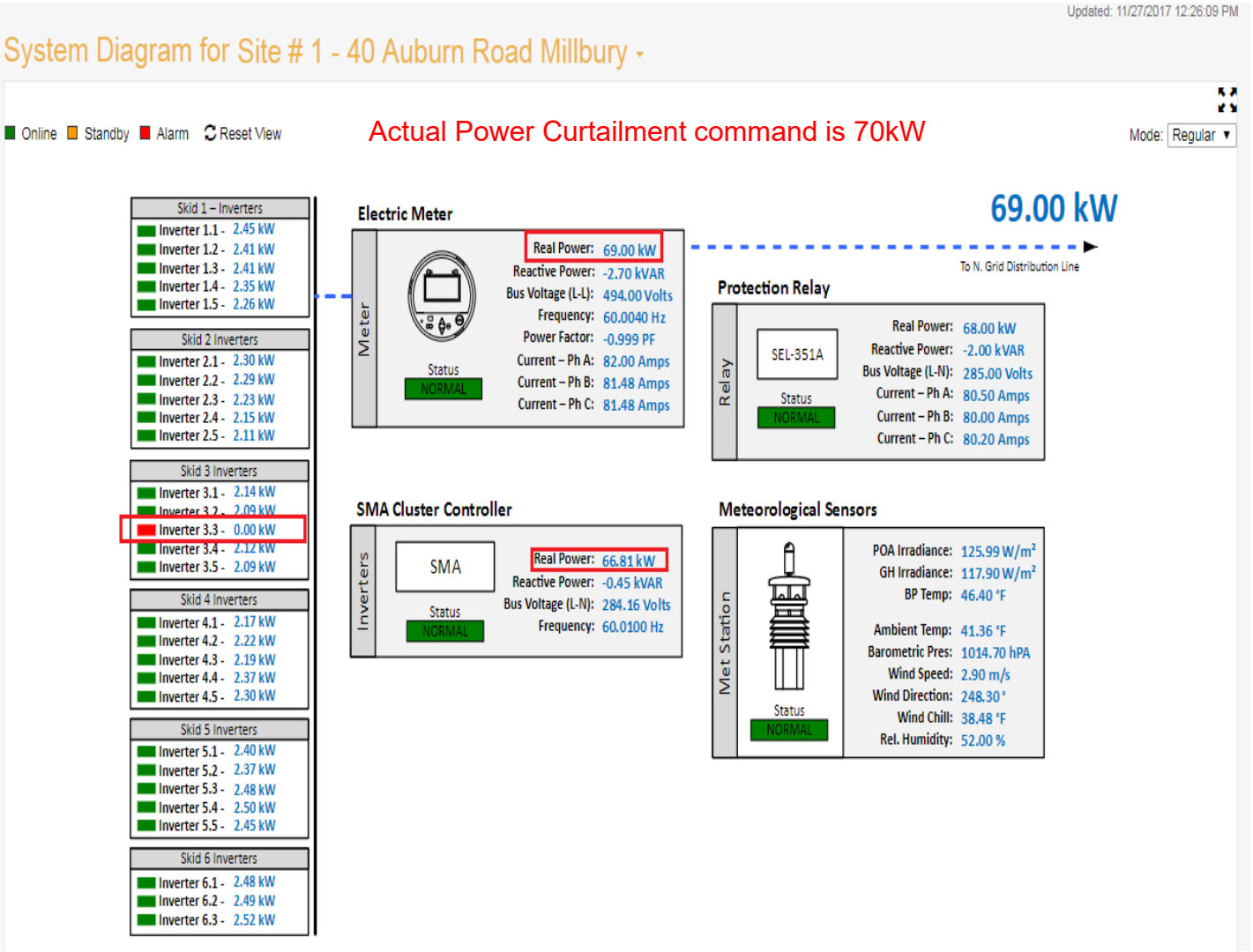

- Improved Accuracy
- Online inverters make up for offline ones.
- Helps to resolve issues caused by communication errors.

What Can Go Wrong?

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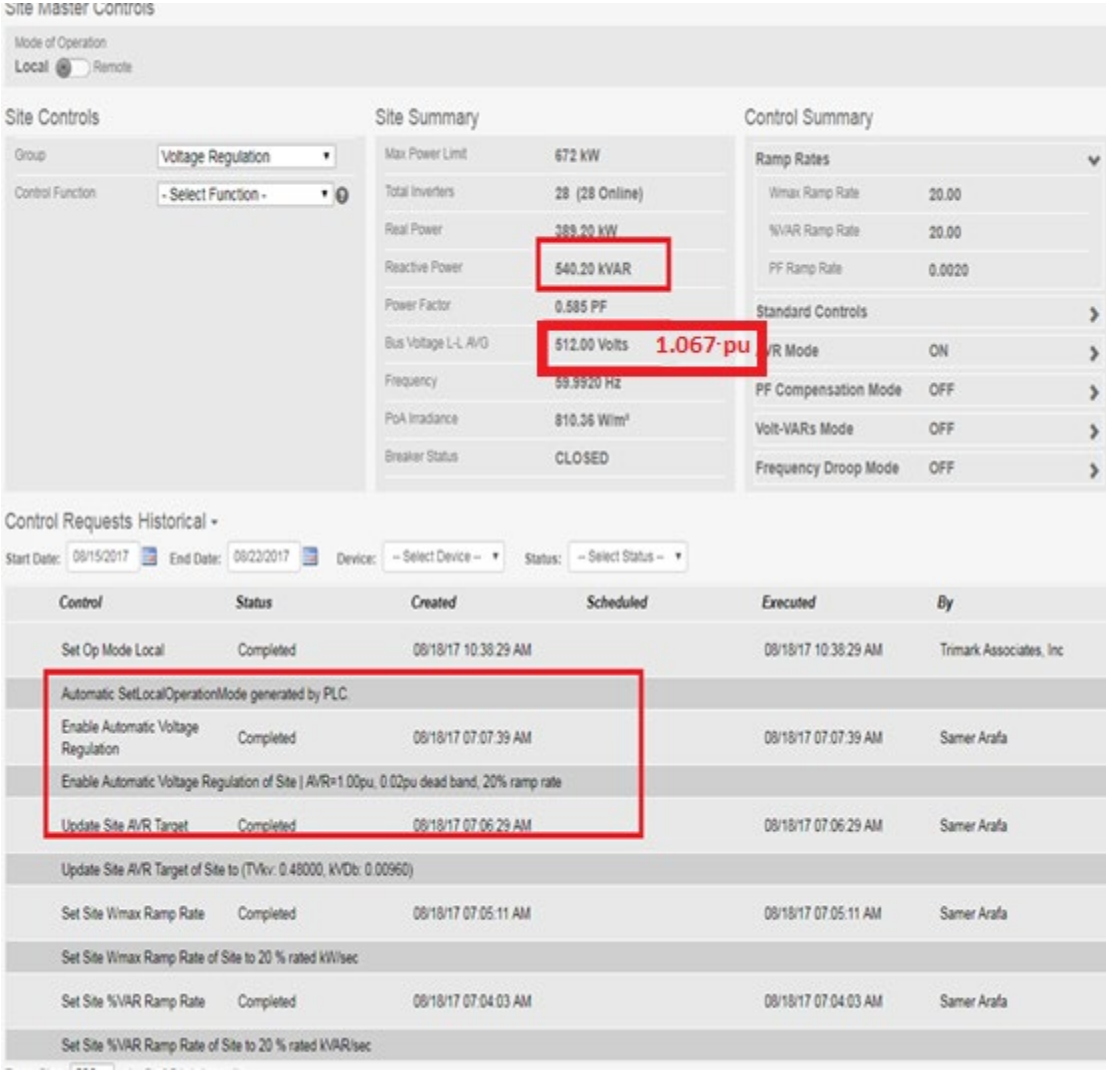
- On the right is an example of a controller that is attempting to regulate the voltage at 1.00pu.
- The end result is the Inverter injecting VAR and further bringing up the voltage despite the Voltage being above 1.00pu at the time.



Closed Loop Voltage Regulation

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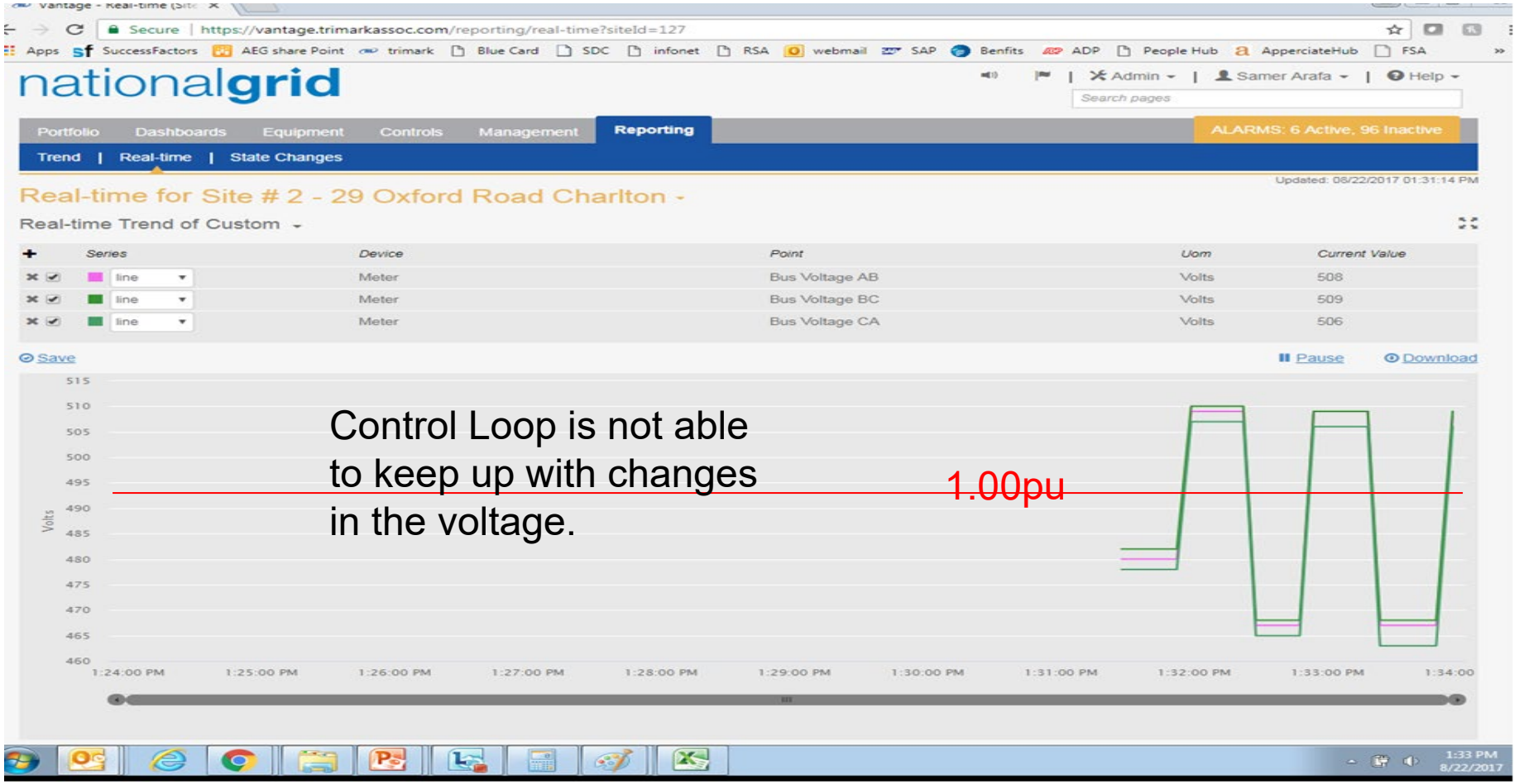
- Ramp Rates will need to be adjusted to better match control loops speed



Closed Loop Common mistake

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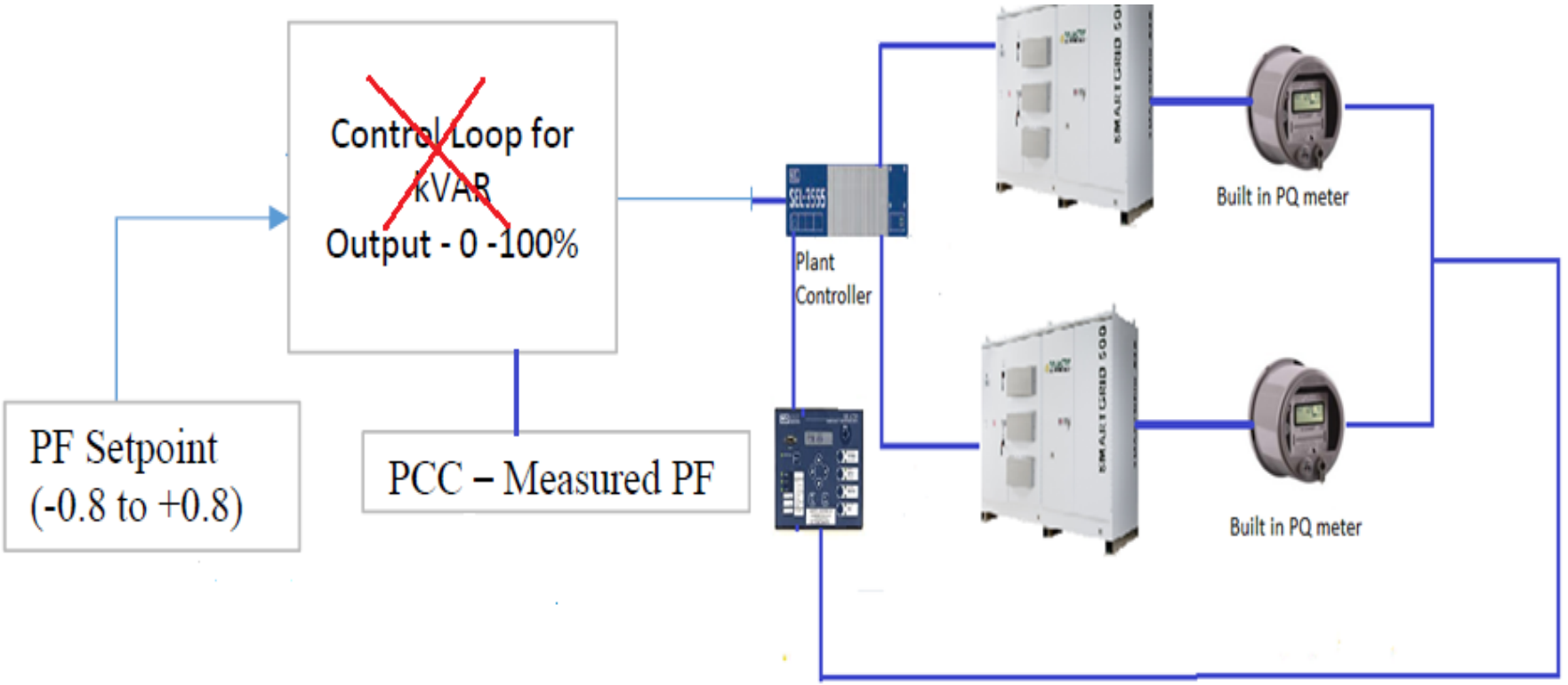
- We recommend against sending kVAR commands to manage PCC Power Factor.
- Without a high speed control loop, it is possible to get very unstable behavior during periods of irradiance variation, when the assumption of constant power in invalid.



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➔➔But most importantly

Never plan for any outdoor activity other than skiing in the Northeast during the winter.

Questions

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