SIMPLIFYING SOLAR

YASKAWA
SOLECTRIA SOLAR

DoE Smart PV Inverter Program- Accomplishments & Achievements

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Making Everybody Happy

SunShot Initative wants to have 300GW of Solar by 2030

Utilities like their "Hz" and "Volts" to know their limits

Inverter Manufacturers like to sell product

Solution: Create a system that allows for higher PV penetration.

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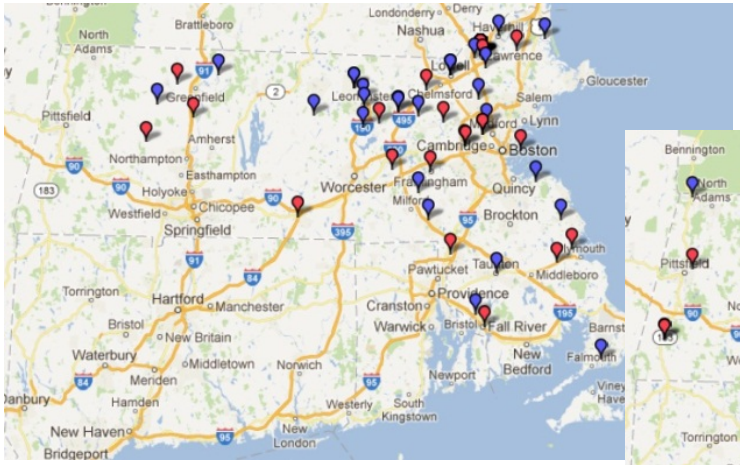
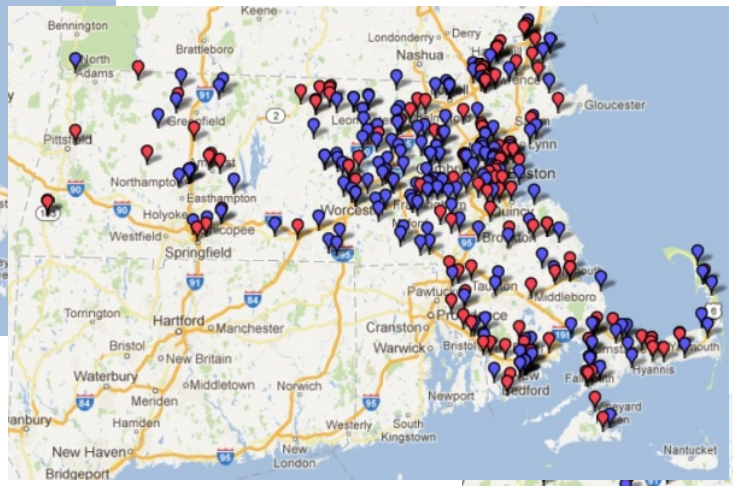
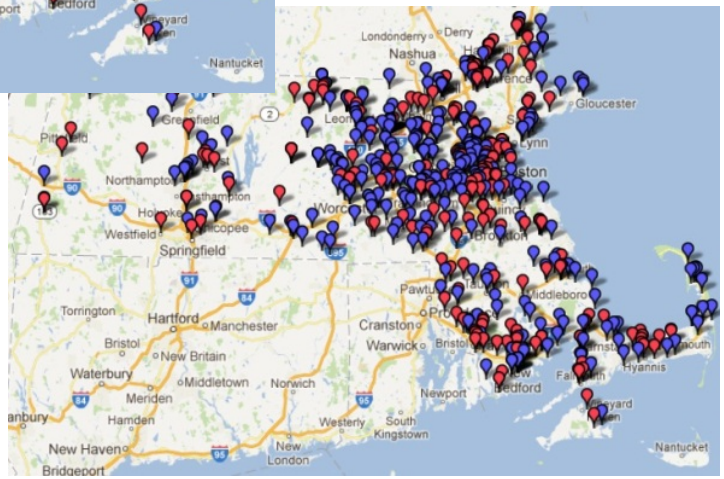
Problems of High PV Penetration?



2008



2010



2012

- As PV penetration increases, it's ability to effect the grid increases.

- The recent proposed German retrofit, estimates about 300,000 inverters will need retrofitting in Germany alone.

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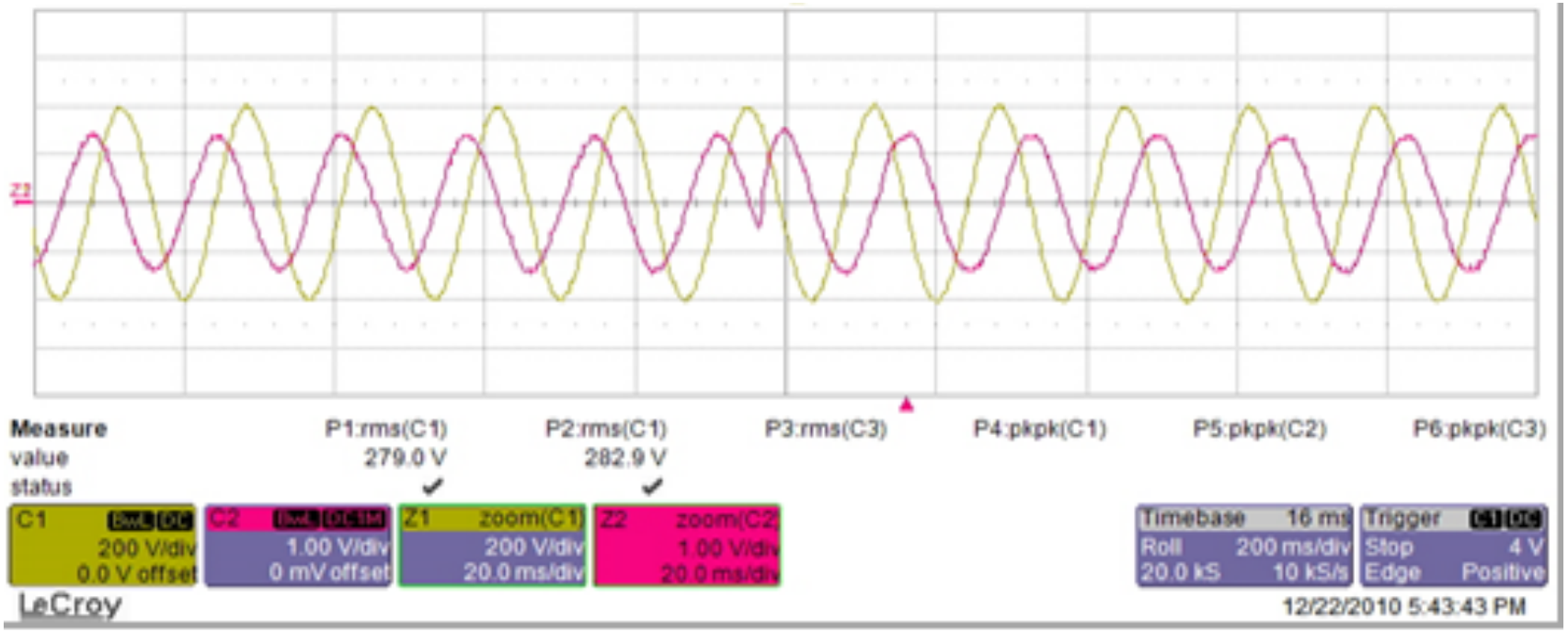
How Inverters Can Help?

- Inverters can change their Real Power within 10's of ms by simply curtailing their current.

- Inverters can change the run angle between the Voltage and Current, also within 10's of ms.



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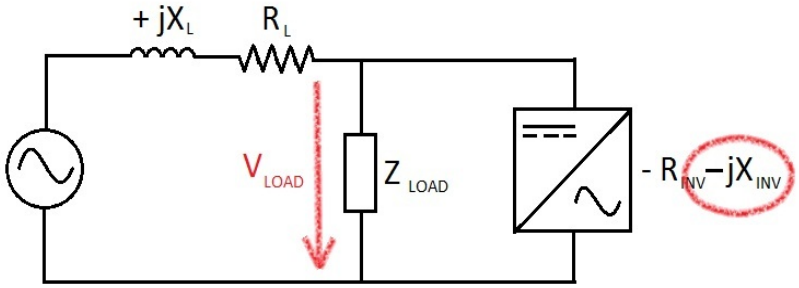
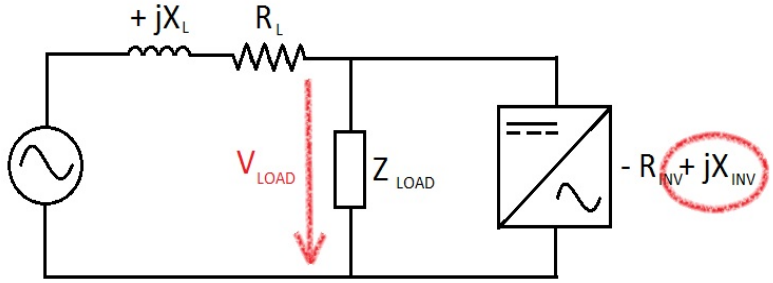
Volts and vars

- Utilities like their "Volts" to know their limits.

- Inverter var absorption (-var) results in reduction in voltage (-Volts) at PCC.



- Inverter var generation (+var) results in an increase of (+Volts) at PCC.



➔ ➔ Inverter functions that control "vars" depending on "Volts" such as Volt-var, Dynamic Reactive Current Support, Low/High Voltage ride through can be useful to regulate voltage and reduce Cap changes.

Volts, Watts and Hz

- Utilities are a bit picky, they like both their Volts and their Hz to know their limits.

•An increase in generation (+Watts) results in an increase in Voltage (+Volts).

➔➔ Inverter functions that control “Watts” depending on ”Volts” such as Volt-Watt can be useful to regulate voltage.

•When generation is High (+Watts) , Frequency rises (+Hz) .

➔➔ Inverter functions that control “Watts” depending on “Hz” such as Frequency-Watt can be are considered as essential safety features.

Phase 1: Product Improvement

- The PVI line which was developed in 2005 required several major changes such as a redesign of the Power Stage and resulted in the Introduction of the PVI 50-100kW.

- The SGI line which was developed later in 2010, only required minor changes in control circuitry and voltage sensing.

Items	PVI 100	SGI 500
Input Voltage	480Vac	480Vac
Power Capacity	100kVA	500kVA
Reactive Power Limit	60kvar	300kvar
Power Factor Range	± 0.8	± 0.8

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Accomplishments of Phase 1

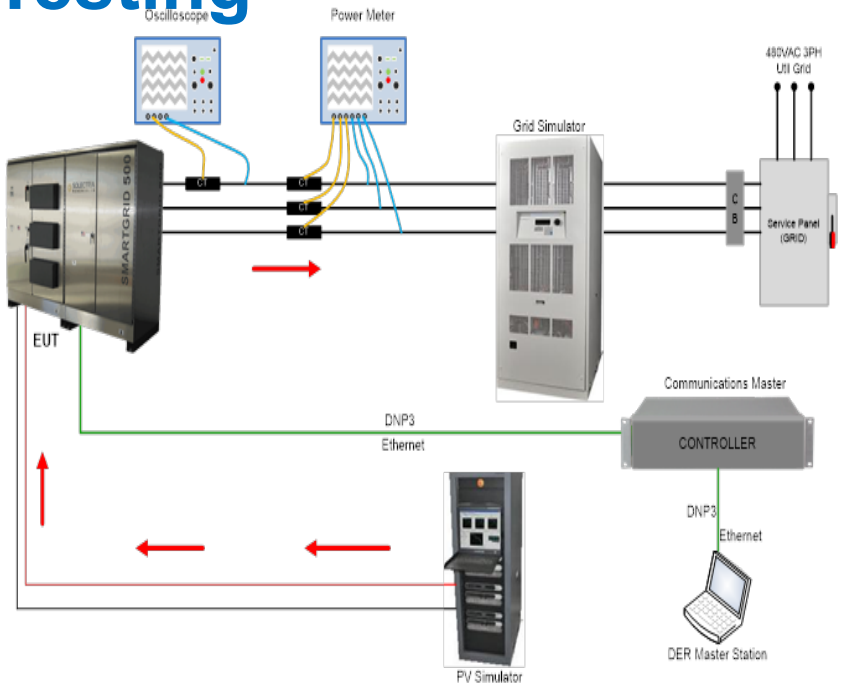
- Introduction of the PVI 50-100kW series to replace the PVI 60-95kW series.
- PVI series CEC efficiency increased by 1%.
- PVI Reliability increased with new design modifications by reducing 114 connection points.
- Power Stage BOM cost reduction by 12%
- Advanced Voltage Sensing introduced into PVI and SGI series.
- Grid support functions developed according to the DNP3 protocol.

Phase 2: Development and Testing

- The Energy System Integration Facility (ESIF) at NREL was chosen to test the SGI 500kW features due to its advanced capabilities.

- The EPRI facility in Knoxville, TN was chosen to test the PVI 100kW for their expertise in inverter testing.

- The Sandia 2013 Advanced Inverter test protocol was the reference for our testing.



NREL Test Setup	Size
PV simulator	1MW
Grid Simulator	1.2MW
Output Power	500kW
Reactive Power	± 300kvar

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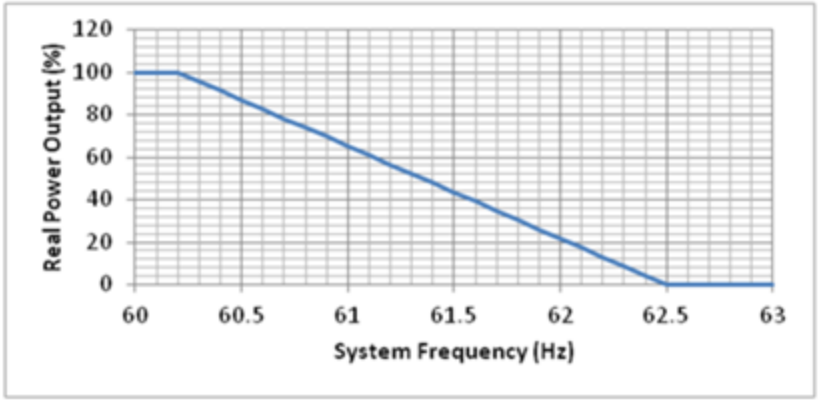
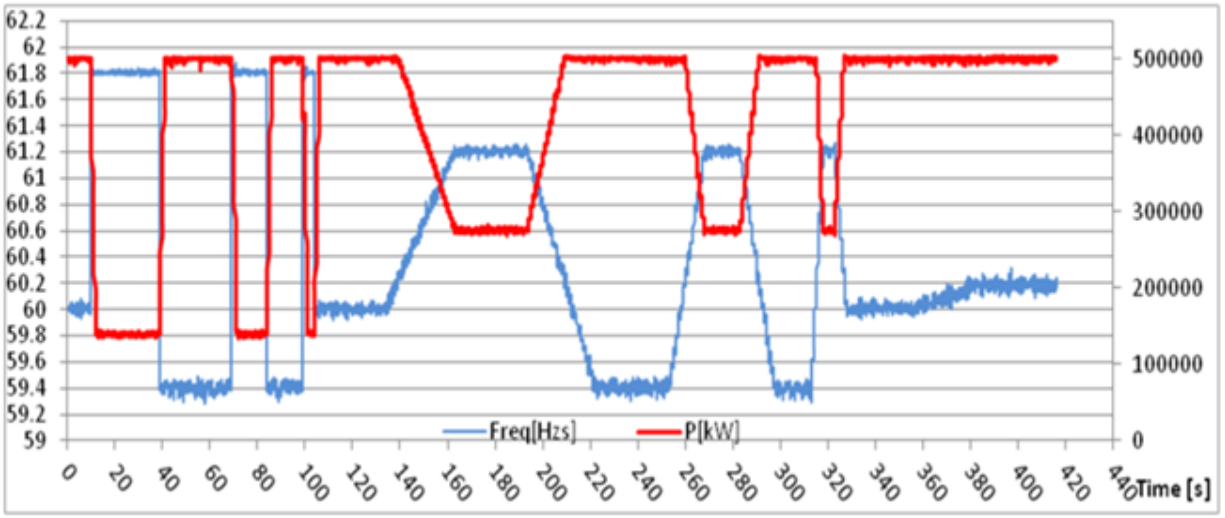
Accomplishments of Phase 2

Key Functions Demonstrated at NREL:

- Balanced Low Voltage Ride Through
- Unbalanced Low Voltage Ride Through
- High Voltage Ride Through
- Frequency Watt



- Testing at NREL was crucial to proving out features that couldn't be easily be proven out on the Grid.



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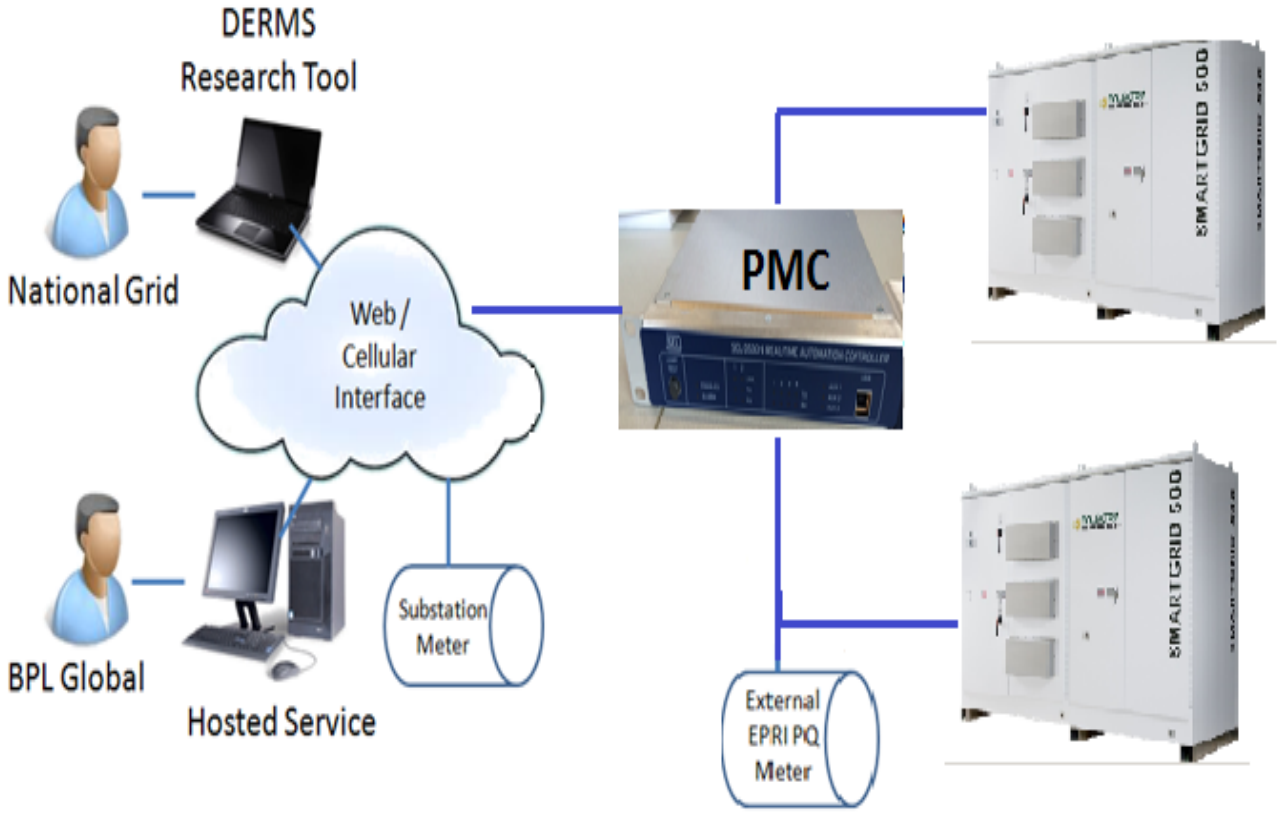
Phase 3: Field Demonstrations



U.S. DEPARTMENT OF ENERGY

nationalgrid

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A DTE Energy Company

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Accomplishments of Phase 3

- Real Benefits Demonstrated. Real Time on Real Feeders.

Table 1-1
Demonstration Plans for Host Feeders

Benefits / Inverter Function	Efficiency		Power Quality				Asset Life			Deference of Capital Spending				Reliability		Enabling
	Reduced distribution line losses	Improve customer efficiency CVR	Flatter voltage profile	Improved harmonics	Voltage flicker	Overvoltage	Reduce LTC tap changes	Reduce line regulator tap changes	Reduce switch cap changes	Defer capacitor additions	Defer line regulators	Defer reconductoring	Defer substation upgrades	Support during momentary	Support during automation	Higher Penetration of PV
Intelligent Volt-Var Control	✓	✓	✓			✓	✓	✓	✓	✓	✓					✓
Power Factor	✓		✓			✓				✓						✓
Dynamic Reactive Current					✓	✓								✓	✓	✓
Remote Connect/Disconnect															✓	✓
Power Curtailment						✓	✓	✓			✓	✓	✓			✓
Intelligent Volt-Watt Control		✓				✓										✓
L/H Voltage Ride-Through														✓	✓	✓

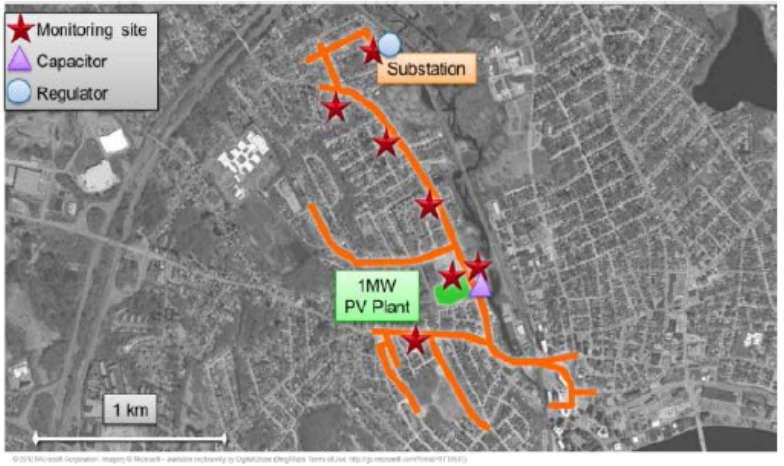
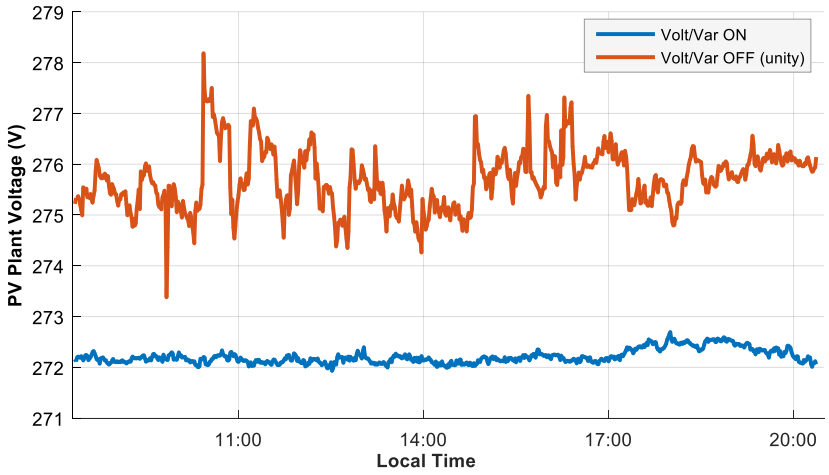


Figure 1-1
National Grid H1 Feeder – 13.2 kV residential feeder with 1 MW PV



Figures courtesy of EPRI

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The Benefits of the DoE Program

- Testing at NREL and EPRI labs gave us access to advanced capabilities.
- The collaborative nature of the work gave us access to top level expertise.

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

ENERGY SYSTEMS INTEGRATION

ESI optimizes the design and performance of electrical, thermal, fuel, and water pathways at all scales.

ESI Partnerships: NREL + Solectria

NREL is partnering with solar inverter manufacturer Solectria at the ESIF to develop 500- and 750-kilowatt photovoltaic (PV) inverters with advanced features that can support the electric grid.

R&D Strategy

The ESIF's utility-scale power hardware allows Solectria to test its inverters using simulated utility grid and solar PV emulation so researchers can see the impact of the inverter's advanced features on power reliability quality. This unique testing capability allows Sc test its inverter's controls and functionality at fu and determine how its integration supports and grid under a variety of conditions.

Impact

This work supports the development of PV inv can provide bulk system support to utilities und conditions—which will ultimately allow for inc penetration of solar on the grid.

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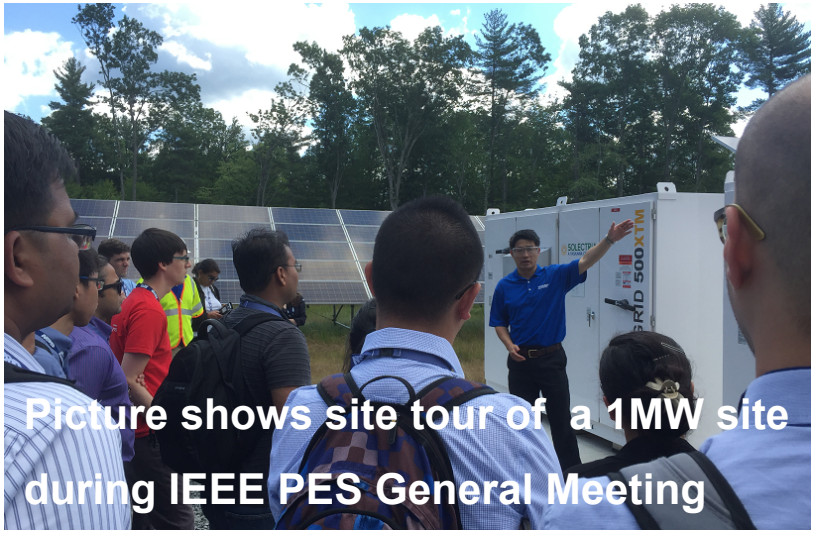
Product Commercialization

- Yaskaw- Solectria Solar was able to commercialize on the lessons they learned during the project. Introducing the XTM 500-750kW, that come with the option of Grid Support Features.

- These features allowed us to compete in several international markets such as Philippines and Brazil.



Picture shows site tour of a 1MW site during IEEE PES General Meeting

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One Final Lesson Learned

- Never Plan any Field Testing in the Northeast during the winter!

Haverhill PV Array, February 2015

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Area's for Future Collaboration

- **Applications:** Energy Storage, Micro-Grids.
- **Cost:** 1500Vdc, can reduce system cost by more than 10%.
- **Power Density:** As power density goes up, maintaining high reliability will become an interesting power electronics challenge.