# Smart Grid Communications

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## Introduction

The NYSolar Smart Distributed Generation (DG) Hub is a comprehensive effort to develop a strategic pathway to a more resilient distributed energy system in New York that is supported by the U.S. Department of Energy and the State of New York. This DG Hub fact sheet provides information to installers, utilities, policy makers, and consumers on software communication requirements and capabilities for solar and storage (i.e. resilient PV) and microgrid systems that are capable of islanding for emergency power and providing on-grid services. For information on other aspects of the distributed generation market, please see the companion DG Hub fact sheets on resilient solar economics, policy, hardware, and a glossary of terms at: www.cuny.edu/DGHub.

## Background

This fact sheet walks through the some of the different types of software products available for resilient PV and microgrid development and implementation, and explains the different functionalities that enable systems to accomplish the objectives of a DG project. Software used for system design, monitoring and metering, control, and billing are all involved in complex grid-connected microgrids. This fact sheet focuses on monitoring and controls software, including the software capabilities of advanced inverters along with the different software layers involved in communicating, operating and controlling micogrids. With appropriate software design, DG can provide electricity resiliency, cost savings, grid services, and additional benefits.

The information in this fact sheet will help readers better understand today's software communication needs and capabilities in order to assemble resilient PV systems and microgrids that can provide a multitude of services and a favorable return on investment.

## Microgrids

Electrical systems that can connect and communicate with the utility grid that are also capable of operating independently using their own power generation are considered microgrids. Single buildings or an entire community can be designed to operate as a microgrid. Microgrid infrastructures often provide emergency power to hospitals, shelters or other critical facilities that need to function during an electrical outage. Microgrids can include conventional distributed generators (i.e., diesel or natural gas gensets), combined heat and power (CHP), renewable energy such as PV, energy storage, or a hybrid combination of technologies. If inverters are used, such as for a resilient PV system, they must be able to switch between grid-interactive mode and microgrid (intentional island) mode in order to operate as a microgrid. For large microgrid systems that include distributed energy resources (DER), a supervisory control system (a system that controls many individual controllers) is typically required to communicate with and coordinate both loads and DER.

## Microgrid Equipment and Associated Software

The equipment and software that are required to form a microgrid will vary depending on the scale and use of the system. For example, a residential scale resilient PV system that is only used for standby power may not require sophisticated control software other than what is provided within the inverter(s). A large, grid-interactive, commercial scale resilient PV system will have more software requirements. For these larger, more complex systems, software is used to monitor and control the microgrid.

Figure 1 illustrates the equipment and software involved in a microgrid system that includes not only PV and storage but multiple power systems with supervisory controls.

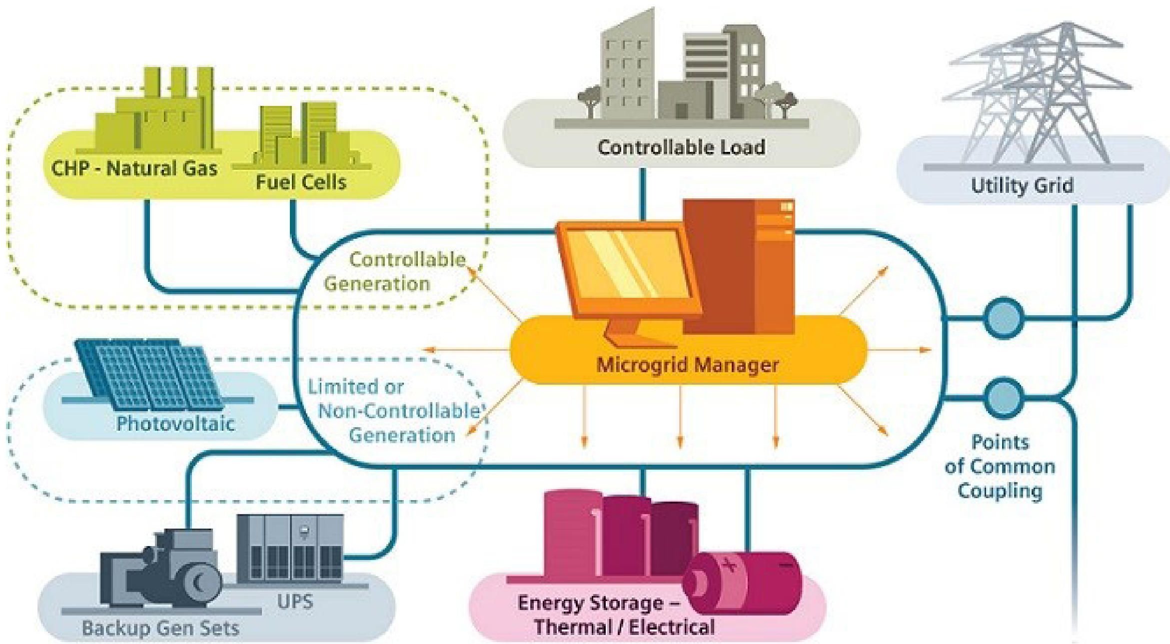


Figure 1. Microgrid with Supervisory controls
Source: Siemens, http://w3.usa.siemens.com

## Monitoring and Management of Smart DG Systems

Traditionally, utilities have relied on centralized power generation, together with transmission and distribution infrastructure to transmit and distribute energy to end-use customers (see Figure 2). Generation can consist of both bulk power (tied to the grid at the transmission level) and distributed generation (DG), which often ties in near the end-user at the distribution level. Today, the grid is experiencing the interconnection of greater levels of DG such as solar, wind turbines, conventional generators, fuel cells, combined heat and power (CHP), and other technologies. Distributed energy storage (ES) can play a role in supporting higher penetrations of DG while also increasing the economic return on microgrid systems. These systems can be designed to disconnect from the utility grid and function off-grid in a stand-alone "island mode." As new technologies are implemented, utilities must continue to adapt and provide customers reliable electric power on demand. This requires complex monitoring and grid management of energy demand, generation, storage, and distribution in both on and off-grid operating modes.

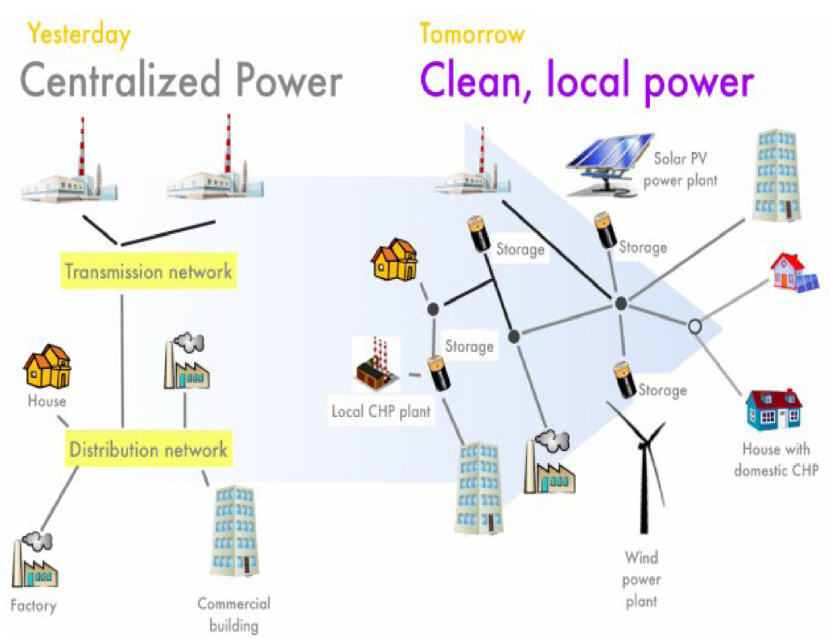


Figure 2. Comparison of Centralized Power system vs Microgrid
Source: CleanTechnica

The software embedded in advanced inverters, often referred to as smart inverters, are largely responsible for the monitoring and management of solar and storage microgrids. Advanced inverters have the ability to switch between grid-interactive mode and stand-alone microgrid mode and some even act as a "master inverter" when used with energy storage to set microgrid frequency and voltages. Advanced inverters can also improve power control and enhance stability when connected to the larger central utility infrastructure. These and other advanced inverter functions are presented in the following section.

## Advanced Inverter Functions

The primary function of an inverter is to convert the direct current (DC) from solar cells or batteries into alternating current (AC) to provide energy (kWh) to offset customer load. For PV systems connected to the utility, the AC output from the inverter must match the voltage, frequency and phase of the utility grid. However, as inverter technology has progressed, inverter functionality has grown to include many functions beyond power conversion. Many inverters currently deployed with PV systems could provide advanced functionality with software modifications or firmware upgrades.

Below is a matrix and detailed description of some of the important functions in advanced inverters:

Table 1. Matrix of Smart Inverter Functions and Ancillary Controls

| Smart Inverter Function Matrix | | Solar and Storage Services that Require Advanced Functions | | | |
|---|---|---|---|---|---|
| | | Peak Load Management | Demand Response | Emergency Power (Islanded Mode) | Ancillary Services (power quality enhancement and curtailment) |
| Advanced Inverter Functions | Isolation switch with grid | | | x | |
| | Frequency and voltage ride-through | | | x | x |
| | Event logging/status report | x | x | x | x |
| | Adjust maximum generation level | x | x | x | x |
| | Power factor and VAR management | | | x | x |
| | Soft start | | | x | |
| | Storage management | x | x | x | |

### a. Isolation switch with grid

This function provides a flexible switching mechanism that physically connects or disconnects the inverter from the grid.[1] One new function in advanced inverters is the ability to communicate with the inverter and command it to go offline. This enable/disable function could be configured to disconnect during unacceptable high or low levels of voltage, or frequency, or if the utility needs to perform maintenance on the grid. There may also be times during which a PV system is not allowed to export; this feature could signal to disconnect if the PV begins to export during these times. Note that this function could not over-ride a local safety switch and reconnect the PV system during a lock-out/tag-out routine. grid. While many of these inverter capabilities exist, these functions are typically turned off to meet certification requirements. Permitting the use of advanced inverter functions may allow resilient PV systems to capture additional value streams, further driving down costs.

### b. Frequency and voltage ride-through

The current Institute of Electrical and Electronics Engineers' (IEEE) 1547 Standard requires that grid-tied inverters disconnect the PV from the grid when the grid voltages or frequency becomes too high or low and extend outside the recommended boundaries. Inverters have the capability of being programmed to "ride through" minor variations in voltage or frequency. The PV would be allowed to stay on-line for a short term occurrence of this type of disturbance. The advanced inverters have the capability to be programmed more broadly in this area and are able to receive commands that change the parameters. In microgrid mode they may be told to stay on even longer if there is a low or high frequency, or to "droop" and reduce power output during high frequency. The inverter does disconnect the PV system if the disturbance is severe or prolonged, and those parameters can be programmed for the location or be changed.

1 B. Seal, EPRI, "Common Functions for Smart Inverters, Version 3" Technical Update, February 2014

c. Event logging/status reporting

The event logging is intended to provide a mechanism for inverters to log a value and time stamp for a specific set of events or alarms to provide the operators at the host site or the utility with a history of the DG and storage system performance. A basic level of monitoring typically includes instantaneous power output, daily energy production and total to-date energy production. Depending upon the type of inverter it may be able to collect information from the battery and adjust the state of charge of a battery system. Voltage and frequency characteristics of the utility grid may also be monitored. Event logging and status reporting is necessary for verification and can provide information for operation and maintenance.

d. Adjust maximum generation level

One way a smart inverter can help manage grid disturbances of over and/or under voltage and frequency events is by controlling the maximum generation level of the DG system. Inverters can assist in voltage control by limiting the amount of generation from the DG system that is fed back onto the grid. Smart inverters are used in Germany to reduce real power output during high frequency events caused by too much generation on the grid by using a droop function (reducing real power generation as frequency goes as high as 50.2 Hz). Generation curtailment is also useful when export to the utility grid at the owner's point of electrical service is prohibited.

e. Power factor & VAR management

Volt-Amps Reactive (VAR) is a measured unit for reactive power. Reactive power is necessary for the operation of motors, transformers, air conditioners and other magnetic devices. The electric system suffers when there is significant VAR content in a distribution network segment, resulting in lowered capacity and voltage. Inverters can provide Power Factor and VAR support during this common occurrence to help maintain grid voltage and offset the need for capacitor banks or excessive cycling of voltage regulating devices.[2]

f. Soft start

Advanced inverters are also capable of helping prevent grid disturbances from reoccurring immediately after an outage. Smart inverters have a soft start method (typically a ramping control) that can delay the time DG systems take to reconnect to the grid. This will help prevent DG systems from coming back on line at the same time and causing an over voltage event. This technique also helps avoid instant spikes in the active power being put back on the grid.

g. Storage management

Some smart inverters have the controls to charge/discharge batteries. The controls provide a charge/discharge rate that is related to the inverter's capabilities. This will limit the energy that can flow into or out of the storage system. Smart inverters with energy storage equipment also have the control capability of adjusting the ramp rate to increase or decrease power output to the grid due to variable DG generation (i.e., during clouding events).

## Communication Technologies and Microgrids

The advanced inverter functions described above could feasibly react either autonomously or to signals communicated by system operators or local grid agents. This section will look at emergent protocols and considerations for advanced inverter deployment which are capable of receiving commands to improve grid stability and react appropriately during grid disturbances or outages to support critical loads or respond to market pricing signals.

### Advanced Inverter Functions and Communication Interoperability

One important distinction to highlight is the advanced inverter functions that are considered autonomous and which require an external communication signal.[3]

2 National Renewable Energy Laboratory, "Advanced Inverter Functions to Support High Levels of Distributed Solar", Advanced Inverter Functions to Support High Levels of Distributed Solar: Policy and Regulatory Considerations

3 E. Reiter, K. Ardani, R. Margolis; National Renewable Energy Laboratory (NREL), 'Industry Perspectives on Advanced Inverters for U.S. Solar Photovoltaic Systems: Grid Benefits, Deployment Challenges, and Emerging Solutions'; NREL/TP-7A40-65063, Sept 2015; http://www.nrel.gov/docs/fy15osti/65063.pdf

### Autonomous Inverter Functions

The autonomous inverter features below are functions controlled by inverter operating parameters which are set at commissioning and can be adjusted later at the site or by remote control. No communication architecture is needed.

- Low/High voltage and frequency ride-through
- Volt-VAR control (dynamic reactive power injection)
- Anti-islanding
- Ramp rate controls
- Fixed power factor/power factor correction
- Soft start reconnect
- Smooth frequency deviations/frequency control

### Communications and Control Infrastructure Required

In order to use the advanced inverter for the following capabilities, communication and control infrastructure is required. The infrastructure must include direct control of inverter behavior either from remote operator commands or feedback based on external conditions.

- Command DER to connect/disconnect
- Limit and set real power
- Black-start capability
- Respond to real power pricing signals
- Possibly enable automatic generator control
- Provide reserves through additional energy storage systems
- Update static set points for independent control points on devices

## Communication Architecture

Unlike microgrids that use dispatchable diesel-based power generation, microgrids that have numerous power resources and are renewable energy-intensive with high levels of intermittency will require layers of controls. Controlling advanced microgrids requires interaction directly with distributed energy generation and storage resources, as well as building energy loads and management systems. The controls must be able to operate not only when the system is grid-tied but also during an intentional islanded mode. Table 2 highlights the different layers of controls that may be required in a microgrid system, from level 1 that handles the different devices to layers four and five that cover the supervisory level and interconnection to the grid. Figure 3 illustrates a concept of the smart communication control layers.

Table 2. Layers of Communication for Microgrids

| Level | Layer Name | Control Functions |
|---|---|---|
| 1 | Device Layer | Connect/disconnect switching, protection devices, inverters, load control |
| 2 | Local Control Layer | Building management controls, smart meters, sensor control, load shedding |
| 3 | Cyber Layer | Network communications, wireless transmission, database |
| 4 | System Control Layer | Data exchange, event recording, scheduling resources, forecasting, power optimization |
| 5 | Market Layer | Grid interconnection, data transfer, ancillary services, economic functions |

Presently, a number of communication languages and protocols exist that cover different layers of monitoring and controls for a microgrid. Most advanced inverters have several communications protocols available for local or remote command and control, and the SunSpec Alliance[4] is working to standardize all functions and communications protocols. In addition, the North American Electric Reliability Corporation (NERC) has developed a cyber security protocol for Critical Infrastructure Protection (CIP)[5] that details the cyber security standards.

4 SunSpec Alliance, Accelerating the Growth of the Renewable Energy Industry, May 2010. http://sunspec.org/wp-content/uploads/2010/06/SunSpec-Backgrounder.pdf

5 North American Electric Reliability Corporation Critical Infrastructure Protection (CIP) Standards; http://www.nerc.com/pa/Stand/Pages/CIPStandards.aspx

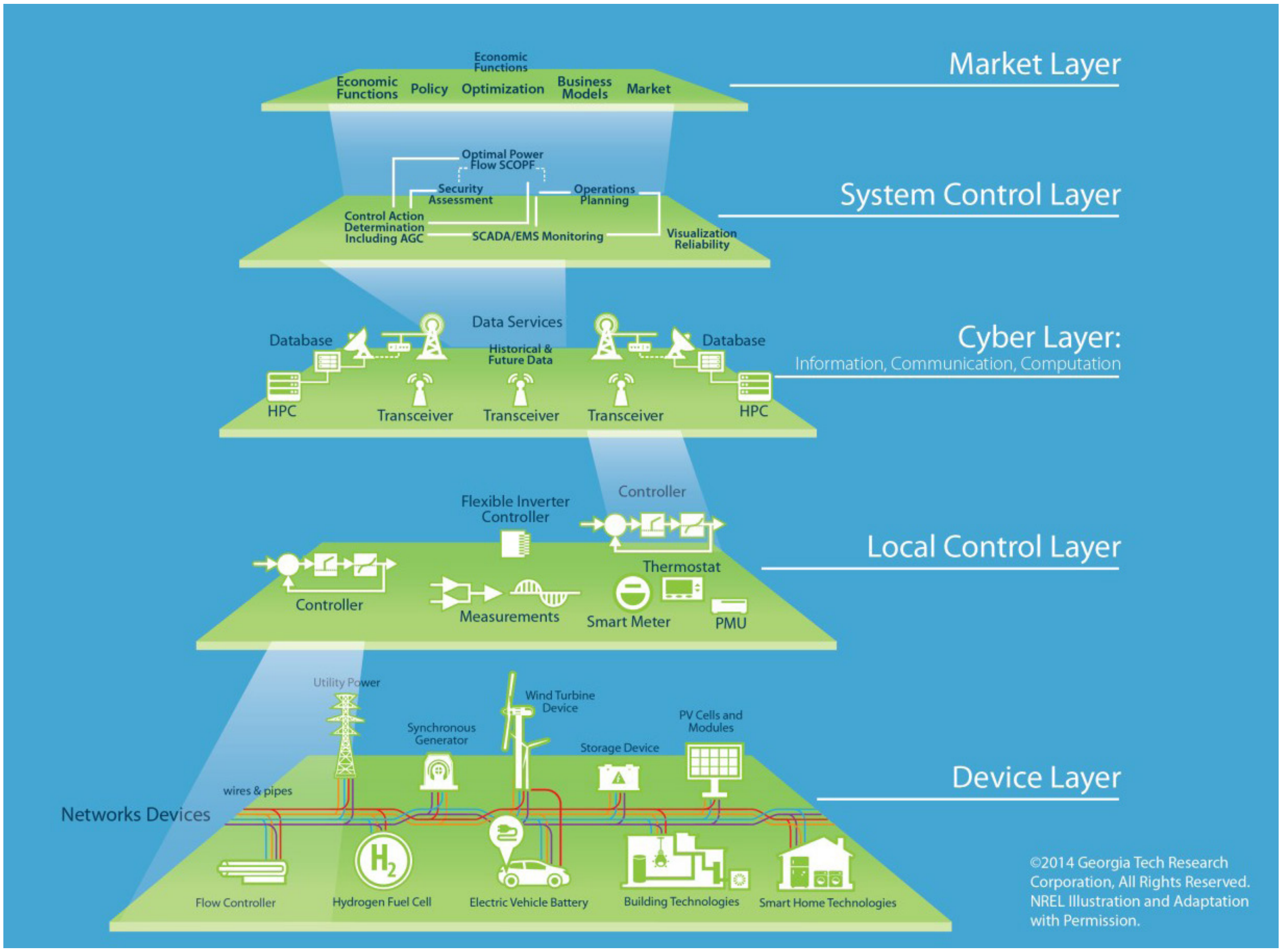


Figure 3. Illustration of the 5 Layers of Communication in a Microgrid
Source: NREL

## Integration with the Grid

For utilities to communicate with advanced inverters in the field they must establish a communications infrastructure. There are multiple protocols and various transfer systems that can be used to build up the infrastructure but standards have not kept pace with the technology advances. In accordance with IEEE Standard 1547, all PV systems must monitor the grid voltage and frequency and disconnect whenever the line voltage or frequency exceeds predetermined levels for a given period of time. In 2013, the California Public Utilities Commission (CPUC) began the process of amending Rule 21 in parallel with the update to IEEE 1547 standard. Both Rule 21 and specifically IEEE P1547 govern the interaction of inverters with the grid.[6] Revisions will enable the advanced functionality of inverters. The use of smart inverters in the design of distributed PV and storage systems can address some of the present challenges of integrating high penetration levels of PV in the electric grid.

### Grid Integration Case Studies

While the standards are being developed, several utilities are designing pilot projects to analyze the advantages of communicating with advanced inverter functions to help inform the standards and develop their own services. The following are some highlights of pilot projects:

6 IEEE (2014). Standard P1547-Series of Standards for Interconnection. http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1335335

*U.S. Marine Corps Air Station (MCAS) – Miramar, CA:*
MCAS Miramar worked with Raytheon to pilot a Primus Power flow battery project. The 250 kW, 500 kWh battery system, called the EnergyPod, is integrated with a 230 kW PV array that provides power to the installation. The microgrid at Miramar is controlled by the Intelligent Power and Energy Management system (IPEM) developed by Raytheon. The IPEM manages the island interconnect device, building HVAC controls, the battery system, and PV array that supplies the critical loads of the Public Works building during power outages. The microgrid is not yet connected to the utility and represents a level 2 communications system. The installation is part of MCAS Miramar's overall plan to rely only on power generated on site. A larger microgrid system is underway that will incorporate the critical loads for the entire base, and is expected to reduce MCAS station's peak electrical demand on weekday afternoons and power critical military systems when grid power is unavailable.

*Fort Hunter Liggett - Jolon, CA:*
In pursuit of resiliency and energy self-production, Fort Hunter Liggett constructed a 1.25 MW, 1 MWh energy storage system in partnership with Tri-Technic Incorporated. In addition to the energy storage system, the installation has 3 MW of solar PV. The energy storage technology is a lithium ion battery, manufactured by Saft. The system uses Siemens inverters, and a control system called WinCC which does system scheduling on the local control level (level 2). The installation partnered with Lawrence Berkley National Lab to implement a system control level (level 4) called DER-CAM (Distributed Energy Resource - Customer Adoption Model). DER-CAM calculates the most economical operation of the system and dispatches the energy storage accordingly. The energy storage system currently has the capability to peak shave, and reduce the amount of solar energy that is curtailed during peak production windows. Due to the remote location, there are limitations on the amount of energy the installation can export to the grid and the energy storage system helps to maximize self-consumption. The end goal is to enable intentional island operation of the critical loads at the installation during grid outages. This will require additional infrastructure investments, more energy storage, and an expansion of the existing control layers (system control layer, cyber layer, and local control layer). The project build out will continue through 2020. The serving utility is Pacific Gas & Electric.

*Eon and Fraunhofer Centre – Pellworm, Germany:*
In 2012 Germany launched a project on the island of Pellworm called: "Smart Region Pellworm".[7] The project integrates the electricity from renewables on the island and decreases the dependency on the mainland grid. The small island generates its own energy from PV, wind turbines, biomass and uses energy storage. The storage system provided by GILDEMEISTER is a hybrid system with lithium-ion battery (1 MW, 560 kWh) storage capacity for peaking and a Flow battery (200 kW, 1.6 MWh) 8 hour storage capacity for baseload. The system is operated by the utility, Eon, and the smart grid controls were developed by Fraunhofer Application Centre for Systems Technology. This design represents a level 5, Market communication layer. The "Smart Region Pellworm" pilot project is an ideal area to demonstrate the integration and controls of decentralized power plants with innovative storage technology and smart grid management systems.

*Arizona Public Service and Tucson Electric Power – State of Arizona:*
Arizona Public Service and Tucson Electric Power Company are presently piloting a program that offers rooftop PV installations to their customers. The utilities will own and operate the PV systems on residential customer homes and compensate their customers with a fee for the use of their rooftops. Through this program the utilities will provide the advanced inverter and controls to manage the systems. The pilot distribution management system will be a level 4 communications testing program that integrates with existing distribution operations. This pilot project for utilities to control advanced inverters is important as new forms of distributed resources such as energy storage and electric vehicles, are deployed on the utility distribution system. Understanding the integration challenges and capabilities of advanced inverters will improve the transition to smart grids in the future.

## Compatibility Challenges

In order to provide valuable on and off-grid services, DG systems must have software platforms that are flexible and can communicate with other devices in the system. Currently, most solar and storage equipment manufacturers create products that are compatible with their own product line, but typically do not have interoperability capabilities to easily integrate with equipment from other manufacturers. This can lead to system design decisions that are made based on compatibility, and not functionality.

7 GILDEMEISTER Energy Solutions, "Treasure Island". Site accessed on 5/31/16: http://energy.gildemeister.com/en/company/news/pellworm-cell-cube-installation/261096

Several organizations are working on establishing industry communication standardization, such as the SunSpec Alliance and the Smart Grid Interoperability Panel but the groups are early in the process and the standards that have been released are not yet robust enough to achieve wide adoption. In the coming years, standardization is expected to accelerate, but there will be a large fleet of legacy equipment that is still in operation.

Communication protocol standardization will support modular systems that are expandable, flexible, re-configurable, interoperable, secure, and which will benefit the industry as a whole and customers alike.

## Summary

To facilitate NYSolar Smart DG Hub's effort to increase resilient PV and storage systems, it is important to understand how resilient PV and microgrid communications and controls function. Systems serving different functions may result in different architecture and communication layers for the microgrid system. Compatible communication controls of diverse devices will be an essential factor in enabling widespread integration. The development of a common language for communicating with distributed inverter-based systems such as PV and energy storage has the potential to improve the industry's monitoring and control capabilities and maximize DG's aggregate benefits.

If you are interested in contacting a vendor to assess the feasibility of a solar+storage project for your home or business, please visit the New York Battery and Energy Storage Technology Consortium's (NY-BEST) Supply Chain Database. Search for battery storage integrators to identify companies that provide energy storage systems.

## About

Sustainable CUNY of the City University of New York (CUNY) is the lead implementer of the NYSolar Smart DG Hub, in partnership with Meister Consultants Group and the National Renewable Energy Laboratory. The DG Hub is supported by the U.S. Department of Energy's Solar Market Pathways program, the NY-Sun Initiative, and the New York Power Authority. The DG Hub thanks the Software Technologies Working Group for their support in the development of this resource.

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