SANDIA REPORT

SAND2012-2215
Unlimited Release
Printed March 2012

Development of Economically Viable, Highly Integrated, Highly Modular SEGIS Architecture

Ward Bower, Sigifredo Gonzalez, Abbas Akhil, Scott Kuszmaul, Lisa Sena-Henderson, Carolyn David, Hussam Alatrash, Ruba Amarin, Evlyn Mark, Mohammad Kuran, Khalid Rustom, Rick Stuby, Ghaith Haddad, Ronald Hamaoui, and Johan Enslin

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

Sandia National Laboratories

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

Available to DOE and DOE contractors from
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831

Telephone:	(865) 576-8401
Facsimile:	(865) 576-5728
E-Mail:	reports@adonis.osti.gov
Online ordering:	http://www.osti.gov/bridge

Available to the public from
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Rd.
Springfield, VA 22161

Telephone:	(800) 553-6847
Facsimile:	(703) 605-6900
E-Mail:	orders@ntis.fedworld.gov
Online order:	http://www.ntis.gov/help/ordermethods.asp?loc=7-4-0#online

SAND2012-2215
Unlimited Release
Printed March 2012

Development of Economically Viable, Highly Integrated, Highly Modular SEGIS Architecture

Ward Bower and Lisa Sena-Henderson
Energy Surety Engineering and Analysis

Sigifredo Gonzalez
Scott Kuszmaul
PV and Distributed Systems Engineering

Abbas Akhil
Energy Storage and Transmission Analysis

Carolyn David
Energy, Security and International Procurement

wibower@centurylink.net, sgonza@sandia.gov, ldhende@sandia.gov

Sandia National Laboratories
P.O. Box 5800
Albuquerque, New Mexico 87185-0734

Hussam Alatrash, Ruba Amarin, Evlyn Mark, Mohammad Kuran, Khalid Rustom, Rick Stuby, Ghaith Haddad, Ronald Hamaoui, Johan Enslin

Petra Solar, Inc.
300-G Corporate Court
South Plainfield, NJ, 07080
hussam.alatrash@petrasolar.com

Abstract

Initiated in 2008, the SEGIS initiative is a partnership involving the U.S. DOE, Sandia National Laboratories, private sector companies, electric utilities, and universities. Projects supported under the initiative have focused on the complete-system development of solar technologies, with the dual goal of expanding renewable PV applications and addressing new challenges of connecting large-scale solar installations in higher penetrations to the electric grid.

Petra Solar, Inc., a New Jersey-based company, received SEGIS funds to develop solutions to two of these key challenges: integrating increasing quantities of solar resources into the grid without compromising (and likely improving) power quality and reliability, and moving the design from a concept of intelligent system controls to successful commercialization. The resulting state-of-the art technology now includes a distributed photovoltaic (PV) architecture comprising AC modules that not only feed directly into the electrical grid at distribution levels but are equipped with new functions that improve voltage stability and thus enhance overall grid stability.

This integrated PV system technology, known as SunWave, has applications for “Power on a Pole,” and comes with a suite of technical capabilities, including advanced inverter and system controls, micro-inverters (capable of operating at both the 120V and 240V levels), communication system, network management system, and semiconductor integration. Collectively, these components are poised to reduce total system cost, increase the system’s overall value and help mitigate the challenges of solar intermittency. Designed to be strategically located near point of load, the new SunWave technology is suitable for integration directly into the electrical grid but is also suitable for emerging microgrid applications. SunWave was showcased as part of a SEGIS Demonstration Conference at Pepco Holdings, Inc., on September 29, 2011, and is presently undergoing further field testing as a prelude to improved and expanded commercialization.

ACKNOWLEDGMENTS

This research was supported by the United States Department of Energy in collaboration with Sandia National Laboratories under the Solar Energy Grid Integration Systems (SEGIS) contract. Petra Solar and Sandia National Laboratories would like to also acknowledge the support and collaboration of the University of Central Florida (UCF), Quanta Technologies, Pepco Holdings, Inc., and Public Service Electric & Gas (PSE&G).

CONTENTS

FIGURES

TABLES

EXECUTIVE SUMMARY

Petra Solar and Sandia National Laboratories have successfully collaborated to complete the work under the third and final stage of the SEGIS initiative. Initiated in 2008, the SEGIS initiative is a partnership that includes DOE, Sandia National Laboratories, industry, utilities, and universities. Its focus is on the development of technologies required to facilitate the integration of large-numbers of solar power generation into the nation's electrical grid [1], [2]. The SEGIS initiative was a three-year, three-stage project that included conceptual design and market analysis in Stage 1, prototype development and testing in Stage 2, and moving toward commercialization in Stage 3.

Under this initiative, Petra Solar developed a comprehensive vision that has guided technology development that intersects photovoltaic (PV) and smart-grid technologies. This resulted in the successful commercialization of Petra Solar's SunWave systems, together with a numerous supporting products.

Technologies developed under this initiative strategically targeted deployment of PV in a distributed fashion near the point of load. PV can be mounted on a wide spectrum of existing structures such as residential or commercial rooftops and utility poles. This eliminates the need for land leasing and citing and associated transmission and distribution infrastructure upgrades, and results in a substantial reduction in transmission and distribution power loss. Advanced control features were embedded in distributed PV, pushing intelligence to the periphery of the power system. A sophisticated command-and-control system offers the coordination of PV deployments with storage facilities forming firm dispatchable "Virtual Power Plants (VPP)" placed under utility control.

Strategic Technology Developments

Petra Solar developments under the SEGIS initiative included these critical components: inverter control concepts, microgrid functionalities, hardware components, and the complete SunWave system that uses a Smart Energy Module (SEM) to communicate with the utility. One of the key developments, the Generator Emulation Controls (GEC), is a unique innovation developed and demonstrated under the SEGIS initiative. It is an inverter control concept designed to approximate electromechanical behavior of synchronous machines that are beneficial for power system stability. GEC is designed to capture the super-synchronous behavior defined by the induced electromotive force (EMF) and synchronous impedance. This equips the inverter with the basic capabilities for voltage regulation support, load following, parallel operation, and seamless mode transitions. Sub-synchronous behavior is then captured through managing the amplitude and phase of the "emulated EMF." This gives the inverter its inertial dynamics, and provides a basis for energy management within the system. GEC-operated inverters exhibit a number of behavioral characteristics that promote stability on the grid. Most notably, GEC features include Volt-VAr voltage regulation support, Hz-Watt frequency damping controls, fault ride-through capabilities, and adjustable voltage and frequency settings.

GEC offers remarkable flexibility and allows the creation of scalable inverter-based microgrids. Adoption of microgrids as building blocks is an effective way of distributing intelligence throughout the grid system. A microgrid hierarchy may be created by arranging microgrids into a pre-defined chain of command and data reporting. This hierarchy will shift the communications and control burden away from a centralized grid controller and create a more "democratic" system. Local microgrid control agents are better equipped with information about local network topology, resources, and requirements. This also allows a small section of the grid to stay operational if it loses its power or communication connection to the grid.

The distinct ability of microgrids to create intentional islands is highly valuable to the grid operator and the end user. For instance, the microgrids can be applied at a feeder level. This provides a means to maintain continuous power supply to local loads in the event of a disturbance elsewhere in the power system. It also isolates both distributed generation and loads within the islanded section during a power quality event. This reduces the interconnected load on the system during a contingency, and enhances the ability of the grid to perform a black start.

The team designed and developed several new hardware components during the SEGIS initiative. Developments included a refined 200W, 120V micro-inverter and a new 200W, 240V model with enhanced features that include night-time communication capability, utility-grade metering, communications network and energy management system, and a clamp-on universal rack and roof-mount rack attachment. Semiconductor integration efforts resulted in the definition and demonstration of an integrated circuit that combines sensing and metering functions.

Petra Solar's AC Module solution naturally addresses the system cost and complexity by eliminating the need for custom string design and requirements for high-voltage DC-fusing and DC-disconnects. Installation is drastically simplified by the elimination of high DC voltage and reducing the system wiring to the familiar service-level AC voltage. Petra Solar's unique utility solution, the pole-mount SunWave system, is a complete system with mechanical racking specifically designed for a short thirty-minute install [3].

Upon installation of Petra Solar SunWave systems, a smart-grid communications infrastructure is created where each SunWave unit serves as a router in the communications network to transport commands, and telemetry to move data to and from the operations center. An important advancement of the SunWave system is installation of "power-on-a-pole" systems that is completed in 30 minutes and less.

The effectiveness of Petra Solar solution is being demonstrated in a number of different ways. A 40MW pole-mount deployment (approximately 200,000 units) is currently under way for Public Service Electric and Gas (PSE&G) in New Jersey that utilizes early design features of the SunWave technology. A lab-scale feeder test-bed was constructed in order to serve as a technology proof-of-concept, and to demonstrate intelligent interconnection functionality advantages of the GEC technology. Quanta Technologies performed a comprehensive grid-impact study that highlighted the benefit of distributed PV, distributed reactive power, and VAr support functionality in mitigating the effect of PV intermittency. In addition, Petra partnerships are installing and monitoring numerous field-trial demonstration sites with utilities around the nation, including a microgrid-capable ground-mount deployment at Pepco Holdings Inc.

A demonstration conference was held on September 29, 2011, at the Pepco Holdings. Inc., field-trial demo site. This was an opportunity to publically display the innovative technology developed through SEGIS funding, highlighting its role as a catalyst to educate and collaborate with strategic stakeholders: the DOE, DOD, Sandia National Laboratories, electric utilities, legislators, regulators, the financial community, and the media. Panel discussions provided a chance for the conference participants to learn from our utility partners about the utility's technical findings and grid reliability challenges of large-scale PV integration.

Petra Solar's development of distributed AC Module technology with two-way smart-grid communications was funded in part by the SEGIS initiative. PSE&G, the largest utility in New Jersey, found this technology to be very attractive, and as a result Petra Solar is now installing its SunWave AC Module systems under a $200M contract with PSE&G. This 40MW installation is the largest distributed solar electric project being deployed in the world today, and has created jobs at all levels of the supply chain, including research and development, manufacturing and assembly, installation and maintenance, finance, legal applications, and marketing. This is in addition to benefits to the supply chain and to the economy.

Petra Solar alone has grown from 15 employees in the spring of 2009 to 170 employees at the end of 2010. The company has developed its own innovative modular assembly line for balance-of-system type solar manufacturing of SunWave systems at its headquarters in New Jersey.

The innovations resulting from this effort contribute to the advancement of the entire PV industry. The advanced technologies demonstrate that PV can be transformed from a threat into a real asset to utilities. It supports Petra Solar's conviction that PV is an effective and reliable way to enhance power quality, achieve a decisive reduction in greenhouse emissions, and relieve the dependence on uncertain sources of fossil fuel.

The Petra Solar team produced numerous technical publications designed to educate the general public, and advance the collective body of knowledge. References to these publications are covered later in the document. This was complemented by active engagement in standards development efforts as a method for catalyzing growth and maturation of the industry.

NOMENCLATURE

ACE	Atlantic City Electric
ASIC	Application Specific Integrated Circuit
black start	Restore power without relying on the external power network
CSP	Concentrated Solar Power
CFD	Computational Fluid Dynamics
CCTV	Closed-Circuit Television
DOE	US Department of Energy
DG	Distributed generation
DMS	Distribution Management System
DFM	Design for Manufacturing
EIA	Energy Information Agency
EPS	Electrical Power System
EMF	Electromotive Force
EMC	Electromagnetic Compatibility
EMS	Energy Management System
FP&L	Florida Power and Light
FEA	Finite Element Analysis
GEC	Generator Emulation Controls
GMS	Grid Management System
LAN	Local Area Network
LVRT	Low-Voltage Ride-Through
LV	Low Voltage
LCS	Lighting Control System
LTC	Tap Changers
MTBF	Mean Time before Failure
NMS	Network Management System
NOC	Network Operations Center
PLL	Phased Locked Loop
PSE&G	Public Service Electric & Gas
PCB	Printed Circuit Board
PCC	Point of Common Coupling
PV	Photovoltaic, Photovoltaics
RPS	Renewable Portfolio Standards
SAI	Solar America Initiative
SCADA	Supervisory Control and Data Acquisition
SC	Petra Solar SunWave™ Communicator
SCA	Supervisory Control Agent
SCADA	Supervisory Control and Data Acquisition
SEGIS	Solar Energy Grid Integration Systems
SEM	Smart Energy Module
SFS	Sandia Frequency Shift
SNL	Sandia National Laboratories
T&D	Transmission and Distribution
VAr	Volt-Amp Reactive
VPP	Virtual Power Plant
WAN	Wide Area Network
X/R ratio	Ratio of reactance to resistance

1. INTRODUCTION

In a world facing economic, environmental, and political consequences from its heavy dependence on fossil fuels, the rapid growth of advanced and intelligent grid-tied PV promises new opportunities. Not only does the PV array convert solar energy into electricity, but the advanced SEGIS system provides electricity with minimal emissions. By exploiting a renewable resource, it leads to greater energy independence both locally and nationally, and contributes to the growth of green jobs in the energy sector and associated supply chain. Moreover, unlike centralized fossil-fuel plants, PV installations can be distributed and placed nearer to loads, thus drastically reducing construction costs and minimizing the need for new transmission lines.

Deployment of large-scale traditional PV faces two distinct challenges. One is total ownership cost, which includes the costs associated with infrastructure development, such as siting and permitting and also the need to buy or lease valuable land. The second challenge reflects characteristics of the resource itself, specifically the intermittency of sunlight and the mismatch between load profile and generation. Such intermittency can become a serious issue for the large-scale integration of distributed PV generation, as it can impact the quality and stability of the grid [2] [4]. Both challenges are further exacerbated by today's constraining standards that govern the interconnection of PV into the grid system (IEEE 1547) [5].

To date, the impact of renewables on grid operation and stability has not been significant, largely because the penetration of solar renewables has been constrained by economic costs and therefore remains limited. As technological improvements lead to cost reductions and value-added functionalities, the percentage of PV energy entering the grid will increase far beyond the recent levels resulting from government incentives and rebates, making the impact of this resource on the grid more tangible.

With support provided by the three-stage SEGIS contracts and partnership, Petra Solar has produced a viable and innovative solution to these challenges, which could radically shift the way PV is deployed. The solution capitalizes on advanced control technology and a distributed generation design to provide renewable power during peak-demand time and very close to the load, thereby eliminating transmission loss when compared with centralized generation. The new technology can be mounted on a wide spectrum of existing structures such as residential or commercial rooftops and utility poles, further adding to its versatility. In addition, advanced control techniques for the system's inverters make possible the coordination of PV deployments to create stable and dispatchable Virtual Power Plants connected to distribution lines that that are under utility control.

1.1. Existing Technology Gap

A closer look at the functions performed on the electric grid reveals a seldom-addressed technology gap in a "traditional smart-grid" approach (see Figure 1.) Specifically, the smart grid must do more than supply energy; it must perform load-following and control functions to regulate the shape its voltage waveforms. Such load-following in turn requires energy storage, spinning reserve, frequency stabilization, voltage stabilization, reactive power supply, and harmonic current supply.

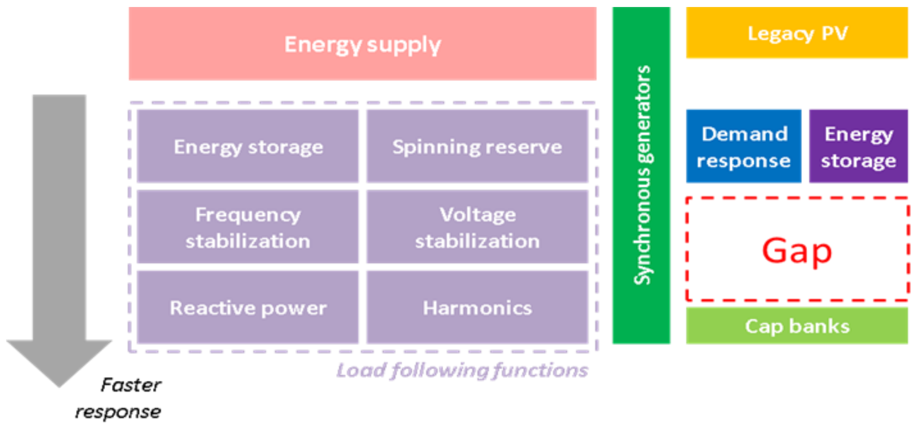


Figure 1. Functions Performed via the Grid, and Interconnected Technologies.

Synchronous generators have inherent electro-mechanical characteristics that facilitate the performance and coordination of such load-following functions, specifically frequency and voltage stabilization. The high-inertia inherent in machine rotors, for example, provides a form of short-term energy storage that in turn results in a natural tendency for frequency and voltage stabilization. In addition, the low stator impedance of these generators allows for the circulation of reactive currents that are required by motor loads. Capacitor banks enhance the ability to locally supply reactive and harmonic currents, resulting in improved voltage regulation, improved signal quality, and reduced network losses.

It is therefore imperative—as PV displaces an increasing proportion of traditional sources of generation—that new technologies are developed to ensure load-following functions are adequately met. Legacy PV systems produce energy when the sun shines and inject non-dispatchable, near-unity power factor current into the grid. But distributed PV generators, which can provide as much as 50 to100 MW, and as much as 100 percent of the distribution load in some regions, are currently not integrated into utilities' dispatch and resource planning solutions. To integrate them properly will require balancing among power resources, as well as energy storage and spinning reserve to absorb load transients, compensate for resource fluctuations, and improve transient and voltage stability in response to such contingencies as the tripping of a large generator. Although demand response and energy storage may offset some of the needs for energy balancing and spinning reserve, and distributed capacitor banks may still be used to supply reactive and harmonic currents, a technology gap remains in the areas of frequency stabilization and voltage stabilization within the "traditional" smart-grid approaches.

1.1.1. The Let-Go Attitude

State-of-the-art grid-tied inverter designs tend to be over-protective: the inverter tends to disconnect from the line at the hint of trouble. This attitude is reinforced by current interconnection requirements [5] (IEEE 1547), posing stability and quality challenges to grid operation in the event of high penetration of distributed generation (DG). The provision for anti-islanding is particularly problematic. This is because state-of-the art methods include two problematic components:

1. Narrow limits: Limits for operating voltage and frequency are limited by today's standards. Interconnection standards require DG to automatically cease to export power whenever observed line voltage and/or frequency fall outside preset limits. As a result of such provisions, DG is unable to ride through temporary grid faults when it may be especially valuable for it to stay online and contribute to system recovery. A particularly troubling scenario is an under-frequency condition due to scarcity of available energy. DG resources would be required to trip—practically simultaneously—while loads continue to be connected to the system. Sudden mass-tripping of DG resources in such a scenario would create a forceful transient that would exacerbate the situation (Figure 2).

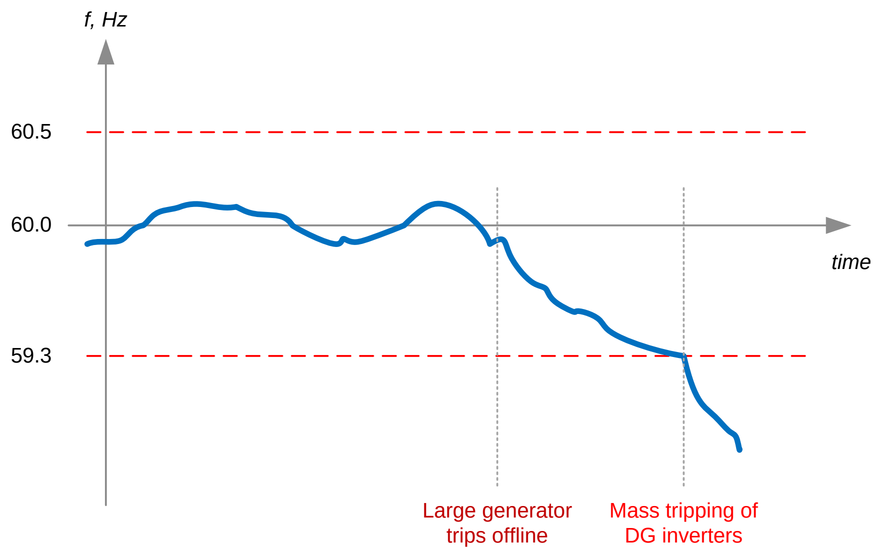


Figure 2. An Under-Frequency Event in a High-Penetration Scenario.

2. Destabilizing behavior: Interconnection standards require DG to cease to energize a closely-matched neighboring load in the case of non-intentional islanding. In response to this requirement, state-of-the-art DG employs an active control algorithm by which real and/or reactive power output of the DG is modulated in a manner that promotes instability in the host Electrical Power System (EPS). Destabilizing behavior is intended to push an island outside the voltage and/or frequency limits, leading to a halt of power generation. It is very important to note that the destabilizing behavior is required to be active as long as the DG exports net active power, even during normal interconnection to a healthy EPS. These algorithms work against natural dynamic damping mechanisms inherent in the EPS. This may result in long-term stability issues for an EPS with large penetration of DG (Figure 3).

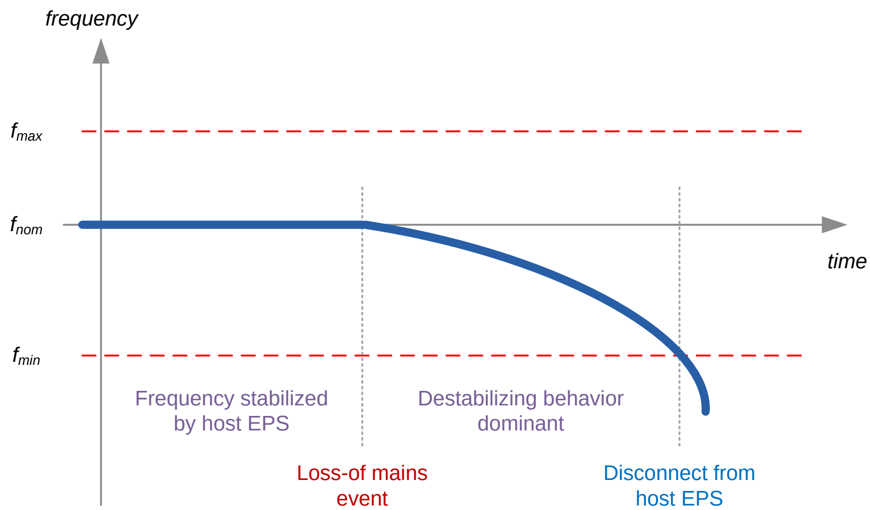


Figure 3. Role of Destabilizing Behavior in Loss-of-Mains Detection.

1.1.2. Command-and-Control

The widespread adoption of DG, along with distributed storage, demand response capabilities, and other intelligent systems on the distribution network, poses a major challenge to the command-and-control architecture of the existing grid. Extending the traditional command-and-control infrastructure to millions of devices anticipated on the low-voltage (LV) side of the distribution grid is neither technically nor economically feasible. Furthermore, exerting direct control over the operation of customer-owned assets may be perceived as an encroachment on their property and privacy.

To address these challenges, communications protocols are being developed in response to the amount of intelligence being added to distributed generation. Also, changes to the command and control model will be made, beginning slowly with scheduled events such as VAr support, which will likely be part of some new interconnections; other changes will come from standards requirements and still others will reflect the many variations in load profiles, distribution networks and generation capabilities. Additional standards will undoubtedly be written as microgrids become more integrated and interconnected with the utility grid. The SEM developed with SEGIS provides communications to the interconnected utility.

1.2. The Road Ahead

1.2.1. Towards Generator Emulation

In order to maintain grid stability and reliability, penetration of PV and DG technologies should be accompanied by a proportional increase in the grid's capacity for load-following functions. One promising approach to reduce the cost of such functions is to integrate load-following directly into DG systems.

Specifically, the controls of a DG inverter can be programmed to emulate the favorable characteristics of traditional generators: controlled impedance [6] [7] and inertia. DG inverters operating in this manner promote voltage and frequency stability in the system to which they are connected. Petra Solar, in fact, developed the GEC technology precisely in recognition of the need for a DG-based technology that enhances grid stability.

1.2.2. The Role of Microgrids

The inverters and controls developed by Petra Solar through SEGIS offer yet another advantage: they can provide power to microgrids, either as a primary source (when the load is not excessive) or as supplementary power to other sources of distributed generation, including engines, fuel cells, or batteries.

With the electricity sector shifting away from centralized generation, microgrid technology offers a promising solution to many grid-based challenges. Operating as a unified system, a microgrid represents a group of energy sources, storage, and loads able to collectively interact with a host EPS. Depending on its design, a microgrid can operate in parallel to the host EPS, and/or it can disconnect and operate as an intentional island. The goals of this behavior are to maximize the value of local energy resources, enhance the reliability of the energy supply to support local loads, and/or support the host EPS [8] [9].

Microgrids can also be thought of as an effective form of distributed intelligence, able to link together into a pre-defined chain of command and data reporting. By further shifting communications and control away from a centralized grid controller, a microgrid also represents a more “democratic” system, with local control agents that have information about local network topology, resources, and requirements. The hierarchical architecture also allows a small section of the grid to stay operational should it lose either its power or its communication connection to the grid.

This distinct ability of microgrids to function as power islands offers great value to both the grid operator and the end user. A microgrid ensures that sufficient power to meet local loads is provided regardless of disruptions that occur elsewhere in the grid, a capability that can be applied at a feeder level. A microgrid also isolates both DG and loads within the islanded section during a power quality event so that the interconnected load on the system is reduced during a contingency, and the ability of the grid to perform a black start is enhanced.

2. SEGIS PROJECT OVERVIEW

2.1. Objectives

The main objectives of the Petra Solar SEGIS initiative are summarized as:

1. Enhance value of PV installation through better system definition.
   - Design micro-inverter-based systems that naturally produce more power and reduce balance-of-system such as protection and installation cost.
   - Develop utility-grade PV systems for highly-distributed applications. This is intended to avoid land and Transmission and Distribution (T&D) infrastructure upgrades, minimize T&D losses, and utilize spatial diversity to mitigate cloud effects.

2. Facilitate the development of lower-cost, high-reliability micro-inverters through circuit innovation.
   - Enhanced circuit design.
   - Semiconductor integration of common components.

3. Mitigate PV impact on grid stability under high penetration through advanced power controls.
   - Develop advanced controls for generator emulation to improve grid stability during transient voltage events, intermittent solar periods, and in microgrid environments.

4. Develop advanced command-and-control.
   - Demonstrate advanced control techniques for grid-tied inverters to bridge existing technology gap.
   - Enable management of a large distributed energy system from a central location.
   - Develop advanced command-and-control strategy as a step towards Supervisory Control and Data Acquisition (SCADA) integration of large groups of PV systems on the distribution network.

2.2. Scope

2.2.1. Utility-Focused System Solution

Petra Solar has pioneered new technology that combines distributed solar energy generation with smart-grid communications and improved grid reliability features to create a utility grade solution that delivers the highest economic value for solar power. Petra Solar's innovative SunWave™ system provides distributed clean energy that ties directly into the electric grid, and does not require an upgrade to either the current transmission or distribution infrastructure, eliminating grid interconnection issues faced by traditional solar systems. One of the key advantages of the Petra Solar solution is its flexible grid integration architecture that enables installation on existing assets that can hold one or more PV modules such as utility and streetlight poles, rooftops, and other available structures.

Petra Solar's highly distributed SunWave PV system evenly distributes generated power throughout the electric distribution network. The system is installed throughout the secondary distribution system of a utility grid, yielding a reduction in T&D losses as well as a reduction in remote generation levels. In distributed PV systems, power is generated very close to the load, eliminating the majority of T&D losses. Distributed generation installed on the secondary distribution system has the potential to eliminate a significant percentage of T&D losses, reduce remote generation requirements, and free up T&D capacity.

Petra Solar's development model also allows streamlined implementation by utilizing existing streetlight and utility poles and other accessible structures. This approach greatly reduces environmental impacts, land use, infrastructure development costs, siting, and permitting, allowing utilities to profitably finance solar through direct ownership.

2.2.2. Communication System

A smart-grid communications infrastructure is created upon installation of Petra Solar SunWave systems. Each SunWave unit serves as a router in the communications network to transport command and telemetry data to and from the operations center. The system utilizes ZigBee as a standard communications protocol, which enables future expansion of additional smart-grid applications.

A utility's investment in solar energy provides the additional benefit of deployment of a tightly integrated wireless communications platform. This allows utilities to eliminate additional costs associated with building a communications network. The SunWave systems and the associated IntelliView™ Portal enable utilities to monitor the operation and health of the units and of the electric grid by recording how much energy is being generated and by sending maintenance and repair alerts to a utility's control center.

2.2.3. New Components

The team developed a 240V/200VA SunWave system as part of the SEGIS effort. The objective of this development was to expand the addressable market. The 240V system will expand the population of utility poles that can accept the SunWave technology. It will also expand the number of systems on the same circuit in residential installations.

On the semiconductor front, Petra Solar's team is constantly working on solutions that address different areas in the design. The advantages of integrating discrete components into semiconductor components include the enhancement in the reliability of the product, in addition to size and cost reduction.

2.2.4. Smart PV on Utility Feeders

Generator Emulation Controls (GEC) is an inverter control concept designed to approximate electromechanical behavior of synchronous machines that are beneficial for EPS stability. GEC is designed to capture the super-synchronous behavior defined by the EMF and synchronous impedance. This equips the inverter with the basic tendencies for voltage regulation support, load following, parallel operation, and seamless mode transitions. Sub-synchronous behavior is then captured through managing the amplitude and phase of the "emulated EMF." This gives the inverter its inertial dynamics, and provides a basis for energy management within the system. For more details about the GEC control, please refer to [10].

The GEC-operated inverter exhibits a number of behavioral characteristics that promote stability on the grid. Most notably, the following features are fundamental to GEC:

Volt-VAr

The Volt-VAr management capability incorporates fixed reactive power (VAR) injection and automated Volt-VAr management. The GEC-operated inverter supports the injection of user-specified fixed reactive power to the full capacity of device operation, both leading and lagging. Automated Volt-VAr operation provides voltage regulation support by sinking reactive power if the line voltage is higher than the selected maximum voltage and by sourcing reactive power if the line voltage drops below the selected minimum voltage shown in
Figure 4. Figure 5 shows the Volt-VAr benefits for over- and under-voltage scenarios.

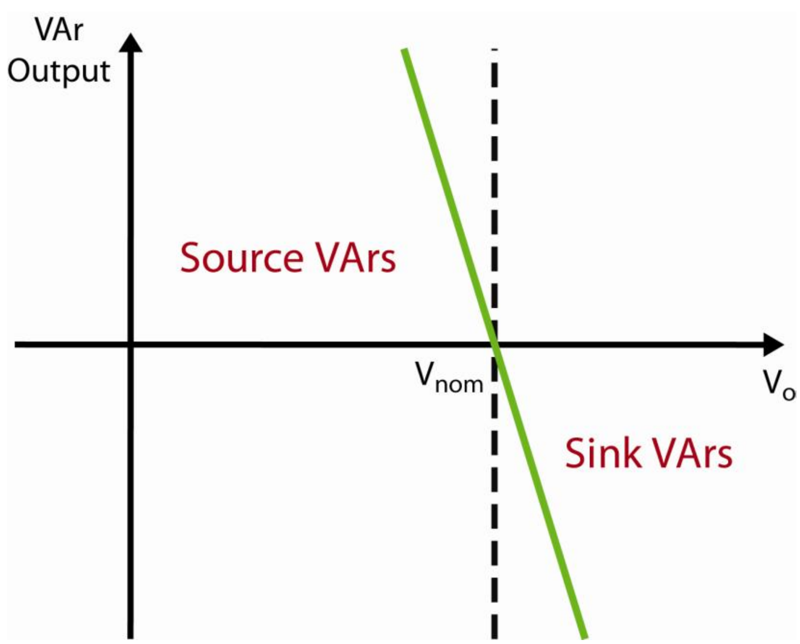


Figure 4. Volt-VAr Droop Characteristics.

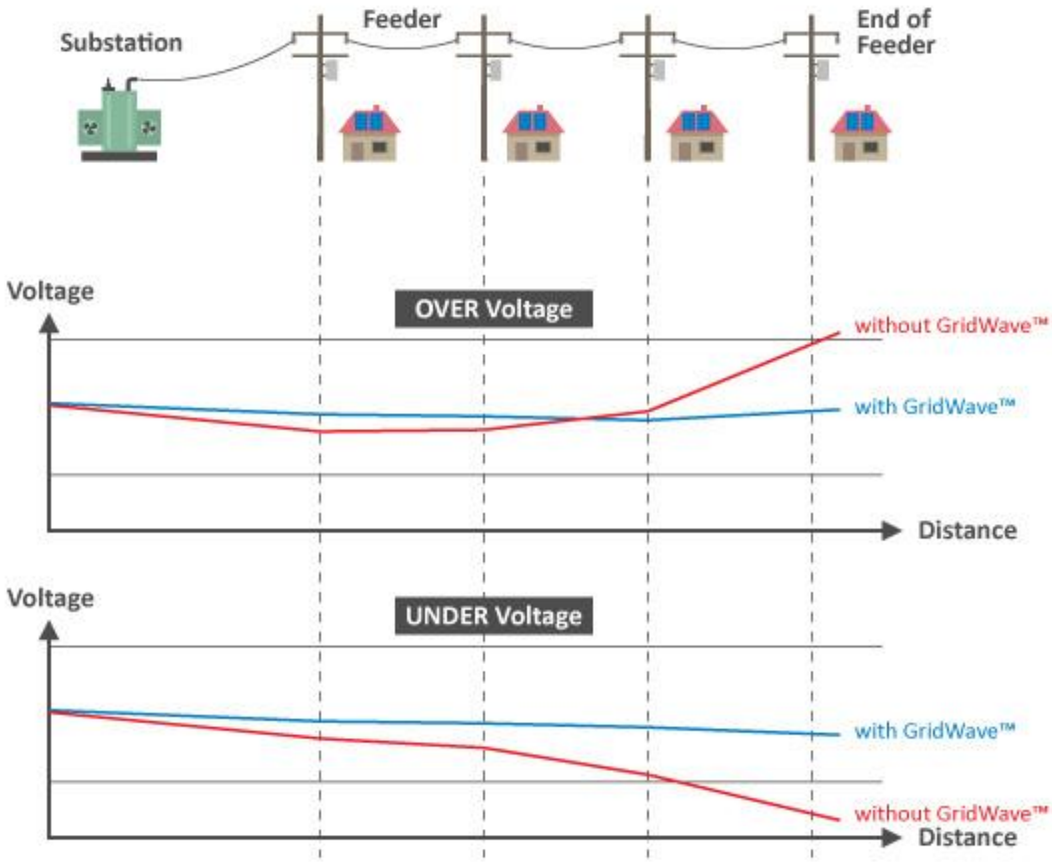


Figure 5. Automated Volt-VAr Benefits.

Hz-Watt

GEC-operated inverters are capable of dynamically modulating real power output in response to frequency transients (Figure 6). This provides a natural protection mechanism against over-generation, particularly in small isolated systems and islanded microgrids. It also provides natural dynamic damping of local load and PV transients in larger systems.

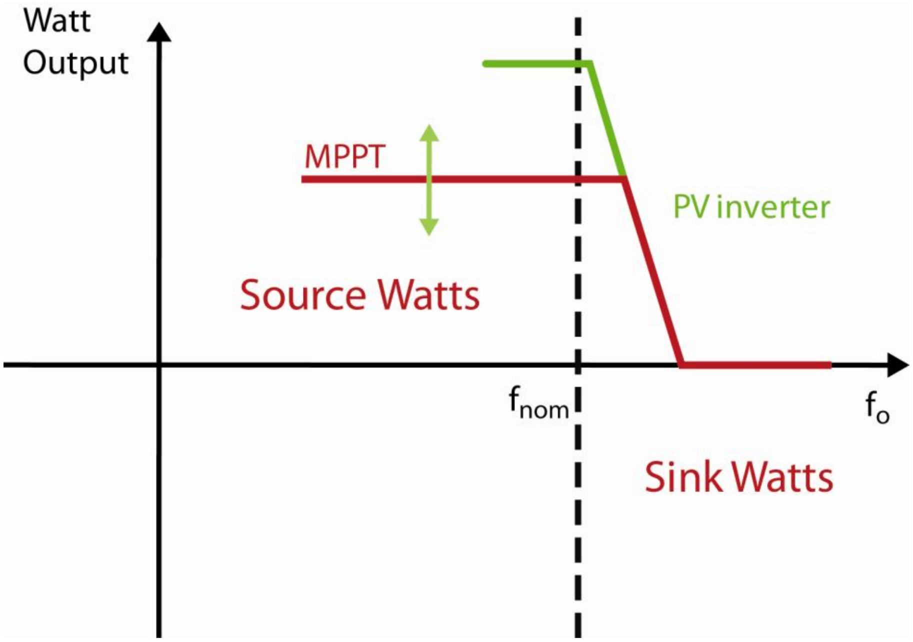


Figure 6. Power/Frequency Droop Characteristics.

LVRT

Low-Voltage Ride-Through (LVRT) enables continued operation of GEC-operated inverter devices for a user-specified voltage limit rather than immediately disconnecting from the grid (as per UL 1741 [11]). As an example, the grid connection will be maintained as a tree falls across a line momentarily, and then falls to the ground. This allows the circuit to rapidly return to its normal state after the clearing/isolation of the fault.

Flexible Voltage and Frequency Windows

GEC-operated inverters support user-specified valid voltage windows within which the device operates when connected to an energized grid. Essentially, this capability allows a GEC-operated inverter to operate within user-selected voltage windows (wider, narrower, or overlapping UL 1741 voltage window requirements). UL 1741 specifies two ranges of operating voltage limits—normal and fast-acting. Grid voltage excursions outside the normal (narrower) limits cause disconnection of the device after a specified number of cycles. A wider excursion outside of the fast-acting limits causes a faster disconnection. GEC-operated inverters follow the same model, but allow the reconfiguration of these limits.

Similarly, GEC-operated inverters support user-specified valid frequency windows within which the device shall operate when connected to an energized grid. Essentially, this capability allows GEC-operated inverter to operate within different frequency windows (wider, narrower, or overlapping UL 1741 window requirements).

2.2.5. Microgrid System Management

A microgrid is an independent local electrical system, which may be interconnected to the utility grid. Microgrids support electrical loads and may support electrical generation capabilities in the form of solar energy, fossil fuel generators, or others, and may also incorporate storage in one or more forms (e.g., batteries). Together, these elements form a self-sufficient electric grid and if interconnected to the utility electric grid, become distributed generation and storage resources from the utility's perspective.

Figure 7 shows an example of a microgrid architecture. During microgrid operation, the microgrid does not exchange real or reactive power with the utility grid; therefore, no utility grid interconnection requirements are applicable.

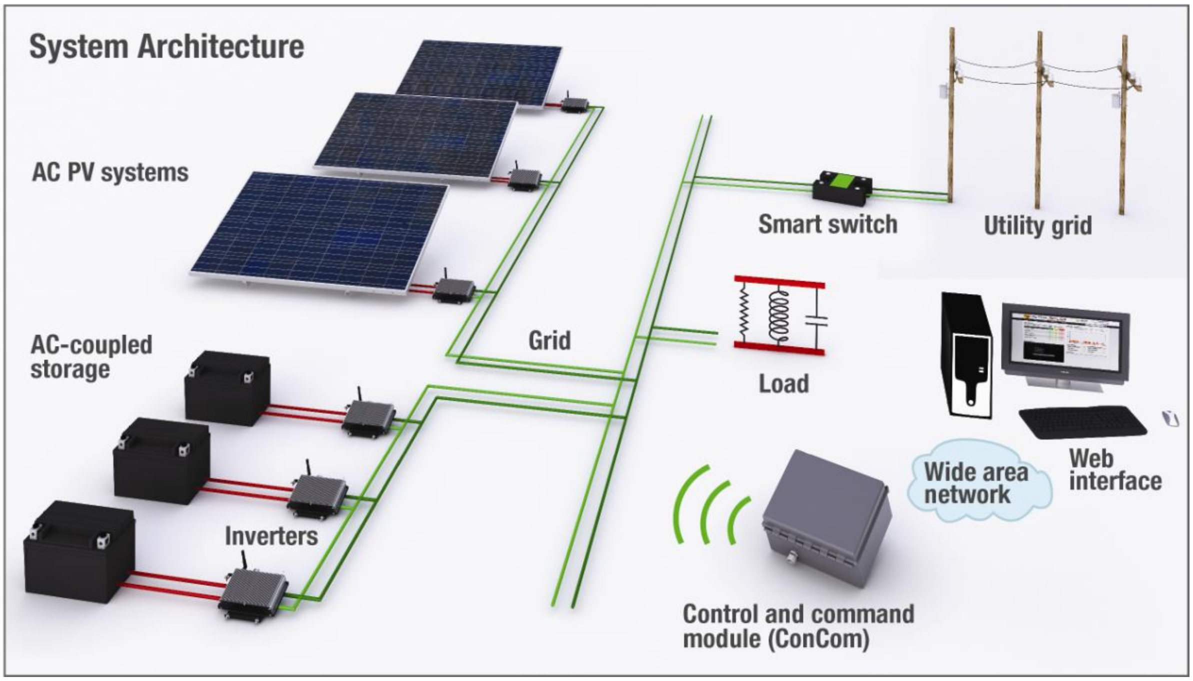


Figure 7. Petra Solar Microgrid Architecture.

A Supervisory Control Agent (SCA) can be used to orchestrate generation, storage, and loads within a locality and can be orchestrated to behave as a coherent microgrid. The SCA negotiates directly or indirectly with the grid management system. The objective of this negotiation is to enhance voltage stability on the grid, and realize the economic objectives of the microgrid. The SCA will have control over a switch at the Point of Common Coupling (PCC) to the host system that behaves as an intelligent gateway. This switch, dubbed the Smart Switch, enables the isolation of the microgrid where it is operated as an isolated island, maintaining power supply to local loads. For example, a future home's microgrid architecture is shown in
Figure 8

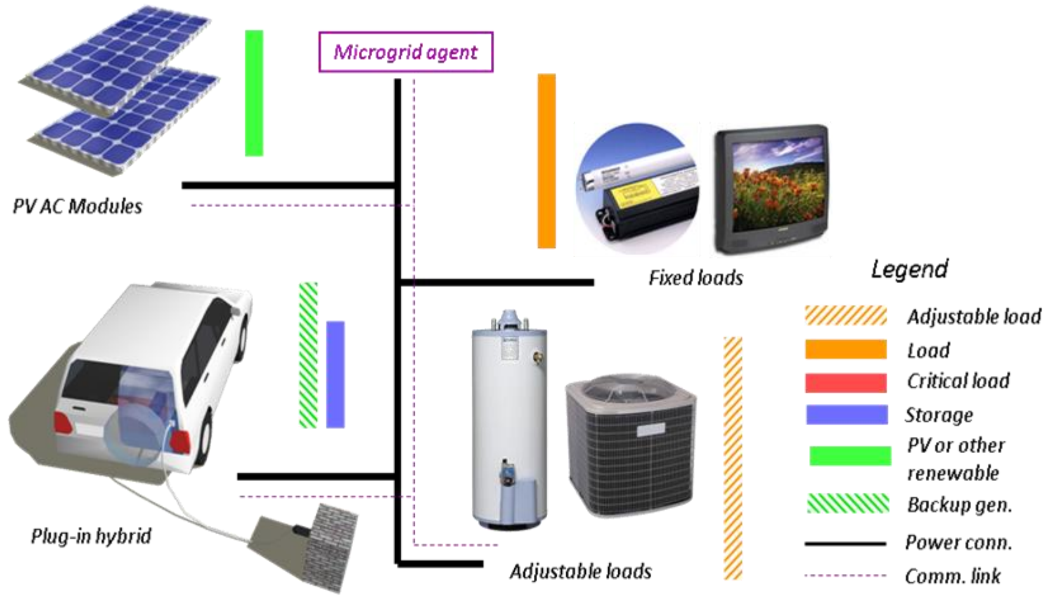


Figure 8. Future Home Microgrid.

2.2.6. Layered Microgrid Management

A layered management approach is proposed for microgrids as outlined in Figure 9.

- Individual resources programmed with GEC controls possess the natural tendency to regulate their terminal voltage and emulate inertial dynamics that promote synchronization and power sharing.
- SCA is used to coordinate their operation into a microgrid. This SCA is responsible for supervisory functions such as synchronization to the host system, management of island voltage and frequency, and compliance to applicable standards at the PCC.
- A third, intelligent control layer performs value-add services. This layer employs resource, load, and weather forecasting techniques together with user preferences, and energy pricing information for monetary and reliability optimization functions. The objectives may be to guarantee power supply to critical loads, engage in energy markets, and/or lengthen the life expectancy of resources.

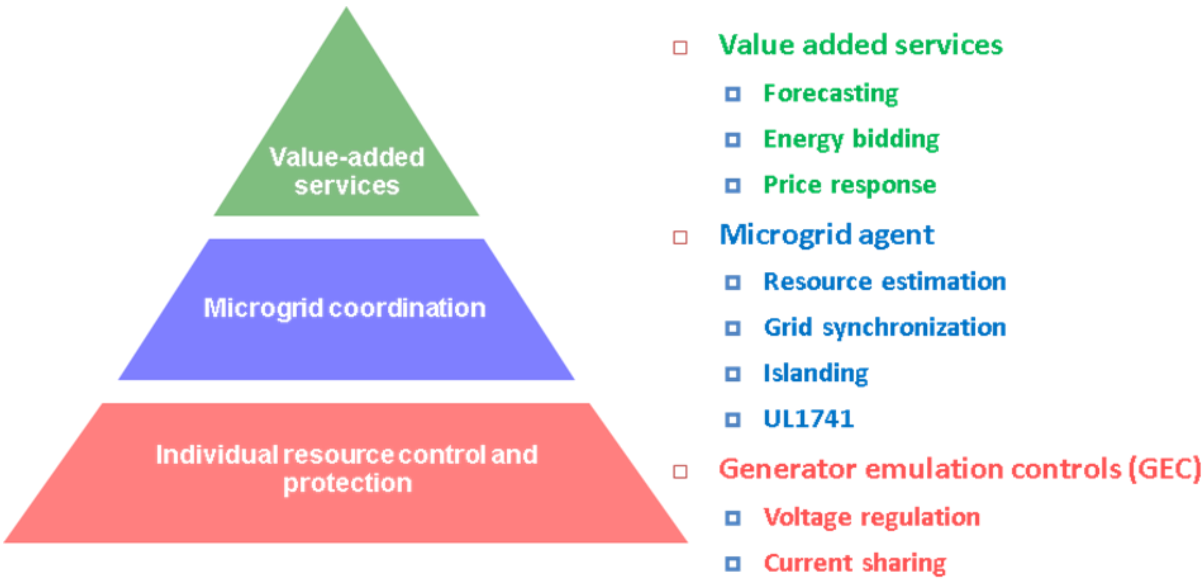


Figure 9. Layered Management Approach for Microgrids.

This layered management approach simplifies the system and reduces the requirements for fast and reliable communications. It also allows individual resources to operate in a safe default mode if the SCA or the communication network is faulted.

Small microgrids will be coordinated to form larger microgrids. Larger microgrids will form mini-grids, and mini-grids will form sub-grids. Figure 10 shows an example of this hierarchy, where a number of nano-grids (small microgrids) form a local microgrid.

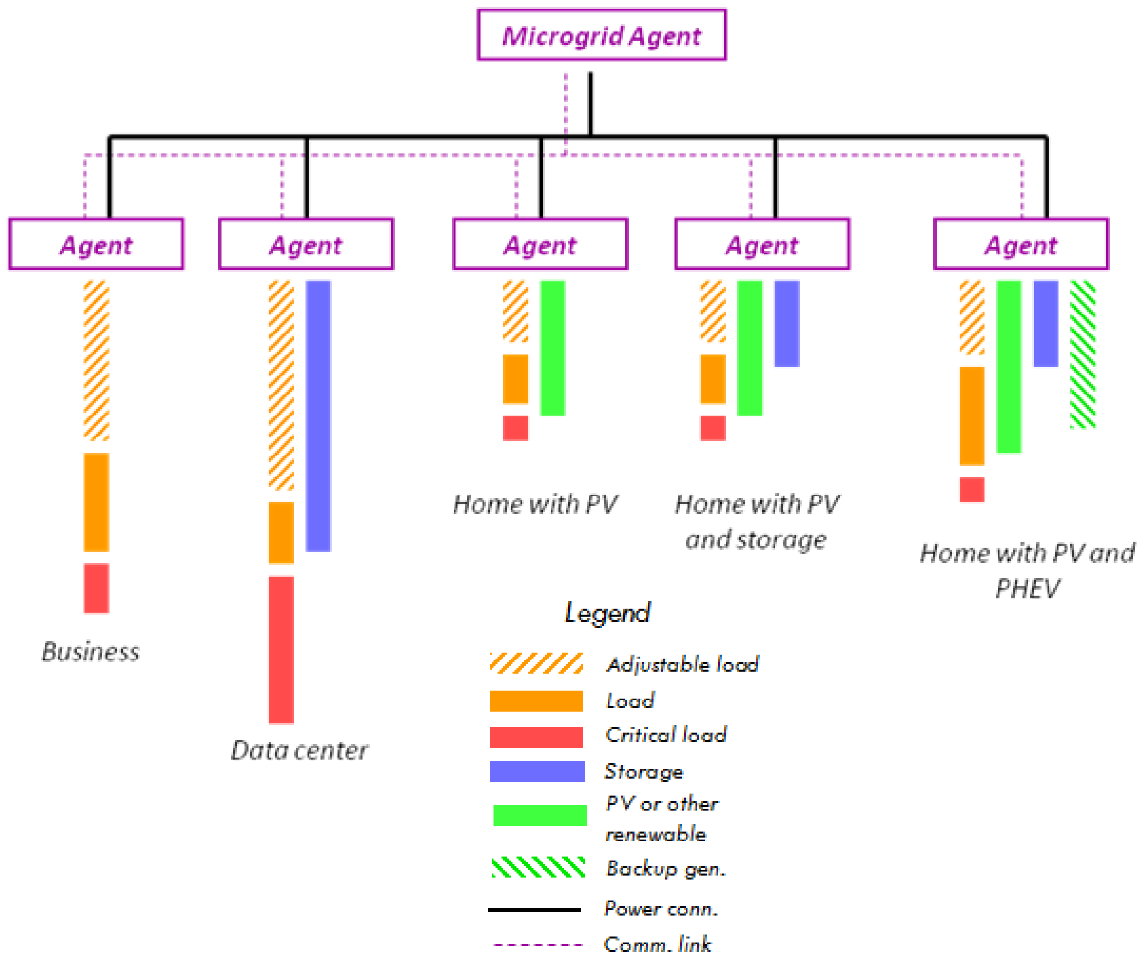


Figure 10. Microgrid Hierarchy Example: Several Home/Business Microgrids Forming a Local Microgrid.

2.3. Methodology

2.3.1. SEGIS Stage 1

Goals

The central theme of Petra Solar's SEGIS effort is to develop an inverter platform that will allow the transformation of the electric grid to a more distributed, robust, safe, and cost effective configuration. To this end, Petra Solar leveraged innovations in power electronics, digital control, communication techniques, and power semiconductor integration to design an advanced integrated grid-tie inverter/controller hardware that:

1. Is more reliable through advanced semiconductor content, high level of integration and packaging, and highly automated manufacturing processes,

2. Is capable of supporting “two-way” communication with the electric grid for enhanced control and monitoring and for taking advantage of protocols utilized by energy management and utility distribution level systems,
3. Has at least a 20 year design life,
4. Achieves a competitive installed cost enabled through a modular architecture allowing for highly distributed deployments.

Deliverables

Per the Petra Solar Work Plan, the deliverables for SEGIS Stage 1 were:

1. Kickoff Meeting
2. Quarterly Report 1
3. Quarterly Report 2
4. DOE program Review in Washington
5. Final Report for Stage 1
6. Critical Program Review at Sandia National Laboratories
7. Stage 3 Proposal

The SEGIS Kickoff Meeting was held at Petra Solar headquarters in South Plainfield, New Jersey on July 23, 2008. This meeting provided Petra Solar with the opportunity to become familiar with Sandia contract administration rules and Sandia’s Technical capabilities that can be leveraged to successfully achieve the SEGIS initiative goals. Petra Solar also provided details on its Statement of Work and project conduct and management.

Quarterly Reports 1 and 2 were submitted on time, respectively on September 19, 2008 and December 12, 2008.

The DOE Program Review was held in Washington DC on February 11, 2009. The Sandia critical Program review was scheduled for April 7 following the submission of Stage 3 proposal on March 6.

Technical Accomplishments

1. A functional distribution grid model was developed to assist our assessment of PV penetration effects on the electric grid.
2. Control and Communication Architecture was designed.
3. Energy Management Junction Box was prototyped.
4. In anticipation of Stage 2 prototyping efforts, an inverter capable of riding through grid disturbances was simulated.
5. Inverters were partitioned into functional blocks that lend themselves to semiconductor integration.
6. Utilities officially joined Petra Solar’s SEGIS efforts and engaged in an accelerated field demonstration projects.
7. Petra Solar participated in the DOE’s Workshop on High Penetration of PV into Distribution Grid on February 24th and 25th in Ontario, California, and provided input to

future research efforts on high level PV penetration in distribution grids. In addition, Petra Solar in collaboration with Center Point Energy and IBM has contributed to the development of a smart-grid demonstration project in Texas.

Market Goals

Market Analysis activities and goals performed in Stage 1 consisted of:

- **Market Sizing:** Petra Solar has recognized the need to engage electric utilities and other power producing entities in the SEGIS market development. To this end, Petra Solar worked with electric utilities and power producers who are required to meet Renewable Portfolio Standards (RPS).
- I**ndustry Cost Structure and Profitability:** Petra Solar was able to significantly lower PV system cost by leveraging existing utility business models and economies of scale. In addition, Petra Solar actively engaged regulators to help its utility clients amortize PV system cost through rate based recovery mechanisms.
- **Distribution Channels and Market Trends:** Petra Solar worked directly with electric utilities, industry groups and regulatory agencies to further utility owned solar deployments. Petra Solar systems were equipped with the proper control and communication features that allowed utilities to maintain grid reliability while accepting distributed energy resources on their customer premises.
- **Specification of key SEGIS Commercial Success Factors:** During the course of Stage 1, Petra Solar and its utility partners have concluded that a more flexible islanding protocol is essential for the commercial success of this program.
- **System Cost Analysis:** Detailed cost analysis of SEGIS architecture prototype development and production unit manufacturing was completed.

2.3.2. SEGIS Stage 2

Goals

The goal of Petra Solar's SEGIS Stage 2 project was to develop an innovative SEGIS architecture, which demonstrates high-level grid-interaction capability, major cost reduction as stated in Solar America Initiative (SAI) goals, and significantly improved reliability and safety of distributed PV Systems. The goal was achieved through a number of technological innovations in the following areas:

- Low cost, easy-to-install, modular and scalable inverter power architecture,
- Multi-layer control and communication architecture allowing a utility distribution system operator to monitor and control a cluster of SunWave AC Module systems,
- Innovative inverter topology offering reactive power control and other voltage regulation benefits for future utility grids,
- Monolithic integration of inverter power-train semiconductor components to simultaneously reduce cost and improve reliability.

Deliverables

Per the Petra Solar Work Plan, the deliverables for SEGIS Stage 2 were:

1. Kickoff Meeting
2. Quarterly Report 1
3. Quarterly Report 2
4. Status Presentation 1 via Web Conference
5. Status Presentation 2 via Web Conference
6. Mid-Year Report
7. DOE Program Review in Washington, DC
8. Final Report for Stage 2
9. Critical Program Review at Sandia National Laboratories
10. Stage 3 Proposal

The SEGIS Kickoff Meeting was held at Petra Solar headquarters in South Plainfield, New Jersey on July 24, 2009. This meeting provided Petra Solar with the opportunity to present the SEGIS Stage 2 objectives and an overview of the major plans and testing considerations. Petra Solar also provided details on its Work Breakdown Structure and project conduct and management.

Quarterly Reports 1 and 2 were submitted on time respectively on August 27, 2009 and January 29, 2010.

Status presentations 1 and 2 via web conference were submitted on time respectively on September 3, 2009 and December 4, 2009.

Mid-Year Report was submitted on time on December 4, 2009.

The DOE Program Review was held in Washington DC on May 24 – 27, 2010.

Stage 2 Final Report was submitted on time on May 28, 2010.

The Sandia critical Program review was held on for June 11, 2010.

Accomplishments

Stage 2 key accomplishments are:

- Development of robust platform to run GEC functionality,
- Development of GEC to enable power generation, ancillary services and grid support, and multiple modes of operations to improve economics of Solar PV Inverters,
- Application Specific IC (ASIC) integration of major inverter building block,
- Development and testing of communications network architectures to accommodate high levels of DG system penetration,

- Development of requirements and best practices for reliable AC Module mechanical integration,
- Lab demonstration of SEGIS system operation,
- Collaboration with electric utilities for development and demonstration of Petra Solar's prototype system.

Market Goals

Market Analysis activities and goals performed in Stage 2 consisted of:

- **Refinement of key SEGIS Commercial Success Factors:** During the course of Stage 2, Petra and its utility partners have focused on refining flexible islanding protocol and the integration of SEGIS control and communication protocols to existing SCADA and distribution management systems.
- **Ongoing System Cost Analysis:** Cost analysis of SEGIS architecture prototype development and production unit manufacturing.

2.3.3. SEGIS Stage 3

Goals

The goals of Petra Solar's SEGIS Stage 3 project were achieved through a number of technological innovations in the following areas:

- Low cost, easy-to-install, modular and scalable inverter power architecture.
- Multi-layer control and communication architecture allowing a utility distribution system operator to monitor and control a cluster of AC Module systems (SunWave).
- Innovative inverter topology offering reactive power control and other voltage regulation benefits for future utility grids.
- Monolithic integration of inverter power-train semiconductor components to simultaneously reduce cost and improve reliability.
- Commercialization of all technologies developed through Stage 1 and 2.

Deliverables

Per the Petra Solar Work Plan, the deliverables for SEGIS Stage 3 were:

1. Kickoff Meeting
2. Mid-Year Report
3. DOE program Review in Washington
4. Final Report Draft for Stage 3
5. Final Report for Stage 3

The SEGIS Kickoff Meeting was held at Petra Solar headquarters in South Plainfield, New Jersey on August 26th, 2010. This meeting provided Petra Solar with the opportunity to present the productization of the Stage 2 SEGIS prototype and the major plans and conference considerations. Petra Solar also provided details on its Work Breakdown Structure and project conduct and management.

Mid-Year Report was submitted on time on April 1, 2011.

Final Report was submitted on time on September 26, 2011.

The DOE Demo Site Conference was scheduled in Mays Landing on September 29, 2011.

Accomplishments

Stage 3 key accomplishments are:

- Productization of Stage 2 prototypes for accelerated field testing
  - Inverter Hardware
  - GEC Control
- Semiconductor Integration
- Network Management System Development
- Field Testing and Demonstration

Market Goals

Market Analysis activities and goals performed in Stage 3 consisted of:

- **Deployment Planning:** During the course of Stage 3, Petra Solar focused market activities on planning for market deployment of SEGIS features including packaging of functionalities for maximum learning and utility to customers.

2.4. SEGIS Concept Paper Comparisons

Through the SEGIS program, Petra Solar developed a long-term strategy focused on advanced PV inverter and system features. This strategy is aimed at facilitating the rapid deployment of vast amount of PV into the national grid system, and is well aligned with the SEGIS initiative vision as outlined in the SEGIS Concept Paper [2]. This alignment is particularly evident through the following efforts and innovations:

Reduced Cost of System and Complexity of Installation

Petra Solar's AC Module solution naturally addresses the system cost and complexity by eliminating the need for custom string design and requirements for high-voltage DC fusing and DC disconnects. Installation is drastically simplified by the elimination of high-voltage dc voltage, and reducing the system wiring to the familiar service-level AC voltage. Petra Solar's unique utility solution, the pole-mount SunWave system, is truly shovel-ready with mechanical racking specifically designed for a short thirty-minute install.

Petra Solar's solution capitalizes on adhoc ZigBee mesh networks for communications. This eliminates the need for complex upfront network design, and enhances the reliability of the communication network through naturally redundancy of data router notes.

Semiconductor integration was aimed at simplified circuit design and enhanced reliability through the combination of various components such as sensing and metering functions. This is a pathway for achieving additional features while reducing the number of solder-joints and simplifying inventory management through reduced component count.

Addressing PV Intermittency

The distributed nature of Petra Solar's pole-mount solution offers geographical diversity that significantly reduces the impact of cloud transients. The installation of PV near the point of load mitigates the requirement for T&D infrastructure upgrades, and reduces power losses through the local supply of real and reactive power.

The system definition achieved through this program packages the distributed PV installation as a VPP under utility control. This is supported by a sophisticated command-and-control solution that places the utility in the driver seat. VPP functionality is based on the ability to supply reactive power, and PV resource firming though the seamless integration with energy storage systems. This is complemented by the LVRT feature, and the ability to modify the operating voltage and frequency windows.

Microgrid Ready Controls

The unique GEC technology developed through the SEGIS contract offers remarkable flexibility, and enables the creation of scalable plug-n-play inverter-based microgrids. This capability dramatically increases the value of the PV system to the residential, commercial, and military customers by enhancing the reliability of the electric supply through intentional islanding. Microgrid functionality is highly beneficial to power utilities as it offers a natural mechanism for sectionalizing the system into cooperative yet independent segments. Such segments can be isolated and reconfigured on the fly to stop the domino effect of system faults. Faults can be confined to a small section of the power system, while power is maintained in other parts of the system.

2.5. Market Update

During the course of the 3-stage SEGIS initiative, the market need for SEGIS capabilities has become clearer and immediate in a number of worldwide markets having significant solar penetration, as well as in certain US regions such as southern New Jersey. Standards are being developed and updated in countries like Germany and Australia to require management of the effects of high solar penetration. These efforts portend of similar needs and expected requirements in the United States for which SEGIS is likely to be a platform. In many ways, the SEGIS initiative has become an enabler for the US market to proactively address solar penetration issues that are being retroactively addressed elsewhere.

3. PETRA SOLAR PRODUCTS AND SERVICES

Petra Solar is a technology company, focused on providing reliable, cost-effective Smart Energy solutions to the electric supply industry. Petra Solar offers a suite of Smart Energy products described in the following sections.

3.1. SunWave Smart Solar Energy Solutions

Distributed PV installation as a Virtual Power Plant (VPP) under utility control is an example of expanded capabilities developed under the SEGIS initiative. It too is supported by a sophisticated command-and-control solution that places the utility in the driver seat. VPP functionality is based on the ability to supply reactive power, and PV resource firming though the seamless integration with energy storage systems.

3.2. SunWave Pole-Mount Solutions

Petra Solar's SunWave pole-mount solutions (Figure 11) offer solar energy generation, smart-grid communications and control, and electric grid reliability capabilities with certified, utility-grade robustness. SunWave systems bring solar online faster, enabling meaningful energy generation utilizing existing assets and time-tested deployment strategies.

The SunWave solution mounts quickly and safely to utility distribution and streetlight poles to deliver power directly to the electric grid. Systems consist of a high efficiency solar module and a Smart Energy Module (SEM™) with smart-grid communications capability, mounted to a utility-grade rack system that is compatible with wood, metal, fiberglass and concrete poles (Figure 12).

This turnkey “mount and play” solution is designed to be easily installed on utility poles by linemen and utility crews in under 30 minutes.

Figure 11. Petra Solar SunWave Pole-Mount Solution.

Smart Energy Module

The SEM (Figure 12) optimizes and manages solar energy production on an individual solar module basis, providing energy harvests averaging more than 10% greater than traditional solar solutions and supports a wider variety of configurations. The SEM also meters energy that is output to the electric grid and safely disconnects the output in the event of a grid fault or disconnect.

Petra Solar's SEM does more than simply provide utilities with visibility into solar energy production. The SEM provides an added benefit of visibility into the distribution grid, and means to mitigate grid secondary performance issues. Each SEM measures the voltage of the electric grid, enabling utility visibility of secondary grid voltage over an area as wide as the solar deployment. SEMs also have the capability to produce reactive power (VAR) to help mitigate voltage or power factor instability on the grid.

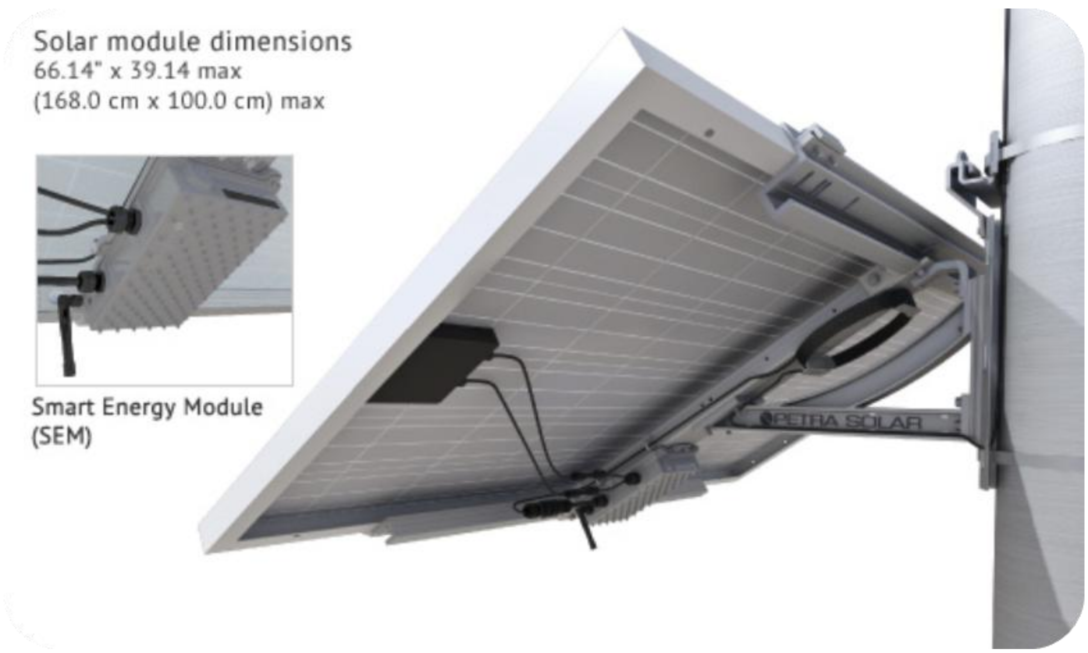


Figure 12. SunWave Pole-Mount System Components.

Communications

Petra Solar provides smart-grid communications for SunWave systems using ZigBee wireless mesh networking sup-ported by cellular, Ethernet, or WiMax backhaul networks. The scalable communications system allows individual monitoring and control of each SunWave AC Module. When coupled with the Energy Portal, this system also enables remote management of geographically dispersed SunWave units as a “virtual power plant.” SunWave communications also support future-proofing of the system through remote upgrade capabilities to leverage future applications and comply with emerging standards; and can be expanded to support integration with other smart-grid management solutions.

The SunWave system serves both the North American (120V, 60Hz) and the international (230V, 50Hz) markets. For the SunWave system 120V and the 230V technical specifications please refer to Appendix A.

3.2.1. SunWave Roof and Ground-Mount Solutions

Petra Solar's SunWave array solutions (Figure 13) offer solar energy generation, smart-grid communications and control, and electric grid reliability capabilities with certified, utility-grade robustness for use in rooftop and ground-mount configurations. SunWave systems bring solar online faster, enabling meaningful energy generation in more configurations in less time.

The SunWave solution centers around a solar AC Module that mounts quickly and safely to rooftop and ground-mount arrays to deliver power directly to the electric grid or behind the meter. AC Modules consist of a high efficiency solar module and a Smart Energy Module (SEM™) with smart-grid communications capability.

Figure 13. Petra Solar SunWave Array Solution.

Configuration

A complete SunWave roof or ground-mount solution includes:

- SunWave AC Module (solar module plus SEM) as shown in Figure 14
- SunWave Communicator®
- Energy Portal software
- Rack and cables

The SEM optimizes and manages solar energy production on an individual solar module basis, providing energy harvests averaging more than 10% greater than traditional solar solutions and supports a wider variety of configurations. The SEM also meters energy that is output to the electric grid and safely disconnects the output in the event of a grid fault or disconnect.

Petra Solar's SEM does more than simply provide utilities with visibility into solar energy production. The SEM provides an added benefit of visibility into the distribution grid, and means to mitigate grid secondary performance issues. Each SEM measures the voltage of the electric grid, enabling utility visibility of secondary grid voltage over an area as wide as the solar deployment. SEMs also have the capability to produce reactive power (VAR) to help mitigate voltage or power factor instability on the grid.

Communications Petra Solar provides smart-grid communications for SunWave systems using ZigBee® wireless mesh networking supported by cellular, Ethernet, or WiMax backhaul networks. The scalable communications system allows individual monitoring and control of each SunWave AC Module. When coupled with the Petra Solar Energy Portal, this system also enables remote management of geographically dispersed solar arrays. SunWave communications also support future-proofing of the system through remote upgrade capabilities to leverage future applications and comply with emerging standards; and can be expanded to support integration with other smart-grid management solutions.

Figure 14. SunWave Roof and Ground-Mount System Components.

The SunWave AC Module serves both the North American (120V, 60Hz) and the international (230V, 50Hz) markets. For the SunWave AC Module 120V and the 230V technical specifications please refer to Appendix B.

3.2.2. SunWave Communicator

The SunWave Communicator® (Figure 15) serves as the hub for advanced communications architecture. It features two-way communications to each smart-grid device connected to it, allowing both individual and system monitoring and control.

Figure 15. SunWave Communicator.

Enabling connectivity to remote, distributed assets using technology best suited to the device applications requirements, the SunWave Communicator is an integral part of the smart-grid network. Much more than a communications gateway, it also provides intelligent communications in any smart-grid. By enabling key decision making processes at this level, utilities can benefit from increased grid reliability and efficiency.

With a variety of wide area network (WAN) interface options and a self-healing reliable local area network (LAN) mesh network, the SunWave Communicator provides a holistic approach to managing the electric grid. As part of the SunWave system, it enables the intelligent energy system to improve grid management by putting much needed data into the hands of utility companies. This is achieved through the continuous monitoring of the system's performance, utilizing operational power flow parameters, real-time analysis, and status updates. The SunWave system enables decision-making processes based on the data from these critical assets.

The standards-based modular architecture provides interoperability capabilities with other smart-grid applications, and leverages the network investment across additional applications and devices as described in Figure 16.

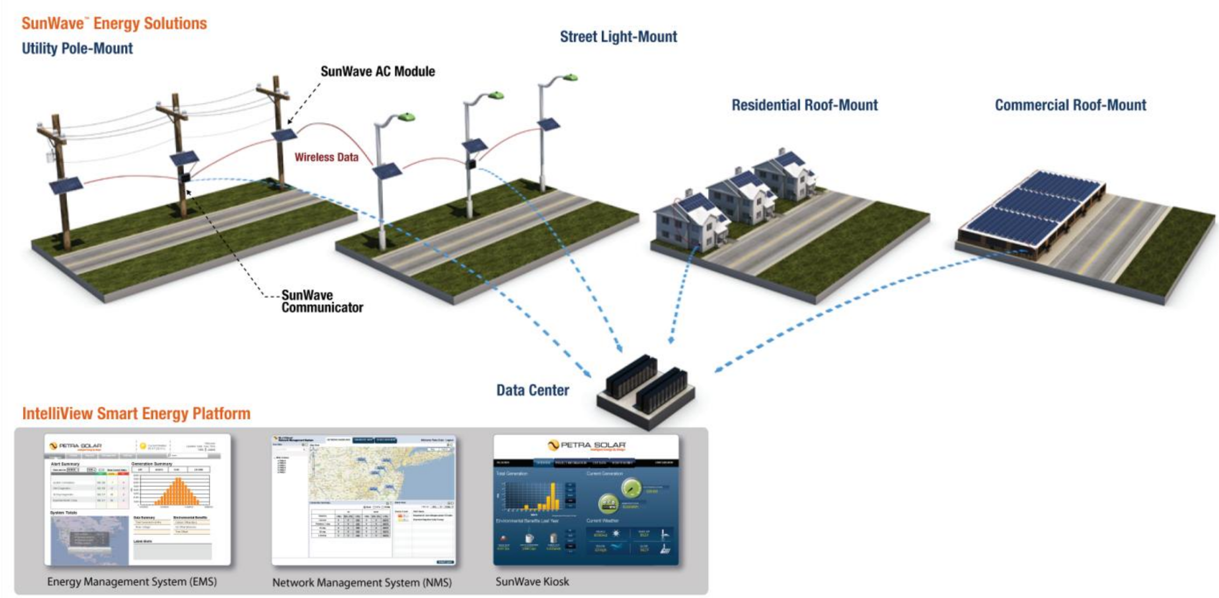


Figure 16. Smart PV Virtual Power Plant.

For the SunWave Communicator technical specifications please refer to Appendix C.

3.3. GridWave Grid Reliability and Efficiency Solutions

GridWave solutions extend the functionality of Petra Solar's SunWave™ Smart Energy offerings with capabilities supporting grid reliability and efficiency (Figure 17). GridWave solutions enable distribution utilities to proactively manage grid effects caused by renewable generation intermittency such as sudden overvoltage or undervoltage conditions as well as supporting existing grid infrastructure by reducing switching frequency of on-load tap changers, voltage regulators and capacitors.

Figure 17. GridWave Grid Reliability and Efficiency Solutions.

GridWave solutions, based on technology developed in coordination with the U.S. Department of Energy's Solar Energy Grid Integration Systems (SEGIS) initiative, are established on the concept of generator emulation which captures the inertial behavior, as well as finite and controlled impedance of a synchronous generator, to facilitate stable grid management. Providing a superset of functionality to UL 1741 operation, GridWave solutions enable utilities to move to next-generation grid reliability functionality while providing for safe return to standard UL 1741 modes. In doing so, GridWave solutions open the door for utilities to proactively manage next-generation standards benefits while maintaining required compliance standards. GridWave Smart Energy solutions are offered as extended firmware capability to the Petra Solar SEM as part of a complete solar Smart Energy solution. Three levels of GridWave functionality are offered: Flex-tie™, Smart-tie™, and Smart-tie™ Microgrid. In doing so, GridWave solutions open the door for utilities to proactively manage next-generation standards benefits while maintaining required compliance standards.

GridWave Smart Energy solutions are offered as extended firmware capability to the Petra Solar SunWave Smart Energy Module (SEM™) as part of a complete solar Smart Energy solution. The three levels of GridWave functionality are explained next:

Flex-Tie

The Flex-tie solution provides an excellent avenue to evaluate and target GridWave capabilities. The Flex-tie offering comprises all of the major GridWave features but provides them as manual, operator driven capabilities. This allows for a clear understanding of cause and effect of each feature and ensures complete control if the operator is unfamiliar with the effects of an automated management system. Additionally, specific grid issues may be targeted on as needed basis prior to deployment of automated functionality.

The Flex-tie package includes:

- AC output power curtailment (manual)
- Reactive power (VAR) injection (manual)
- Voltage operating window setpoints
- Frequency operating window setpoints
- Voltage ride-through controls
- Power ramp rate management

Smart-Tie

The Smart-tie solution is the principal component of the GridWave management solutions. Smart-tie functionality adds automated voltage regulation operation to GridWave through Volt-VAr management and AC output power curtailment. As part of an overall grid voltage optimization system including standard utility practices such as using voltage regulators and capacitor banks, Smart-tie solutions complete the system by managing rapid voltage changes and solar-induced conditions at the grid secondary.

The Smart-tie package includes:

- Reactive power (Volt-VAr) injection (automated)
- AC output power level curtailment (automated)

PLUS all Flex-tie features

- AC output power curtailment (manual)
- Reactive power (VAR) injection (manual)
- Voltage operating window setpoints
- Frequency operating window setpoints
- Voltage ride-through controls
- Power ramp rate management

Smart-Tie Microgrid

Smart-tie Microgrid solutions take Smart-tie operation to the next level, enabling full microgrid (intentional islanding) operations. In a microgrid, GridWave-enabled Petra Solar SunWave solutions are capable of bringing up the grid from a complete off state (black-start) and managing the microgrid load across all GridWave devices. Additionally, if the microgrid is capable of grid-tie through a Smart Switch, Smart-tie Microgrid devices are able to automatically synchronize with grid frequency and voltage for seamless connection, with similar autonomy for smooth disconnect from the grid.

The Smart-tie Microgrid package includes:

- Microgrid black-start
- Support for seamless transition to and from grid-tie
- Automated load sharing (among GridWave compatible devices)

PLUS all Smart-tie features

- Reactive power (Volt-VAr) injection (automated)
- AC output power level curtailment (automated)
- AC output power curtailment (manual)
- Reactive power (VAR) injection (manual)
- Voltage operating window setpoints
- Frequency operating window setpoints
- Voltage ride-through controls
- Power ramp rate management

For the GridWave features please refer to Appendix D.

3.4. IllumiWave™ Smart Lighting Energy Management Solutions

Municipalities and other providers have the responsibility to supply street lighting for their service territories. However, the costs of energy consumption, maintenance, and operations of these devices are considerable. Entities are seeking ways to increase their overall savings and drive energy efficiency and conservation measures at the same time.

The Petra Solar IllumiWave™ smart lighting energy management solution (Figure 18) is designed to address these needs. The IllumiWave intelligent lighting control system provides ON/OFF control of streetlights using traditional photo controls (dawn-dusk sensor) enhanced with two-way communications on the Petra Solar designed smart-grid network. The IllumiWave device mounts on streetlights using a twist-lock installation in a standard compliant three prong socket. In conjunction with light sensing, users can remotely schedule lights to turn on or off at predetermined times for additional savings. Alerts on bulb outages, energy consumption data, and reports are managed via the IntelliView™ Lighting Control System (LCS). The LCS is a secure web-based communications module of Petra Solar's robust IntelliView Smart Energy Management System.

Figure 18. Petra Solar IllumiWave Solution.

IllumiWave System Advantages

The SunWave smart solar solution, with an integrated smart-grid communication network, is the backbone for smart energy applications such as IllumiWave streetlight control systems. The patented pole-mount system allows customers to mount SunWave systems on wood, concrete and metal poles. Many of these poles are collocated with streetlights or at least within the same general vicinity.

When a SunWave system is deployed, it forms a mesh communications network, which intelligently routes data from each unit back to a secure data center. With access to the IntelliView portal, users can remotely command-and-control all smart energy applications on the smart-grid network including SunWave solar systems and IllumiWave intelligent lighting controls (Figure 19).

With IntelliView, LCS users can manage lights by defining groups and implement schedules for energy efficiency according to individual requirements. The system's dashboard provides alert notifications of bulb outages and energy consumption reports. This information reduces the customer call-in volume, thus reducing operational costs. In addition to energy efficiency and conservation measures, LCS can leverage the built-in two-way communications capability to react to load control and disaster events.

Figure 19. IllumiWave Intelligent Lighting Controls.

For the IllumiWave technical specifications please refer to Appendix E.

3.5. Network Operations Center

The Petra Solar Network Operations Center (NOC) offers a highly skilled network asset management service to monitor and manage smart energy assets with advanced monitoring facility staffed by highly skilled operations and technical support engineers (Figure 20).

Figure 20. Petra Solar NOC.

The NOC also expands its smart energy services offering from support of SunWave smart solar systems to the option for full remote 24/7 operations of Petra Solar designed smart-grid networks. Utilities can leverage the expertise of the Petra Solar highly trained technical staff to be the first line of defense in managing, monitoring, and troubleshooting the system. This model allows utilities to focus on other key functions of their operations, while deriving full benefits from their investment in the Petra Solar designed smart-grid system.

Petra Solar's smart-grid services feature data analytics coupled with highly skilled management of critical energy systems. This premiere offering is comprised of the NOC services and IntelliView™, Petra Solar's intelligent energy management portal. This powerful combination allows customers to collect useful data along with operations and support services to manage their smart-grid, including energy efficiency systems.

Network Operations Center Services

Petra Solar's highly trained technical staff, integral to the NOC, provides critical support and operations for the smart-grid and energy efficiency systems, enabling optimal operations of the system and network.

Customers wishing to focus on their core activities outside of the Petra Solar enabled system may choose to leverage Petra Solar's full *NOC Operations /*services, while those wishing to be the primary operators of the system will require only *NOC Support* services.

Network Operations Center Key Features

- Highly trained technical staff
- Remote monitoring
- Troubleshooting
- Problem resolution
- Energy management services
- Grid reliability verification
- State-of-the-art facilities
- Secure monitoring and data hosting using industry standard implementation
- Physical security to NOC location
- Pass card access
- Monitored Closed-Circuit TV (CCTV)
- Redundant data storage and back-up
- Back-up power

Service Levels

- Operations or
- Support

Data Security

- Remote data center
- Secure VPN
- SL
- Firewall and router

For the NOC services please refer to Appendix F.

3.6. IntelliView™

Petra Solar's intelligent energy management portal places data for all deployed remote assets on Petra Solar's smart-grid network into the hands of the customer. Additionally, the processing of myriads of data points in a useful manner empowers the user to effectively operate systems, pinpoint issues, receive alerts, and create reports.

With a two-way communications network to support all deployed systems, not only is the operational data (telemetry) important, but so is the communications network-related data. With the ability to view the status and health of the network, it assures optimal connectivity of all systems. IntelliView is made up of several modules which aid in the analytics of the system.

3.6.1.

IntelliView Services Key Features:

- Manage network remotely to support
    - Grid reliability
    - Energy efficiency
- Isolate and/or overlap network layer from added on applications
    - Network Management System (NMS)
    - Energy Management System (EMS)
    - Grid Management System (GMS) - Available 2012
    - Lighting Control System (LCS) - Available 2012
- Manage by exception – focus on issues only
- Reports on network and system health
- View historical data enabling:
    - Troubleshooting analysis
    - Trending
    - Forecasting
- Secure web hosting
- Secure updates and patches
- Continuous database replication
- Database backup
- Branding customization
- Management dashboards and reports
- Training and user manuals

The IntelliView smart energy platform provides critical analysis of smart-grid application data to enable remote command-and-control of large distributed energy systems. With the NMS as a foundation module, users have a dashboard view of all elements of the communications network. Alerts, performance summaries, and mesh networking diagnostics are provided for problem identification and resolution on an exception basis.

For more details about the IntelliView services please refer to Appendix F.

3.6.2. Network Management System

Network Management System (NMS) as a foundation module (Figure 21), allows the user to configure the network, and ensure maximal system up-time. Therefore, when monitoring core assets (such as the SunWave system), the user has the ability to get the necessary data for reporting or troubleshooting in an efficient manner. Additional modules in IntelliView are added with respect to the devices deployed. Each device with built-in communications is displayed on an interactive map, and users can readily visualize network connectivity, status and issues. A dashboard view allows management by exception, by displaying connection summaries and traces the path of the mesh network via a Radial View.

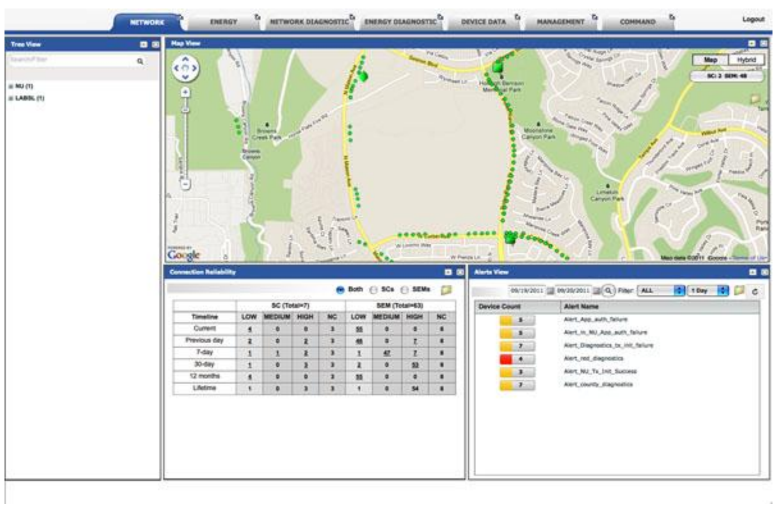


Figure 21. Petra Solar NMS.

3.6.3. Energy Management System

Energy Management System (EMS) module enables a centralized view of a virtual power plant consisting of a large installed base of AC Modules distributed over a broad geographical area (Figure 22). The user can perform remote monitoring, command-and-control capabilities and energy generation reporting.

With distributed generation systems, when data is aggregated in an intelligent manner, it is most useful to the user and familiar, looking more like a power plant. Therefore, in like fashion to the NMS, the EMS provides management by exception features, where expected energy values can be compared to the actual values on an on-going basis. This provides the ability to quantify pre-determined periodic values of energy generation and quickly identify systems which may not be functioning as expected. The EMS features a dashboard view where energy generation can be correlated to geographic locations on a map view, and performance issues are identified and addressed in the alerts and performance summaries.

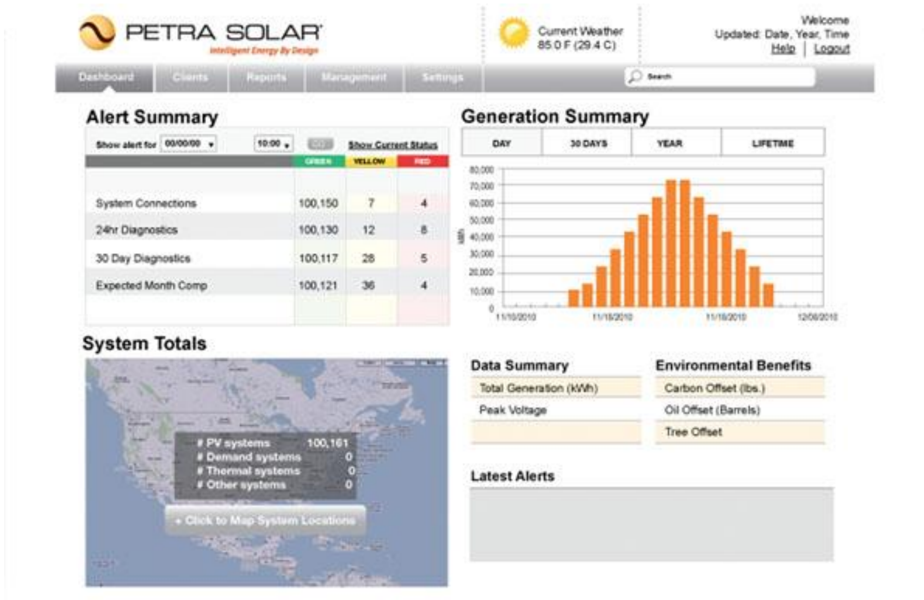


Figure 22. Petra Solar EMS.

More information about the Petra Solar products and services is provided on the Petra Solar website [12].

4. SEGIS TASK DESCRIPTIONS AND GOALS

4.1. Task 1: Productization of GEC Controls

This task focused on the packaging and tuning of GEC implementation in order to prepare for a product launch. This is a first step towards establishing GEC as the standard inverter controls platform for Petra Solar moving forward. The following sections explain the areas that were addressed through this effort.

4.1.1. Dynamic Stability Modeling and Tuning

A detailed dynamics model of a GEC-operated inverter was devised in order to support the systematic tuning of GEC implementation parameters. Design guidelines were derived from this model for supporting controller stability and power quality in two frequency ranges: super-synchronous and sub-synchronous.

Super-synchronous dynamics govern the device response to short-term transients above line frequency. This affects stability and power quality within each line-cycle, and dictates the resulting harmonic signature. To address these dynamics, design recommendation were derived relative to the design of the virtual emulated impedance network used under GEC.

Sub-synchronous dynamics govern the device response to longer-term transients below line frequency. Phase-Locked Loop (PLL) design and short-term energy storage management have a marked direct impact on such dynamics. Design recommendations were derived relative to the design and tuning of the PLL and power flow management used with a GEC-operated device.

4.1.2. "Corner" Testing and Resolution of Nuisance Tripping

Prior to placing the product in field trials and in customers' hands, it was exercised through various "corner" tests. These are stress tests designed to exercise the product under extreme worst-case combinations of conditions such as:

- Excessively high grid voltage
- Low grid voltage conditions
  - Extended period of zero grid-voltage (hard short-circuit)
  - Abrupt recovery from zero voltage to normal
  - Very slow recovery from zero voltage to normal
- Frequency transient: up and down
- Operation with various levels of available PV power
  - Low power operation, close to 0%
  - Full power operation
  - Transients between very low and full power
- Various levels of reactive power
  - Max rated inductive

    - Max rated capacitive
- Various loads in islanded mode
    - No load
    - Full rated load
    - Sudden transition between no load and full load
    - Sudden transition between short-circuit and full load
    - Sudden transition between short-circuit and no load
    - Capacitor load switching
    - Load with high inrush current, such as cold incandescent lamps
- End-of-life conditions: operation with degraded dc capacitance.

These corner tests highlighted conditions that result in "nuisance tripping" of the inverter. These are conditions that cause the inverter to shut-down temporarily and then start back up. Various design solutions were implemented in order to address such events:

- Modified current-limit logic to allow the inverter to cap max output current and continue to ride-through the event. This proved effective in addressing nuisance tripping due to capacitor switching and load inrush currents.
- Revisited voltage set-point for energy storage capacitors, and implemented protection mechanisms that limit discharge and over-charge of these capacitors during transients.

4.1.3. Tune-Up of Inverter Operation in the Standard (Legacy) Mode

A Standard Mode, or "legacy" mode, was defined that will allow a GEC-operated device to behave in a traditional standards-compliant mode. In particular, inverter controls were tuned to meet UL1741 [11] and IEEE 1547 [5] requirements. The Standard Mode is the default operating mode of the inverter at startup and upon loss of communications with its supervisory controller. Advanced GEC features can be activated by remote command.

Three areas were revisited in order to create the Standard Mode:

- DC injection. Active algorithms were utilized to perform cancellation of the dc-current output.
- Harmonics injection. The emulated impedance was tuned in order to allow the harmonic content of the output current to comply with IEEE 1547 requirements.
- Active anti-islanding. The Sandia Frequency Shift (SFS) algorithm was embedded in order to allow effective destabilization and detection of non-intentional islands.

4.2. Task 2: Smart Switch Development

4.2.1. Major Hardware Developments

For wider market acceptance, a decision was made to redesign the Smart Switch to handle a load up to 5kW. In the process of upgrading the Smart Switch to handle a higher capacity microgrid, opportunities for some useful improvements to the original design were capitalized upon.

Capabilities of the expanded Smart Switch included:

Controller

- Ability to drive external contactors, allowing synchronization of larger microgrids
- Act as a controller for intentionally isolating sections of the microgrid
- Control safety disconnection of microgrid sections
- Ability to interface with other controllers

Hardware

- External current sensing greater than 200A
- External LED indicator lamps/and or alarms
- Hardware interface for Interoperability with existing Industrial Controls Systems/Protocols

Expanded Smart Switch Development Progress:

The redesign and implantation of the Smart Switch was successfully completed in Stage 3. Figure 23 shows the actual hardware that was implemented and tested. The Smart Switch was scheduled to be tried in the field at the Pepco test yard.

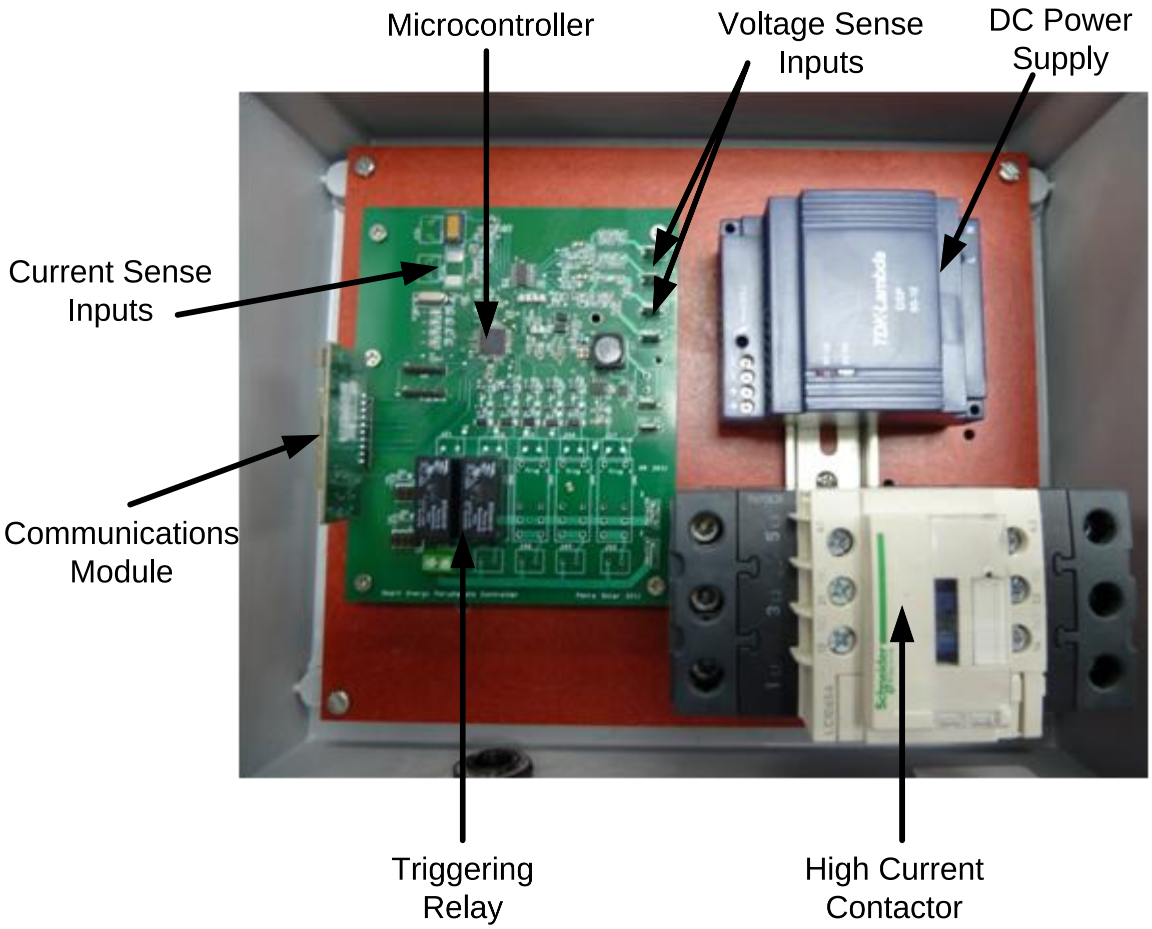


Figure 23. Smart Switch Final Layout.

4.2.2. Major Firmware Developments

Major firmware developments are summarized below:

- Broadcast mode function was implemented to facilitate efficient synchronization of voltage amplitude, frequency and phase.
- Implemented frequency, phase, and voltage amplitude synchronization to the grid.
- Implemented protection functions:
  - Grid voltage and frequency monitoring per UL1741 limits
  - Disconnect if either local or host EPS leaves voltage/frequency windows
    - Isolates faults internal to the local EPS,
    - Allows the microgrid to recover if fault is external (in host EPS).
- The switch operates in the following modes:
  - Bypass modes:
    - Forced disconnect, switch stays open at all times. No synchronization/regulation.
    - Force connection, switch stays closed at all times. No synchronization/regulation.
  - Automatic modes:
    - Regulate island: when local EPS is up, but host EPS is faulted, the Smart Switch

sends regulation commands that manipulate device nominal voltage and frequency settings to keep the voltage and frequency tightly regulated.

- Synchronize and reconnect: when both local and host EPS's are up, the Smart Switch will send synchronization commands that manipulate nominal voltage and frequency settings until the two EPS's are properly synchronize to allow reconnection.
- Connected: the Smart Switch reconnects the local and host EPS's when properly synchronized, and acts as a protection device when they are interconnected. Synchronization/regulation settings for nominal voltage and frequency are cleared.

4.3. Task 3: Inverter Hardware Development

4.3.1. 120V Inverter Development

In order to drive productization of SEGIS hardware, a comprehensive revolution of the 120V inverter platform was completed during Stage 3. Since Petra Solar currently has ongoing partnerships with utilities on the 120V inverter hardware, the decision was made to mature the improvements on the 120V platform and then port these changes over to the 240V platform currently being developed. The scope of the development covered key improvements in the robustness of mechanical, communications, and Power Electronic elements of the design.

Added Features on the 120V SEGIS inverter platform:

1. Night-time communications
2. Utility grade metering
3. Universal rack and roof-mount rack attachment

Performance Improvements:

1. DC injection
2. Electromagnetic Compatibility (EMC), both conducted and radiated
3. Improved wireless communication protocols
4. High metering accuracy

Mechanical Improvements:

1. Weight and cost reduction benefit due to introduction of conformal coating solution.
2. Higher levels of Design for Manufacturing (DFM), practices with focal points on ease of assembly for increased productivity, reliability, reduced hardware count leading us to lower assembly cost overall.
3. Finite Element Analysis (FEA) and Computational Fluid Dynamics (CFD) thermal and gasket design simulation work has been completed in conjunction with our product layout; here again focusing on a high reliability product with a 20 year design life. Confirmation of specification testing continues with initial results indicating Petra has met the design objectives.
4. Creation of a clamping mechanism to attach it to various PV Modules and other racking systems. Eliminating the need for drilling during assembly allowing for cost reduction and higher levels of productivity in manufacturing.

5. Improvements in cable-choke assemblies, and internal insulation systems for the purpose of cost reduction and reliability.

4.3.2. 240V Inverter Development

Further hardware development work has been completed on the 240V inverter hardware. The work has focused on:

- Performance improvement
- Efficiency improvement
- Productization
- Added functionalities

Performance Improvements

To improve the reliability of the inverter and to comply with general de-rating rules for the aluminum electrolytic capacitors, the voltage stress on the capacitor should not exceed 70% of the rated voltage. On the 240VAC inverter, the bus voltage was around 450V, which would require 650V capacitor rating. The commercial long-life capacitor rating only goes to 450V. To mitigate this issue while using long-life capacitor, two 350V rated capacitors were placed in series, and enhance the de-rating on the needed capacitance; two capacitors are also placed in parallel. To avoid any imbalance issues, the flyback secondary winding was split into two equal parts feeding bus capacitors. Figure 24 illustrates this concept and the new configuration for the flyback converter.

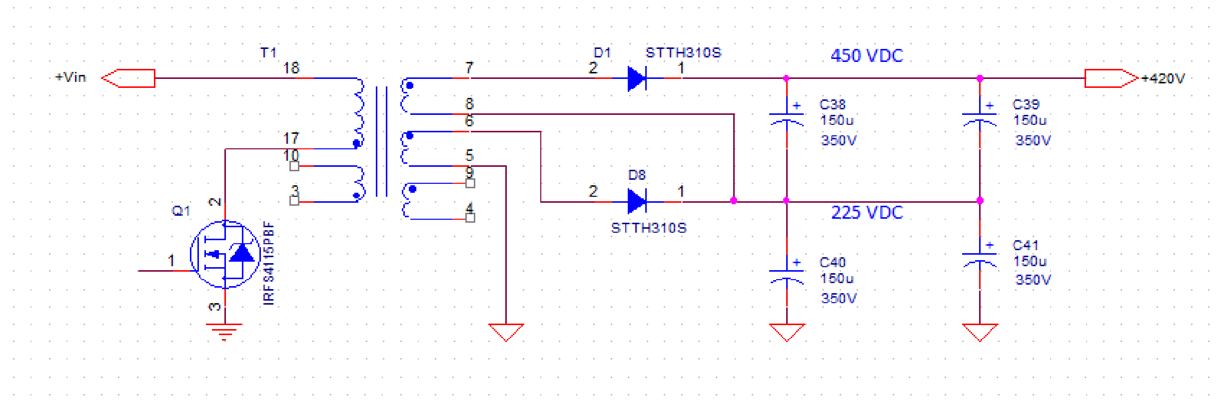


Figure 24. Concept and New Configuration for the Flyback Converter.

Other improvements on the circuit include the enhanced DC current injection circuit. Going from 120VAC to 240VAC on the output voltage while maintain the same power rating resulted in lower AC current in general, and required enhancement to the current sensing circuit to be able to detect lower DC current to comply with the new limit of 5mA on the 240V inverter. To accomplish this task, a new current sensing circuit was utilized, and a separate gain circuit was added for the DC current only.

Productization
As part of the productization of the 240V inverter for deployment, an internal comprehensive validation and reliability test has been performed.

Added Functions

During Stage 3, the inverter was redesigned to add some additional functions to improve reliability and enhance manufacturability. Among the added functions was high accuracy power metering.

Realizing the potential benefits for continuous monitoring of the grid voltage and frequency, Petra Solar also added a night-time power circuit that could keep the metering functions and the communication running while there is no input power.

During this revision as well, the communication circuit was integrated into the main power board. This will reduce the number of assemblies needed and enhance the overall reliability of the circuit.

4.4. Task 4: Semiconductor Integration for SEGIS

Petra Solar has always been a believer in the advantages of integration in power electronics systems. This has been the driver behind the semiconductor team in the company. The team is constantly working on solutions that address different areas in the design. The advantages of integrating discrete components into semiconductor components are many, including:

- Enhance the reliability of the product through reducing the number of solder joints on the PCB.
- Reduce size, which means a smaller inverter, less shipping and manufacturing cost.
- Reduce cost due to the smaller number of components and the reduced size.
- Protect intellectual property in concealed integrated circuits.

However, semiconductor integration is not a trivial task. It involves long lead times and requires accuracy in the design. While discrete components' replacement is easy and straightforward, modifying the circuit inside an integrated circuit requires mask changes and processing of new circuits. This usually takes months. Therefore, it is the custom with integrated circuits that the design is verified over and over before releasing it to make sure that it is error free. Mistakes can be costly and can introduce massive delays to the programs.

Petra Solar's work in semiconductor integration led to the introduction of an ASIC that integrates the components needed for sensing the output current and voltage. The new integrated circuit replaces conventional discrete solutions consisting of voltage sense transformers, current sense transformers, and hall-effect devices with a single integrated solution improving accuracy, reliability, and size.

The new AC Sense ASIC features high speed, high resolution circuitry with integrated analog to digital (A/D) converters making the sensed voltage and current signals available in high resolution digital format. The new chip is therefore very suitable for control functions in addition to the monitoring capabilities for grid tied solar systems. Other features include programmable gains, on-chip calibration to compensate for external component variability, and fast over-current detection for enhanced protection. In addition, the chip offers advantages over alternative approaches in terms of reduced DC current injection, facilitating compliance with various standards.

Petra Solar continues to drive semiconductor integration efforts targeting the output sensing circuitry and other segments of the design.

4.5. Task 5: Network Management and System Development

Petra Solar has leveraged the SEGIS Stage 3 funds to develop the NMS to better manage distributed solar PV and other distributed energy resources. The NMS design has led to the opening of a NOC from which Petra Solar is managing existing installations all over the United States, Canada, and soon across Europe, the Middle East, and Australia.

The NMS is a central management system that provides a single web portal to handle user actions such as:

- Managing Petra Solar mesh-network control, configure and monitor a dispersed population of solar systems,
- Track and save results for further analysis,
- Providing easy access to histograms and statistics of the network activity.

NMS Description

NMS allows remote monitoring, management, and control capabilities of the physical wide-area smart-grid network. Every AC Module is a network element in this system. Having a view of the network connectivity ensures proper network operation and enables fast diagnosis of communications issues.

The NMS has several functional views and windows. An outline for the applications can be summarized as follows:

- Dashboard View
    - Tree widget
    - View Alerts widget
    - Maps widget
    - Connection Summary widget

- Diagnostic View
    - Tree widget
    - Information widget
    - Maps widget
    - Radial widget

- Device Data View
  - Tree widget
  - Data Grid widget
    - Information Section
    - Telemetry Data
    - Health Data
    - Network Diagnostics Data

A brief description of the main functionality of the NMS system is explained next.

Network Dashboard

The Network Dashboard enables management of the network elements from a high level management view (Figure 25). This functionality displays a roll-up of network alerts, which may require attention or maintenance. These alerts are part of a "management by exception" structure, allowing the operator to be alerted to problems as they happen, rather than searching for them.

An "integrated" map display of the network resources, coupled with alert data, facilitates the monitoring of the wide-area smart-grid network. The dashboard consists of the network functionalities that provides access to devices and monitors their connectivity, providing communication statistics and alerts to units that are not communicating reliably. The functionalities within the Network Dashboard are Tree View, Map View, Alerts, Connection Summary, Communication Traffic, and Search.

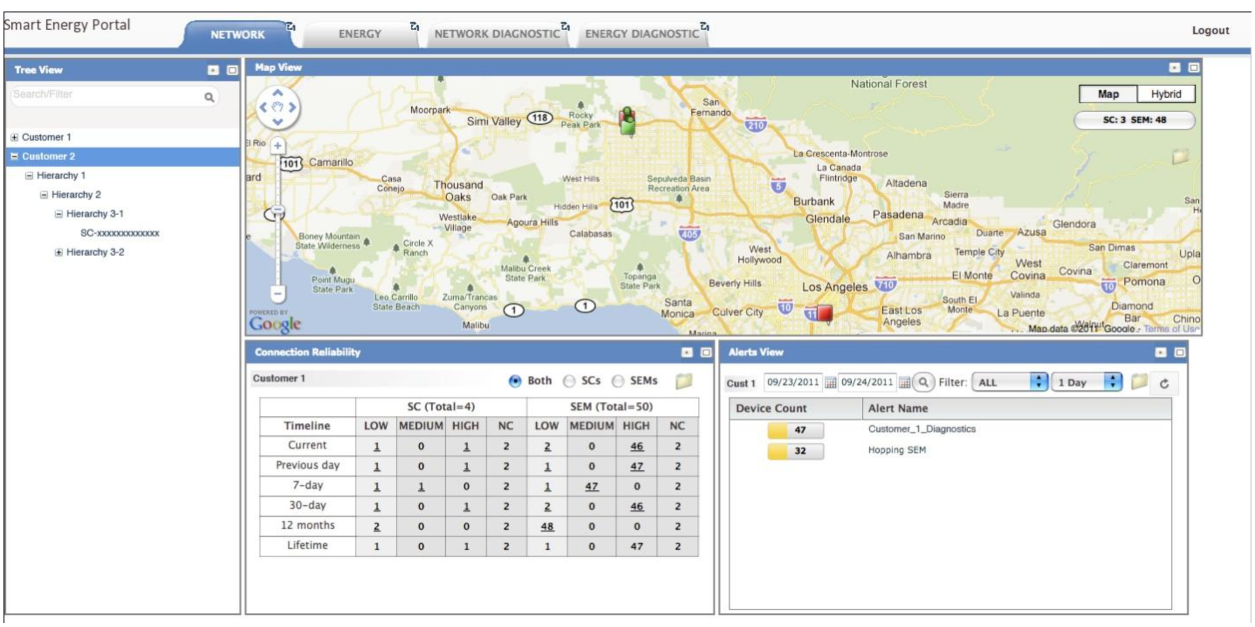


Figure 25. Network Dashboard View.

Tree View

The Tree view provides a hierarchical view of the system, where each AC Module will be grouped under the SunWave Communicator™ (SC) through which it communicates.

Map View

The Map view gives the geographical view of the system, enabling users to visualize the location of each system, and the path that its data takes to reach the Smart Energy Portal.

Connection Summary

The Connection Summary provides a statistical overview of how many devices are reporting to the Smart Energy Portal. The user can view the number of AC Modules and Communicators that are actively reporting, as well as the number of units that are not reporting reliably or not reporting at all.

Network Alert

Network Alert indicates the alerts triggered by network connection issues. Each SEM is designed to report to a particular Communicator. When a SEM fails to report or reports a non-designated Communicator the alerts are triggered. These are displayed in the Network Dashboard. The Alerts are color coded based on their priority.

Communication Traffic

Communication Traffic displays data communication between Communicators and SEMs. It is a graphical representation of amount of data flow between Communicators and SEMs in a given timeline.

Automated Reporting

The Report button generates a screen shot and exports the image of the dashboard view selected by the User.

Radial View

The Radial View is one of the key functionalities of the NMS (Figure 26). It allows the operator to monitor the mesh network by displaying the communication path between each AC Module and associated Communicator, displaying the routing path of the network. The center of the radial view represents the Communicator, and the colored dots represent the AC Modules that are communicating through that Communicator. There are multiple levels of AC Modules shown because AC Modules communicate through each other, forming a mesh network, to reach the Communicator.

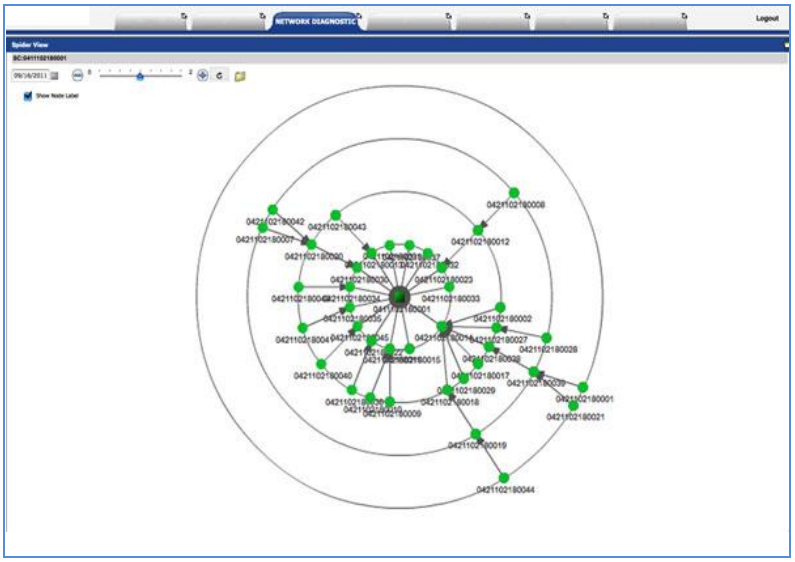


Figure 26. Radial View.

4.6. Task 6: Demonstration and Impact Studies

4.6.1. Laboratory-Scale Feeder Test-Bed

The team built a laboratory-scale feeder test bed to serve as a platform for technology proof-of-concept demonstrations. It is targeted towards feeder-level distribution automation functions such as Volt-VAr voltage regulation, harmonic compensation, and PV firming using energy storage.

A typical simplified 12kV/10MVA feeder was scaled down to 120V/5kVA on a per-unit basis. The substation was simulated by a constant-voltage AC source, while loads and PV clusters were installed at four points along the feeder.

The layout of the feeder is shown in Figure 27. It consists of four segments of 5% impedance with an X/R ratio of 2.0. This impedance was simulated in the test-bed using air-core wound inductors designed for the appropriate parameters. Four load centers are tapped off the end of each segment, some of which have PV installed. The test-bed was also outfitted with power analyzers to measure voltages at various points along the feeder, along with the real and reactive power flow out of the substation and into each of the load centers. This allows for the demonstration of the effect of reactive power on feeder voltage profile, as well as the effect of distributed real and reactive power generation on distribution losses along the feeder.

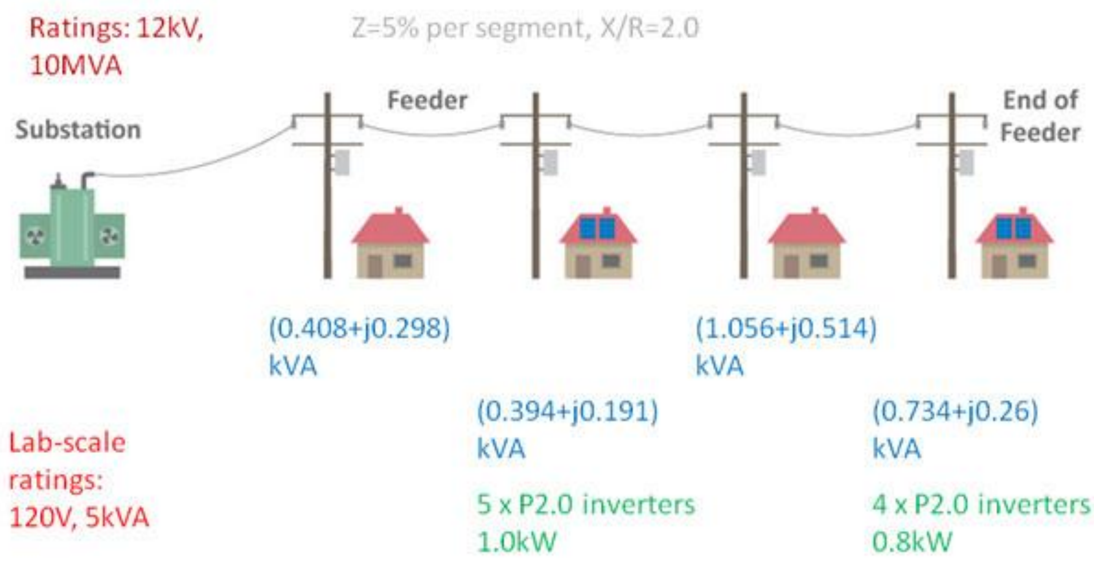


Figure 27. Simple Feeder Diagram.

4.6.2. Customer Site Field Demo

The SEGIS field demonstration system was installed at PEPCO's Atlantic City Electric training yard located at 5100 Harding Highway in May's Landing, New Jersey. The Installation occupies approximately 500 square feet in the south portion of the training yard. Figure 28 illustrates the installation location.

Figure 28. Installation Location.

The electrical one line diagram for the demonstration system is summarized in Figure 29.

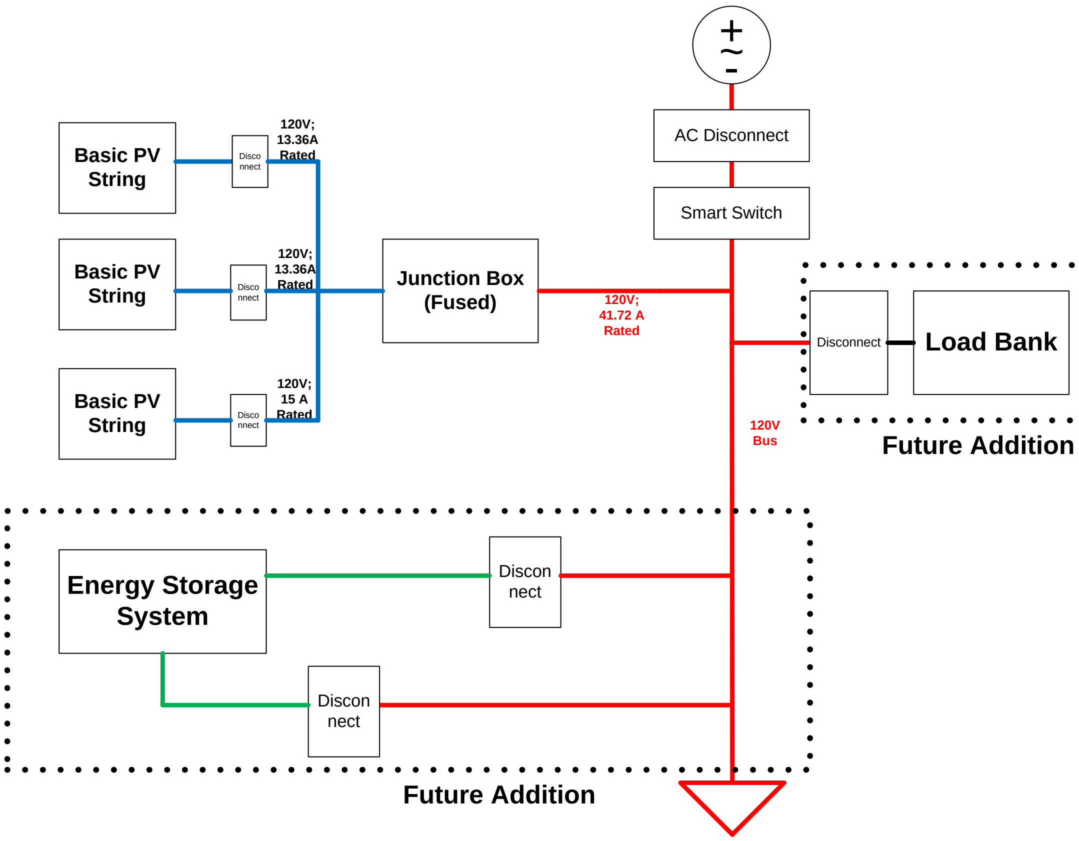


Figure 29. The SunWave SEGIS System – Electrical One Line Diagram.

Note: The SunWave SEGIS System is referred to as the "system" throughout this section of the document.

System Description

The system includes three main circuit branches, which connect to a central 120VAC bus. These branches are:

- The Solar PV Branch
- The Energy Storage Branch
- The Load Branch

In addition to these circuit branches, the system includes:

- A Smart Switch
- A Communications System

Solar PV Branch

The Solar PV Branch consists of a 5kW solar PV system. The PV system includes a total of 25 AC Modules, each rated at 200W, with an output of 120V/60Hz. These 25 AC Modules are grouped into three parallel connected strings. Each string includes either eight or nine AC Modules connected in parallel.

AC Module Specifications

Table 1 summarizes the AC Module specifications.

Table 1. AC Module Specifications.

Electrical Characteristics		
Specifications	*Typ*	*Max*
Output Power (VA)		283
Real Power (W)		200
Reactive Power (VARs)		200
Output Voltage (V)	120	
Output Frequency (Hz)	60	
Current THD		<5%
RMS Output Current (A)		1.67
Efficiency		
Weighted Sunlight to AC Output		13%
DC-AC Conversion		
Peak		95%
CEC Weighted		93%

Thermal Characteristics			
Specifications	*Min*	*Typ*	*Max*
Operating Temperature (°C)	-40		85
Temperature Derating above 65 °C Ambient (W/°C)		-2.5	

Key Features
Ancillary Functions
Automatic (Volt/VARs Droop) and On-Command VAR injection
Automatic (Power/Frequency Droop) and On-Command Power Derating
Outage Ride Through per Utility Command
Low and Zero Voltage Ride Through
Communications & Monitoring
Remote Monitoring, Control, and Configuration of Solar PV systems
Integration into Smart Grid Communications Networks

Modes of Operation		
Legacy Grid Tie	**Smart Grid Tie**	**Islanded**
UL1741-compliant operation	Line Voltage & Frequency Support	Microgird Voltage & Frequency Regulation
	Programmable voltage/frequency windows	Automatic load sharing between AC Modules
	Low and Zero Votlage ride-through	Black Start Support
	Reactive power injection	Seamless transition to and from grid-tie
	Power de-rating	

AC Module String Configuration

Figure 30 shows the string configuration of parallel connected AC Modules.

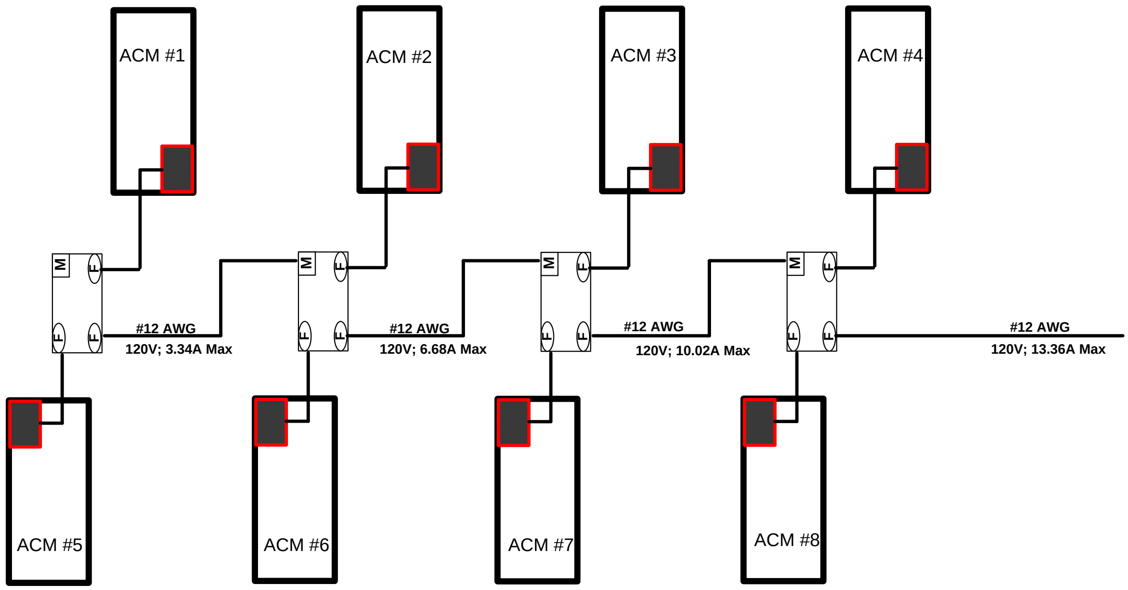


Figure 30. String Configuration of Parallel Connected AC Modules.

Energy Storage Branch

The Energy Storage system is interfaced to the central AC bus via a bidirectional inverter. This branch is added to the installation to demonstrate the ability to dispatch energy and the ability of the system to operate in islanded mode to support a microgrid. Charging and discharging of the storage elements will be done through the inverter. Charging may also be accomplished via a dedicated charge controller.

Load Branch

The Load Branch was used to demonstrate the ability of the system to support a microgrid in an islanded mode of operation. Operation of the system in islanded mode requires the existence of the Energy Storage Branch. The Load is being specified in conjunction with the Energy Storage system. Detailed specs of the Load Branch were provided and validated with Pepco prior to the installation.

The Smart Switch

The Smart Switch is a controllable relay that handles the intentional connection and disconnection of the system with the grid. The Smart Switch is installed in conjunction with the Energy Storage and Load Branches.

Communications System

The system includes a communications system for command, control, and monitoring of the different branch circuits (Figure 31). Key features of the communications system are as follow:

- Each AC Module and other elements of the system (i.e., energy storage and Smart Switch) communicate bidirectionally with the SC via ZigBee Protocol.
- The SC gathers telemetry information (performance and status) from each element of the system and relays that information to a web based portal via cellular communications network.
- The SC also leverages the web based portal and cellular communications network to receive and broadcast control and configuration commands to the elements of the system.
- The Web portal is the communications interface to the system. Performance information can be accessed and control/configurations commands can be sent from the web portal.

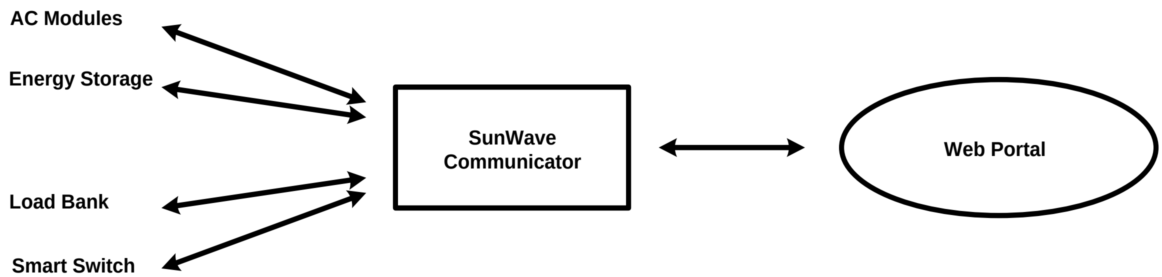


Figure 31. Communications System Configuration.

4.6.3. Grid Simulations / Studies

The grid simulation effort was commissioned to provide detailed numerical models of utility provided sample feeders. The study covers a number of fronts:

1. **Feeder Strength** was factored in as both stiff and intentionally weakened feeder models and both were used.
2. **Clustering and Penetration.** Both moderate and high PV penetrations were considered, with each subdivided into centralized and distributed test cases.
3. **Generation Mode:** both traditional current mode grid-tied inverters (legacy) and GEC based energy conversion technologies were tested for all test case scenarios.

Comparative analysis of results under the aforementioned parameters was conducted for **Steady-State** operation using CYMDIST [13] while **Dynamic Analysis** was handled under PSCAD [14].

5. SEGIS TASK RESULTS

5.1. GEC Controls

The Generator Emulation Controls (GEC) concept has been implemented and demonstrated using Petra Solar's SunWave micro-inverters. This section presents some experimental captures with the 120V model, rated at 120V/200VA, and is capable of supplying current at a full range of power factors: unity down to zero lead or lag.

GEC parameters were carefully chosen to provide strong voltage and frequency regulation/support, yet allow proper load-sharing among identical inverters. The emulated synchronous impedance, L_S, was chosen to be 0.12 pu, or 23mH. Combined with the actual filter inductor of 3.5mH, this resulted in a simple Volt-VAr droop with a slope of 12.2 VAr/Volt. Real power output responds to the power angle at 1.47kW/rad. Other emulated circuit parameters were chosen based on guidelines based on the dynamic model for GEC.

Different power-frequency profiles were setup for PV inverters and battery inverters. Power-frequency droop was programmed at a slope of 0.8kW/Hz for both profiles. PV inverters were programmed with a nominal frequency of 60.27Hz allowing full power delivery at 60Hz. Battery inverters were programmed with a nominal frequency of 59.96Hz, preventing discharge at 60Hz. These profiles grant PV the priority to supply load over batteries.

The first test setup is a simple circuit consisting of a combination of PV and load connected to a simulated grid through a series impedance as shown in Figure 32. This was geared at experimental demonstration of voltage regulation and transient suppression. The nominal voltage of the system is 120V, and all values are specified relative to 120V/400VA base. Two PV inverters are incorporated that are rated at 200W each for a total of 400W. The load consists of two portions: a 260VA (0.64 pu) R-L load at 0.78 lagging power factor, and a 200W (0.50 pu) incandescent light-bulb.

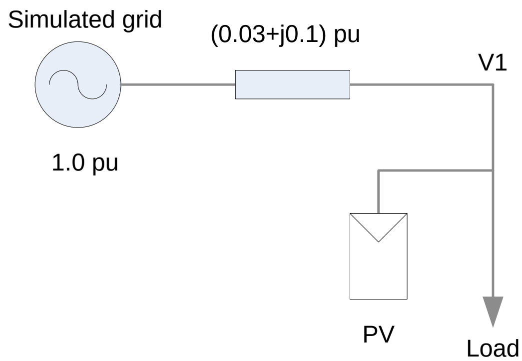


Figure 32. Single-Line Diagram of First Test-Bed.

The effectiveness of voltage regulation support is evaluated through measurement of the voltage, V_1, in three different scenarios: no PV, traditional PV, and GEC-operated PV. In each case, the voltage level is recorded at three loading conditions: no load, R-L load only, and R-L load combined with the bulb load. The results are shown in Figure 33. Traditional PV results in a voltage rise on the feeder, which is helpful at heavy loads, but potentially problematic at light loads. The voltage flattening effect of GEC is apparent: GEC-operated PV results in better restoration of the voltage under heavy load, in addition to a lower voltage rise at light-load conditions.

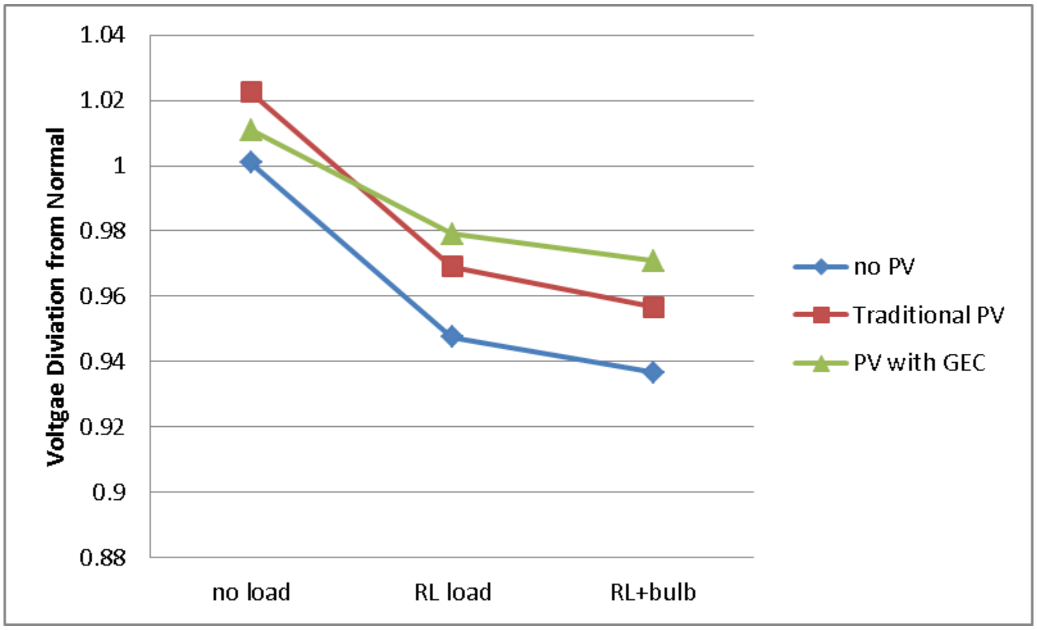


Figure 33. Voltage Regulation Performance.

This setup was also used to demonstrate the unique ability of GEC-operated inverters to suppress sharp load transients. GEC-operated inverters tend to supply part of the load transient currents locally due to inherent inertia. This reduces the magnitude and severity of the transient as seen by the rest of the power system. Figure 35 compares the behavior of GEC-operated PV to that of traditional PV, shown in Figure 34, during a load transient. During this experiment, the bulb load is switched in, creating a transient amplified by its inrush current. Traditional PV inverter current is virtually undisturbed, and so is its bus voltage. The current generated by GEC-operated PV inverters, however, shows an immediate same cycle response to the load. The disturbance is also reflected in a temporary dip in the DC-bus voltage waveform, as the transient energy is supplied from this reservoir within the PV inverter before return to steady-state operation. This naturally happens as a response to the phase disturbance created by the load transient. The reaction of GEC inverter acts as a damper that reduces the sharpness of the transient as seen by the power system.

Figure 34. Behavior of Traditional PV during Load Transient.
Traces: [1] Load Current (2A/div), [2] PV Inverter Current (2A/div), [3] Inverter DC-Bus Voltage (Zoomed, 10V/div)

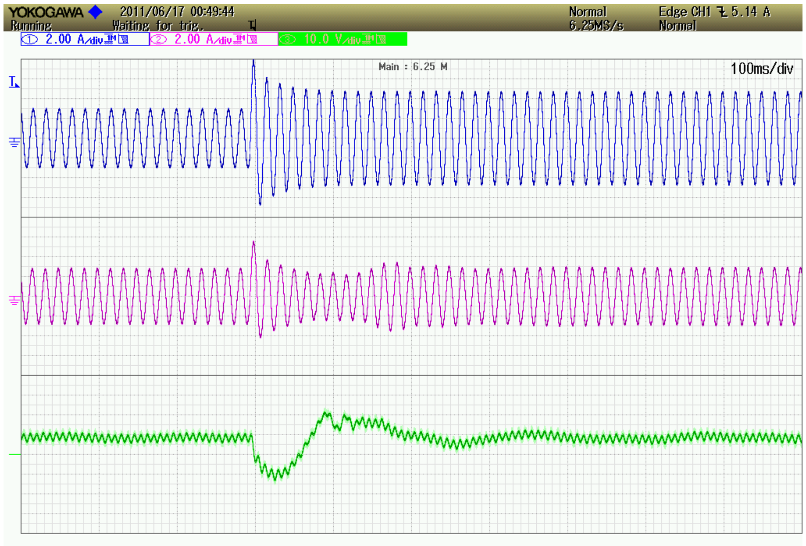


Figure 35. Behavior of GEC-Operated PV during Load Transient.
Traces: [1] Load Current (2A/div), [2] PV Inverter Current (2A/div), [3] Inverter DC-Bus Voltage (Zoomed, 10V/div)

The second test setup was focused at demonstrating micro-gridding features, and is depicted in Figure 36. A 3kVA proof-of-concept microgrid was built out of fifteen inverters: ten PV inverters (2kVA total), and five battery inverters (1kVA total). The microgrid was set up to support a local electronic load that was set at 2.5kW during experiments captured in Figure 37.

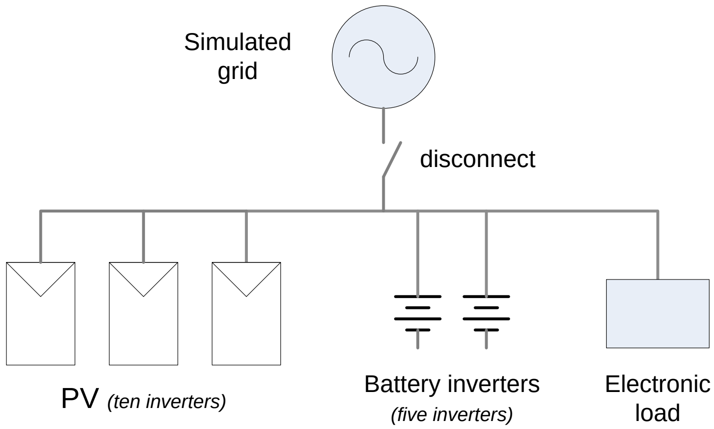


Figure 36. Microgrid Test-Bed Diagram.

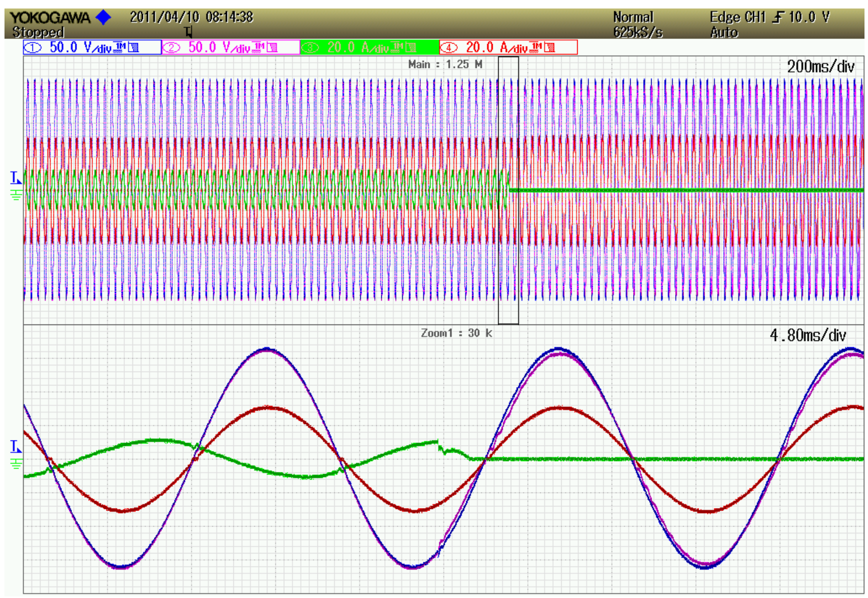


Figure 37. Seamless Microgrid Transition from Grid-Tied to Islanded Mode.

Traces: [1-blue] Grid Voltage (50V/div), [2-magenta] Local Voltage (50V/div), [3-green] Total Microgrid Current Exported to Grid (20A/div), [4-red] Load Current (20A/div)

This test-bed demonstrated the plug-n-play ability of GEC-operated inverters to build scalable microgrids that can perform seamless disconnection and reconnection to a host EPS. Figure 38 shows a transition from grid-tied mode into islanded operation. During grid-tie, only PV inverters are contributing power to the load, while battery inverters are idling near zero power. Some power is imported from the grid as the local load exceeds available PV. Upon interruption of the grid-connection, emulated inertia allows the inverters to pick up voltage regulation with phase continuity. A slight frequency drop allows battery inverters to pick-up the power balance. Figure 38 shows a transition back to grid-tied mode. The grid-connection is reestablished when the local and host voltages are acceptably synchronized. The grid forces the frequency to return to 60Hz, prompting batteries to idle, allowing the grid to pick-up the load balance.

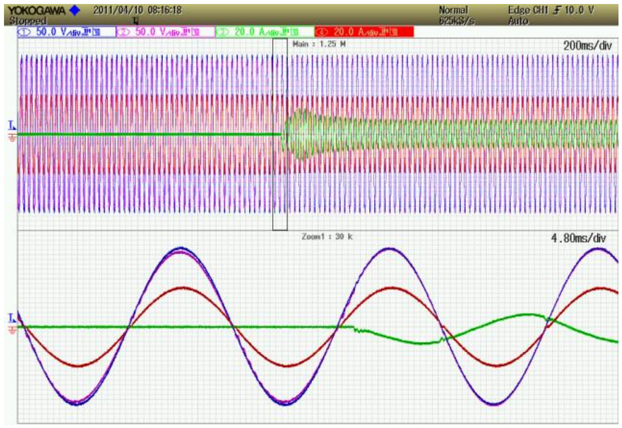


Figure 38. Seamless Microgrid Transition from Islanded to Grid-Tied Mode.

Traces: [1-blue] Grid Voltage (50V/div), [2-magenta] Local voltage (50V/div), [3-green] Total Microgrid Current Exported to Grid (20A/div), [4-red] Load Current (20A/div)

5.2. Demonstration and Impact Studies

5.2.1. Laboratory-Scale Feeder Test-Bed Results

The feeder test-bed was utilized to demonstrate the effectiveness of Volt-VAr support and LVRT functionality in mitigating the effect of PV intermittency on voltage regulation. It was also utilized to demonstrate the value of distributed PV with reactive power capability in minimizing distribution losses. The feeder test bed was operated under six various conditions in order to compare the behavior of traditional PV inverters to GEC-operated PV with LVRT.

Voltage regulation challenges were first demonstrated by operating PV in Standard Mode, with near-unity power factor. Cloud activity was simulated by modulating DC power available to PV SEMs in the test bed. The voltage profile and distribution power losses across the feeder were captured as shown in the Graphical User Interface (GUI) snapshot in Figure 39. The loading on the feeder causes the voltage to sag naturally, even on a sunny day. The voltage at the substation is set at approximately 1.01pu in order to compensate for this drop. In the event that total PV power output is rapidly reduced due to cloud activity, the voltage at the end of the feeder falls below the acceptable regulation limits. Traditional voltage regulation equipment such as tap-changers and capacitor banks are not designed to respond quickly enough or frequently enough to address this situation. The utilization of traditional equipment to respond to such events would result in voltage flicker, and accelerated ageing of such devices.

The GridWave voltage regulation support feature based on Volt-VAr droop was then activated. This allowed SEMs to respond to sagging voltage by automatically injecting reactive power into the circuit. This resulted in much more flat voltage profiles, both in the presence and absence of clouds. The voltage at the end of the feeder remained decidedly within the acceptable window with a less pronounced response to cloud cover. The utility can capitalize on this “flatness” by reducing the voltage at the substation for enhanced operating efficiency without risking a breach to the regulation limit.

A close look at the relative distribution power losses reveals two important trends. Distributed PV reduces total power losses, particularly on a sunny day, because more power is supplied locally to loads at that circuit. Power losses can be further reduced through the local supply of reactive power to the loads. This can be achieved through the GridWave Volt-VAr feature.

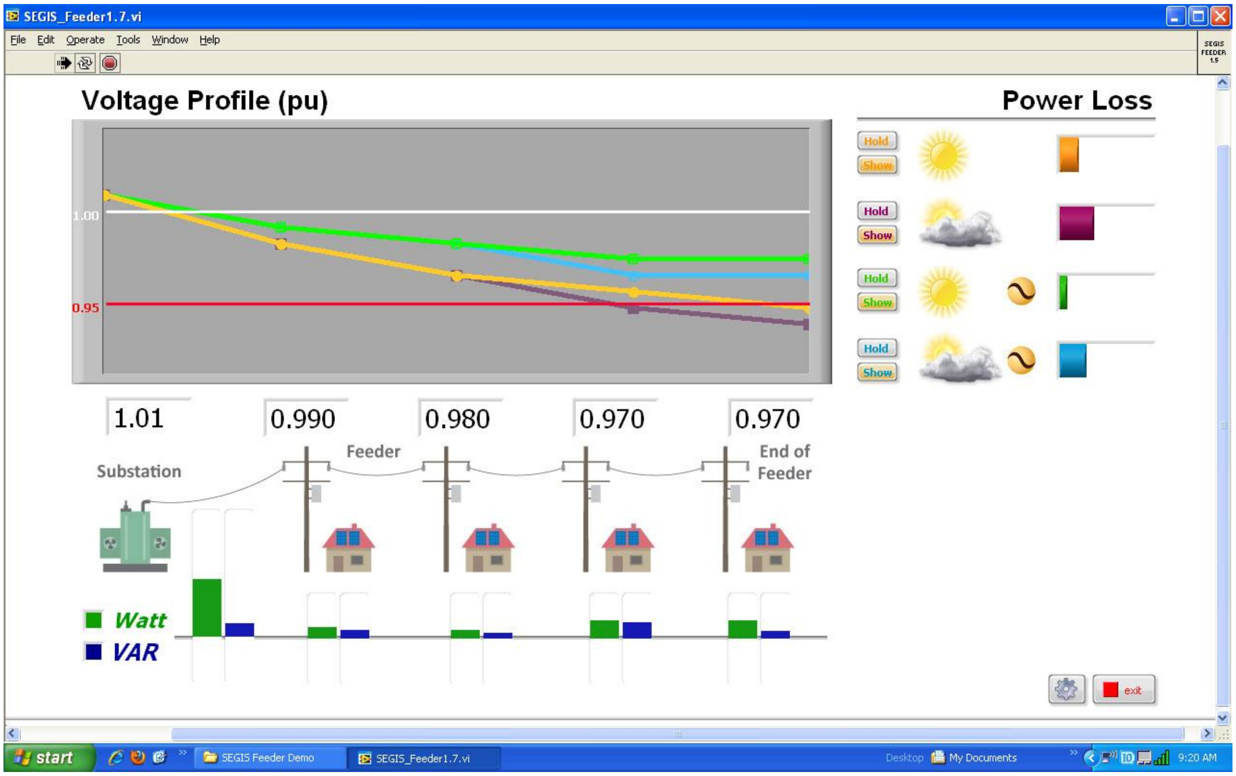


Figure 39. Voltage Regulation Demonstration Results.

Traces: [1-orange] Grid Voltage, [2-purple] Grid Voltage with Cloud Activities, [3-green] Grid Voltage with GridWave Voltage Regulation Support Feature Activated, [4-blue] Grid Voltage with GridWave Voltage Regulation Support Feature Activated and with Cloud Activities.

The value of the GridWave LVRT feature was demonstrated by simulating a fault condition, and observing the state of the feeder test bed immediately after. When this feature is disabled, the fault event causes all PV to shut-off for five minutes. This results in a severe voltage drop at the end of the feeder circuit as shown in Figure 40. Enabling the LVRT features allows the PV systems to ride-through the fault event, assisting the restoration of the system to its original state immediately after the fault is cleared. The voltage profile is immediately restored to its flat shape, within the regulation window, as show in Figure 40.

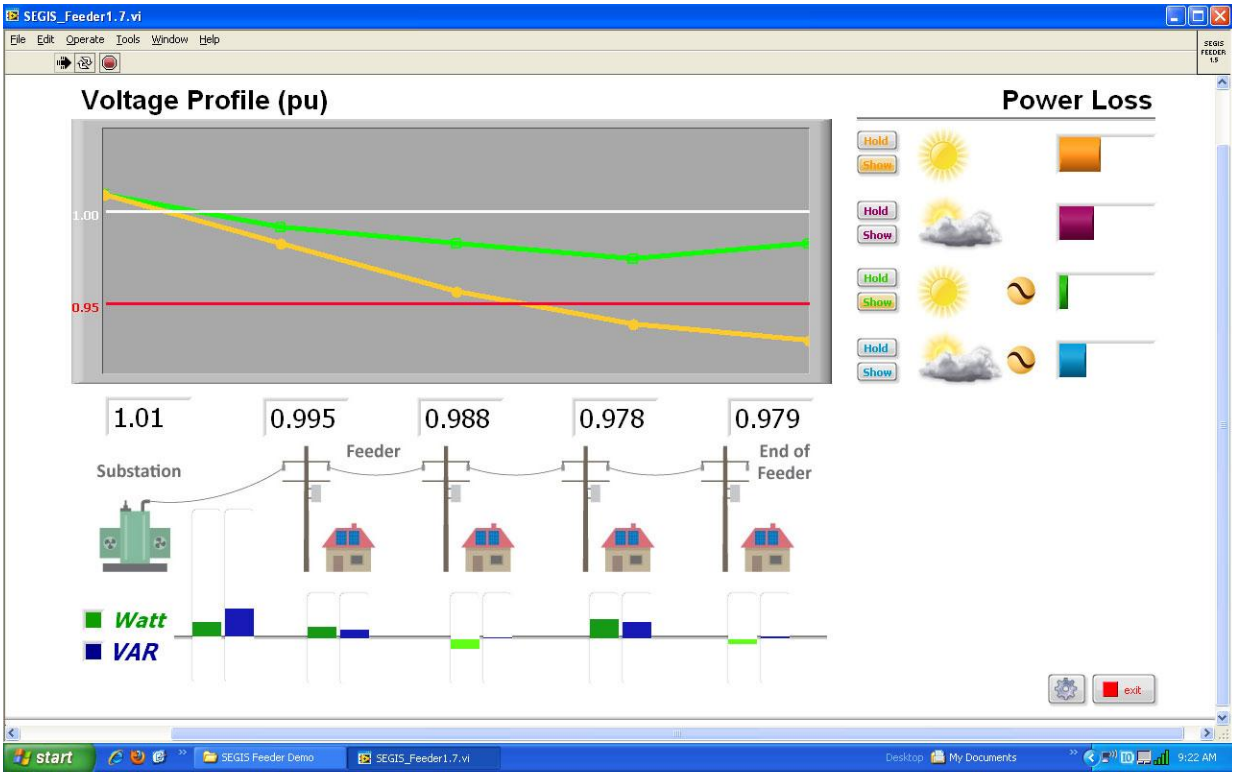


Figure 40. LVRT Demonstration Results.

Traces: [1-orange] Grid Voltage, [2-green] Grid Voltage with GridWave LVRT Feature Activated.

5.2.2. Customer Site Field Demo

Installation of the field demonstration system commenced at the Pepco facility at May's Landing on Monday August 15, 2011. The system was fully operational on September 20, 2011. Prior to the final demonstration conference, testing was conducted on the installation.

The SEGIS functionalities were verified as follows:

- Legacy grid-tie mode was successfully accomplished
- Islanded operation was demonstrated
- Black-start for 1kW loading was verified

The field demonstration is a 5kW field installation where the GridWave smart microgrid technology is demonstrated. Petra Solar has developed and productized the GridWave technology through the SEGIS initiative. The GridWave smart microgrid operating in both legacy grid-tied mode and off-grid "islanded" mode of operation with battery support is demonstrated, with the system seamlessly disconnecting and then synchronizing and re-connecting to the grid was observed.

The following modes of operation were demonstrated:

1. Legacy grid-tie Operation
2. Microgrid Operation

Mode 1: Legacy Grid-Tie Operation:

This mode included showing a normal legacy generation, where the system is exporting power to the grid from the PV units. Figure 41 shows that the PV is running, batteries are not outputting energy, and the load is being supported by both the grid and the PV. Both the grid and the PV voltage and frequency are synchronized.

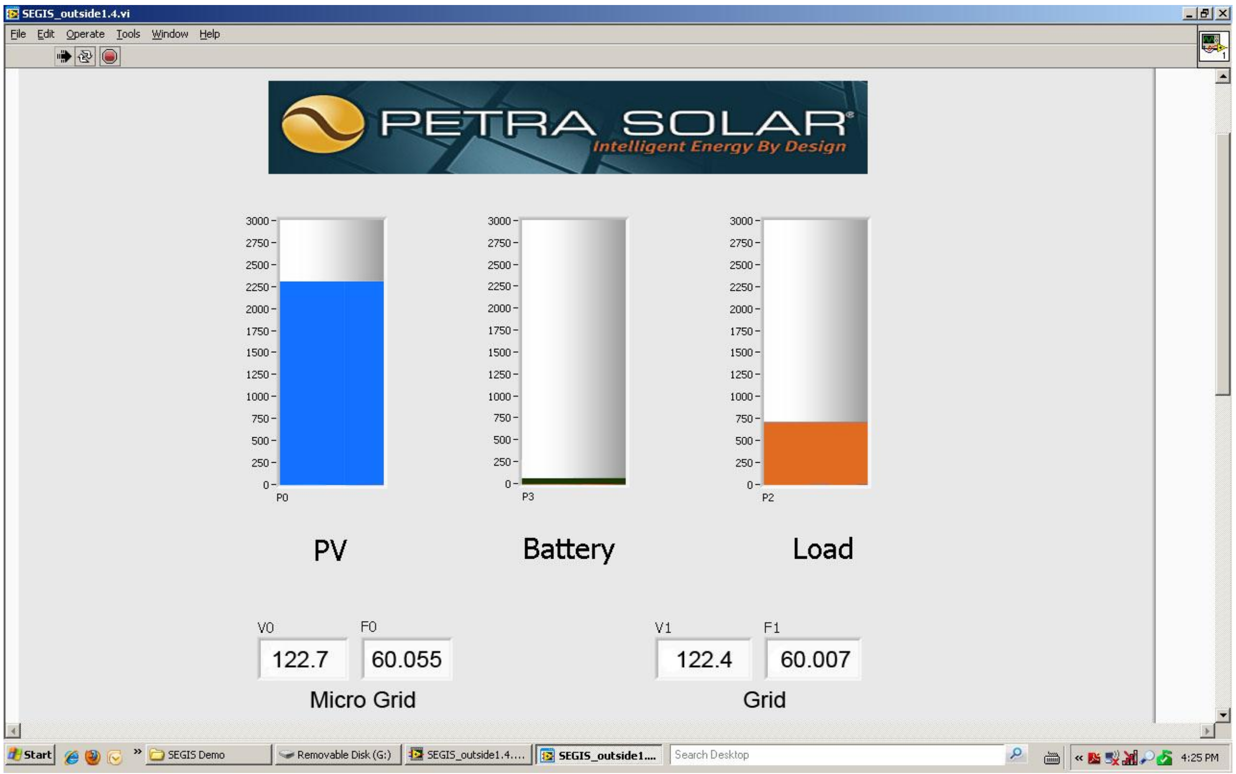


Figure 41. Normal Legacy Generation.

Next, the grid was disconnected and, as a result, the PV shut off and the loads lost power as shown in Figure 42. As a conclusion, once the grid is removed, the loads are not supported during the Legacy mode of operation.

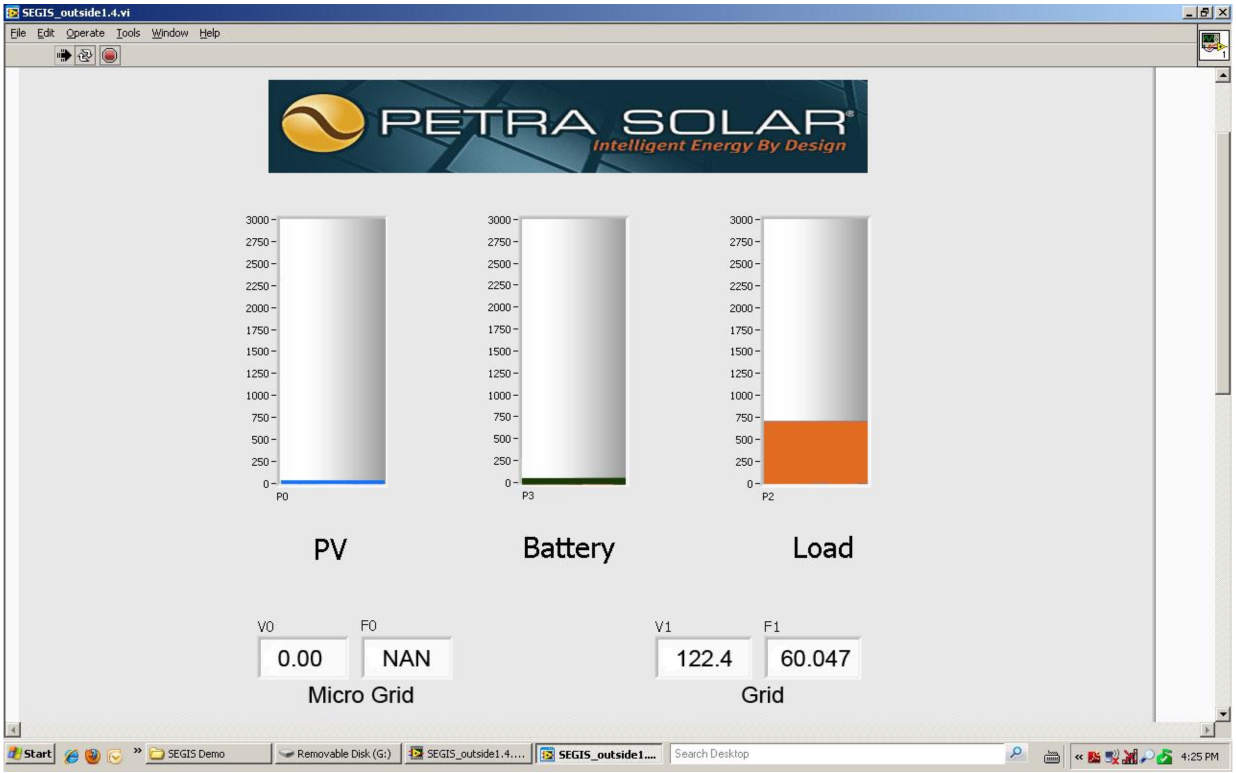


Figure 42. Disconnecting the Grid.

Mode 2: Microgrid Operation:

Microgrid operation supports the following functions that were demonstrated:

- Black-start
- Seamless transition to and from grid-tie
- Automatic battery back-up support

This part of the demo started by reconnecting the grid in Smart-tie mode, where the PV is running, batteries are not outputting energy, and the load is being supported by the grid and the PV. Both the grid and the PV voltage and frequency are synchronized, as was the case in the "Legacy" operation.

Next, the grid was isolated by manually opening the Smart Switch contactor, and it was shown how the power to load is maintained. The PV stays on and the load is supported as shown in Figure 43. Batteries will export power if the system is loaded beyond the capacity of the PV.

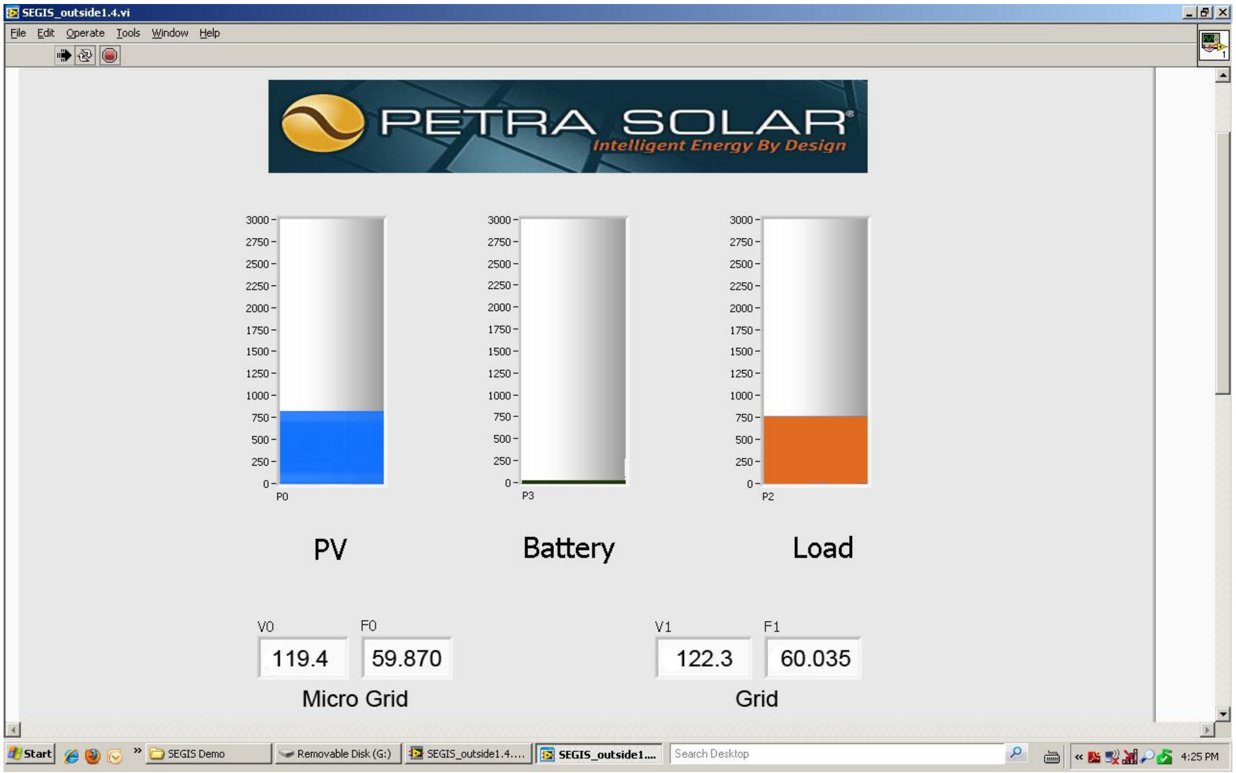


Figure 43. Maintaining Power to Load.

The load was then increased, and the batteries' back-up support was demonstrated. Figure 44 shows that PV output is not enough to fully support the load, so battery support is invoked to support the load.

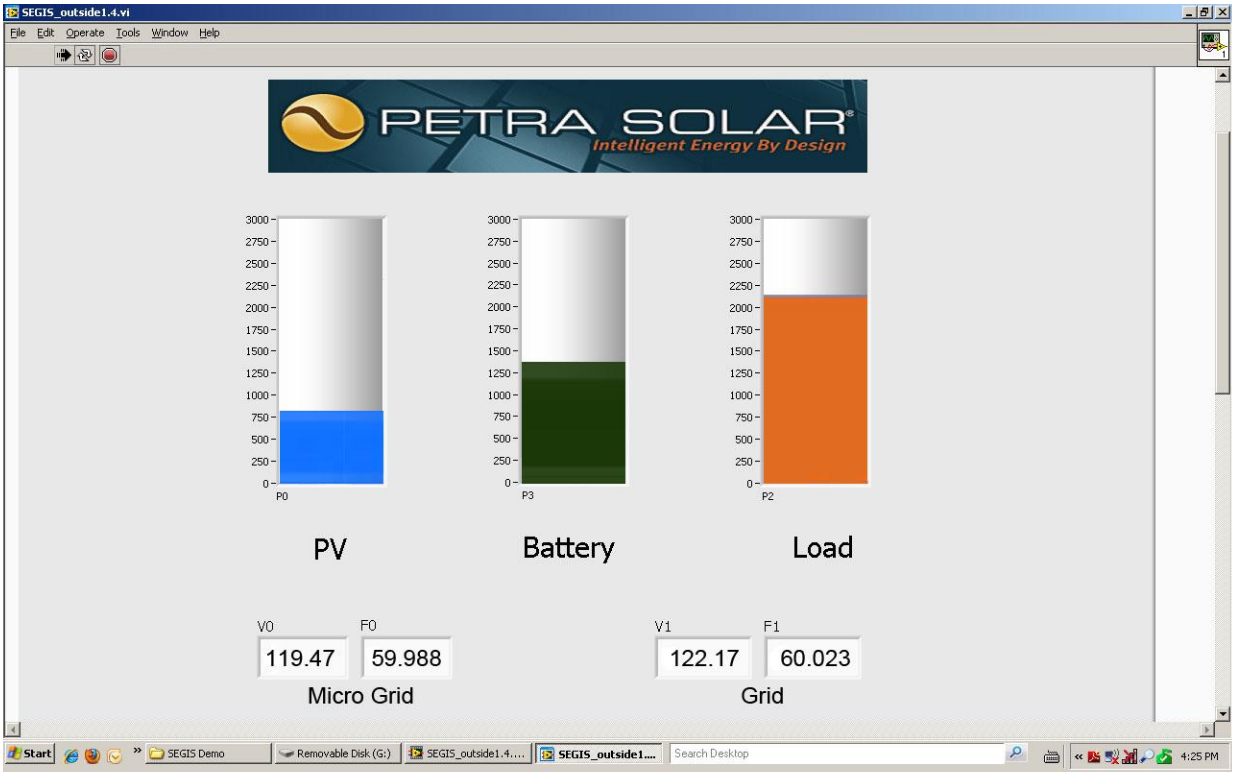


Figure 44. Batteries Back-Up Support.

Last, all the generation sources were reset to show a black-start function, which is the ability to initiate in a de-energized microgrid. The microgrid was de-energized with all the loads connected. The PV and battery generation branches were then commanded to bring up the microgrid. The battery generation branch provides momentary power to handle the inrush current of the starting loads. Once the microgrid is in steady state, the battery branch provides only the difference between the total load consumption and the available PV. Figure 45 shows the inrush response of the black-start operation, while steady state operation post black-start is shown in Figure 46. In this particular case, during steady state operation the loads are completely supported by the PV branch and no battery support is invoked.

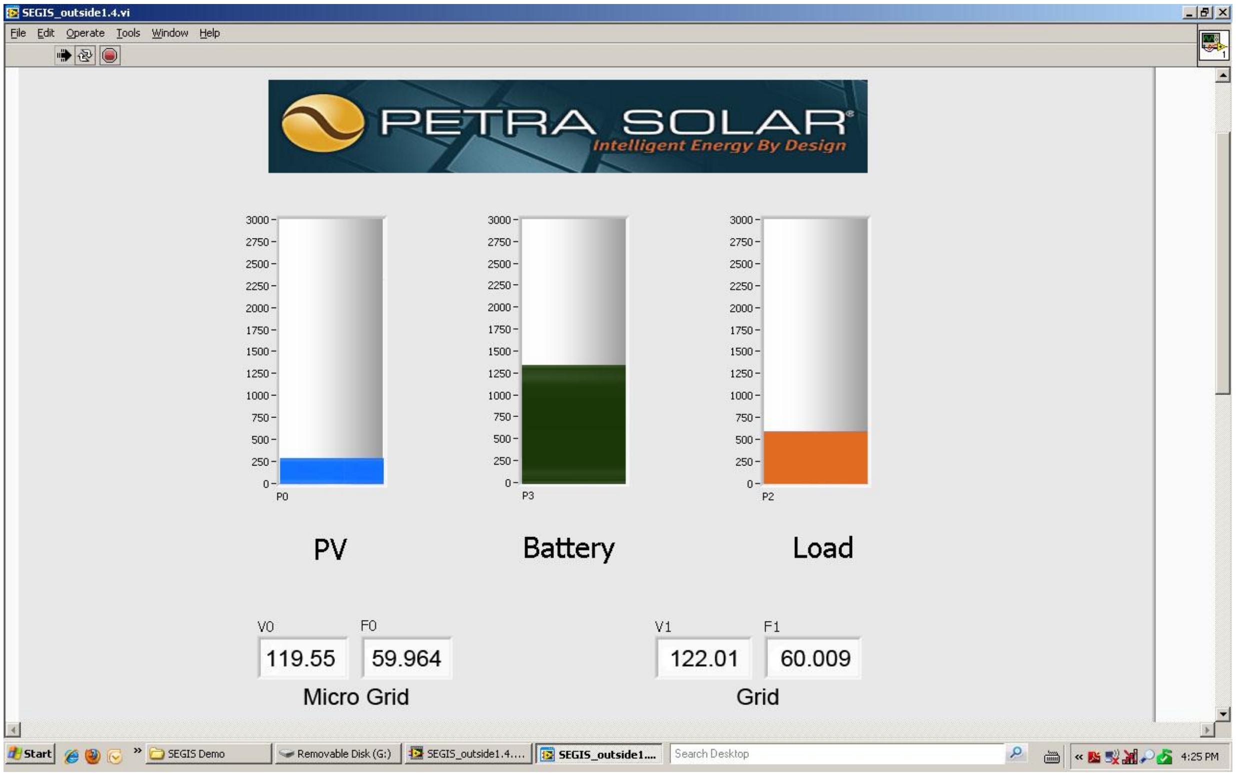


Figure 45. Black-Start of Microgrid Showing Inrush Support to the Loads.

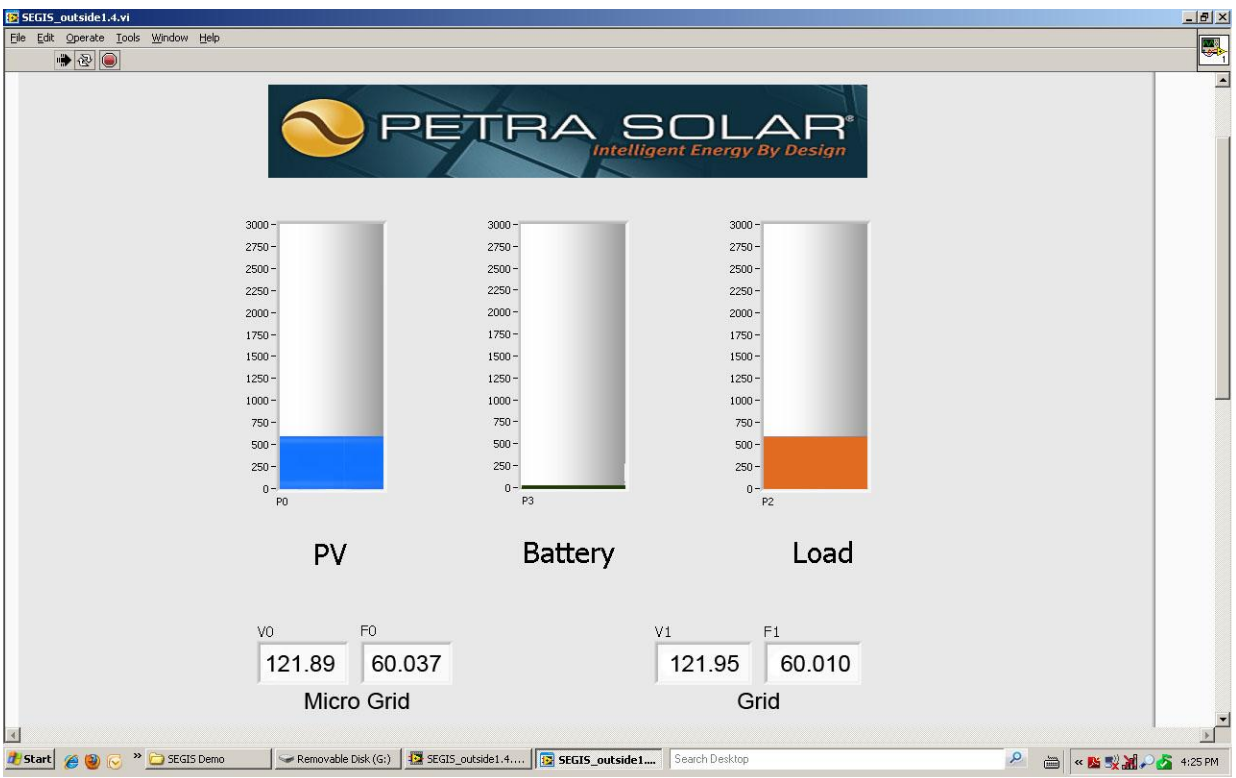


Figure 46. Black-Start Operation in Steady State.

The final demonstration shown during microgrid operation was the resynchronization of the islanded microgrid to the utility grid via the Smart Switch module. The system was instructed to resynchronize to the grid. The Smart Switch senses the voltage and frequency on the microgrid and compares the values. Broadcast instructions are sent to all the SEMS in the system so that voltage and frequency are synchronized. The Smart Switch engages and couples the microgrid to the utility grid when synchronization is detected. At this stage the loads are supported by the grid and generation sources in the microgrid. Battery generation is no longer utilized in this scenario. Figure 47 shows the PV output after synchronization.

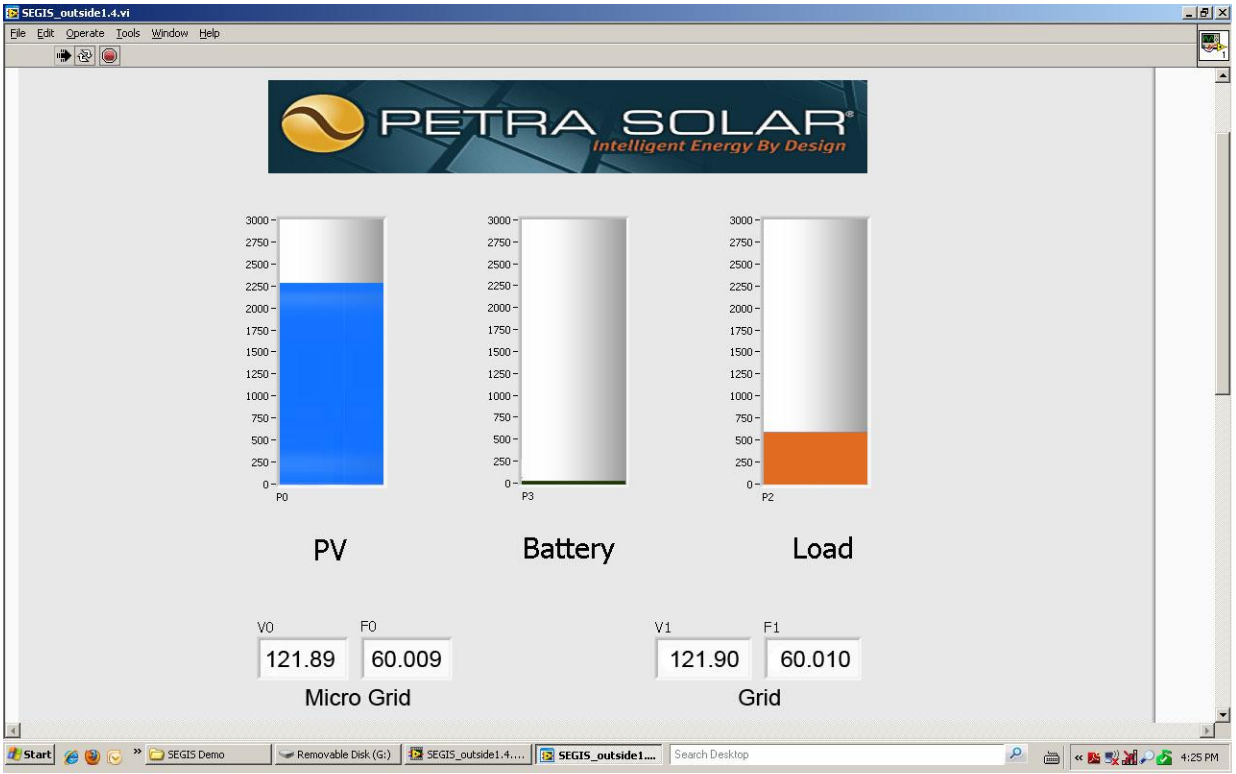


Figure 47. System after Resynchronization to the Grid.

5.2.3. System Impact Studies

Petra Solar contracted Quanta Technologies to perform a study to evaluate the impact of high PV penetration, and to assess the value of various features developed through the SEGIS initiative. Quanta Technologies created a detailed model of a distribution circuit as shown in Figure 48. The state and performance of this circuit was compared when outfitted with centralized "utility-scale" PV, and with highly distributed PV installations. The coupling of the PV assets to the circuit depended on the type and scale of PV, as exemplified in Figure 49 (a) and (b). The circuit was simulated with medium penetration of 2MW and high PV penetration of 4MW.

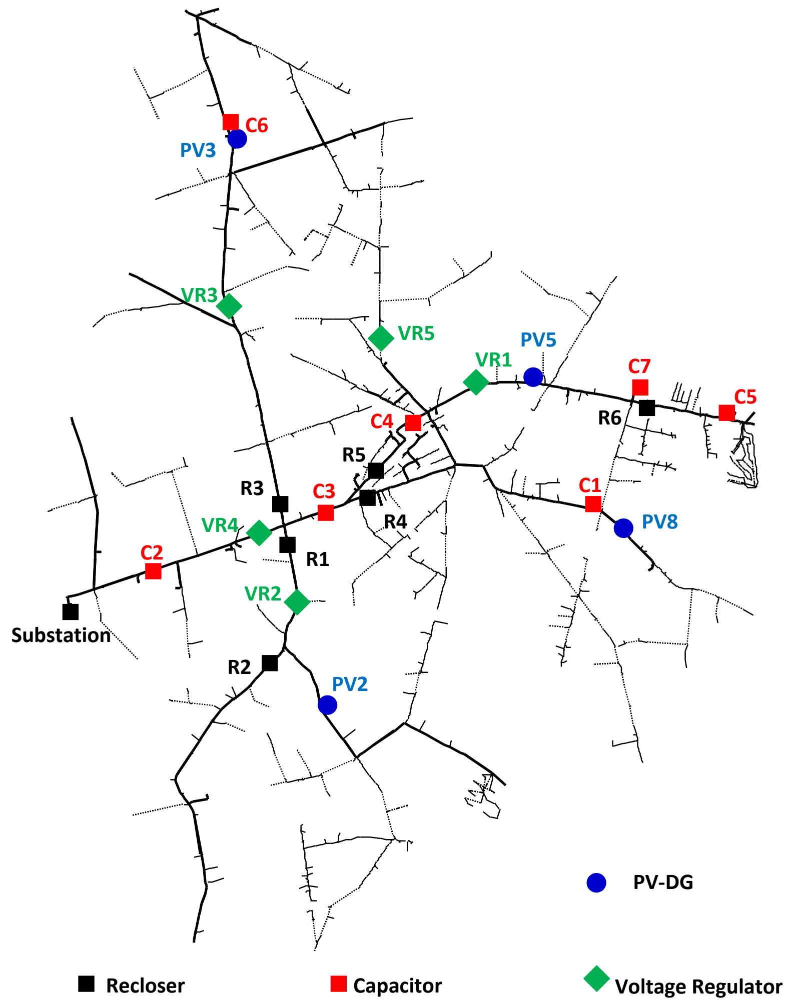
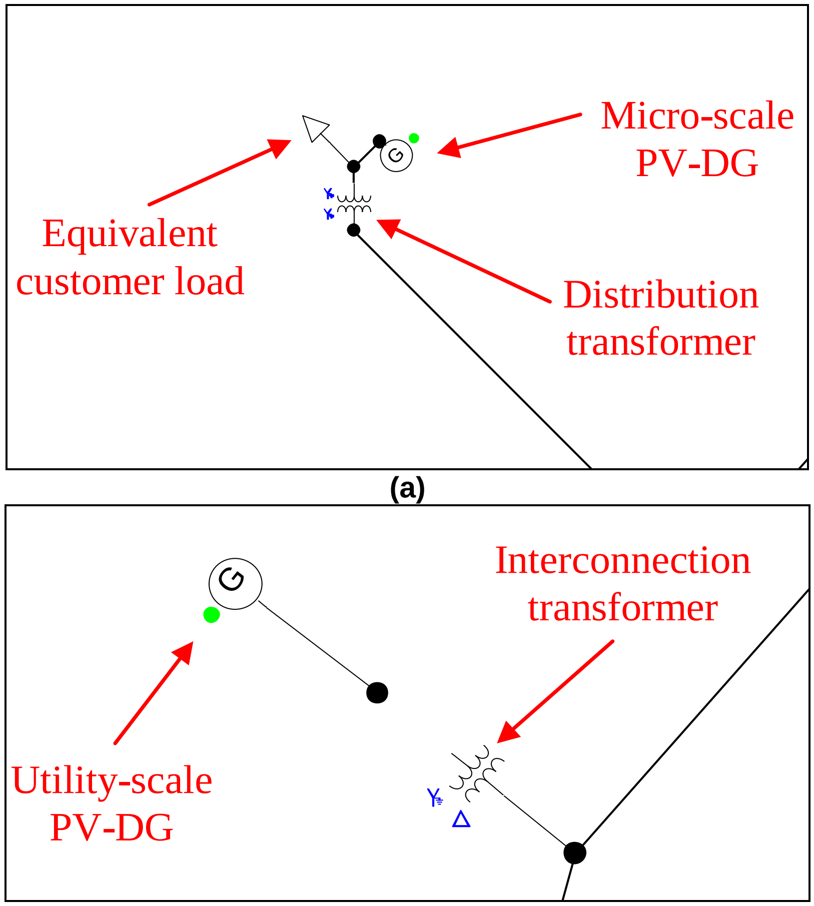


Figure 48. Quanta Distributed Circuit Detailed Model.



(b)

Figure 49. (a) Interconnection of Utility Scale PV, (b) Interconnection of Distributed PV.

The first set of results demonstrates the value of distributed PV in reducing power losses as shown in Figure 50. Utility-scale PV resulted in a limited amount of reduction of power losses at medium penetration. At high penetration, however, the power loss level increased again relative to the no-PV case due to increased current circulation within the circuit. On the other hand, distributed PV provided more consistent reduction of power losses. This reduction continued at high penetration as power was directly delivered to near-by loads.

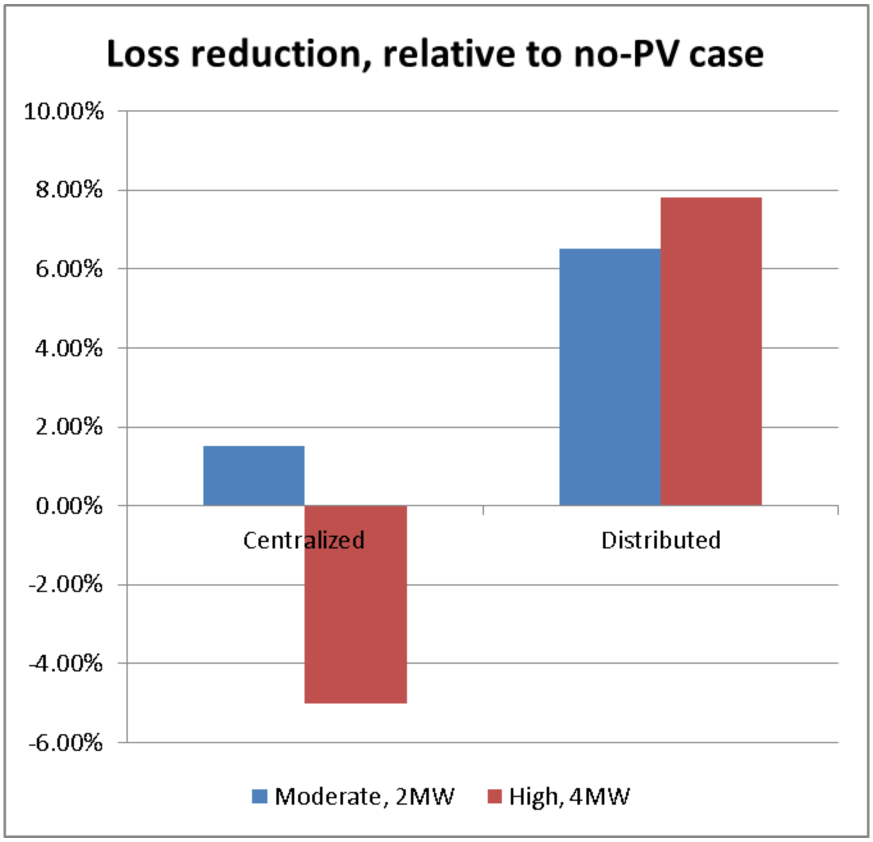


Figure 50. Average Losses Reduction.

A particular challenge associated with distributed PV is voltage regulation. Localized pockets of PV can increase the local voltage beyond the appropriate standard limit, causing voltage regulation violations. For the purposes of the study, a voltage violation is defined as an increase in RMS voltage beyond the 1.04 pu limit. The study demonstrated that GEC-operated PV inverters equipped with Volt/VAr dramatically reduced the frequency of voltage violations. These results are summarized in Figure 51.

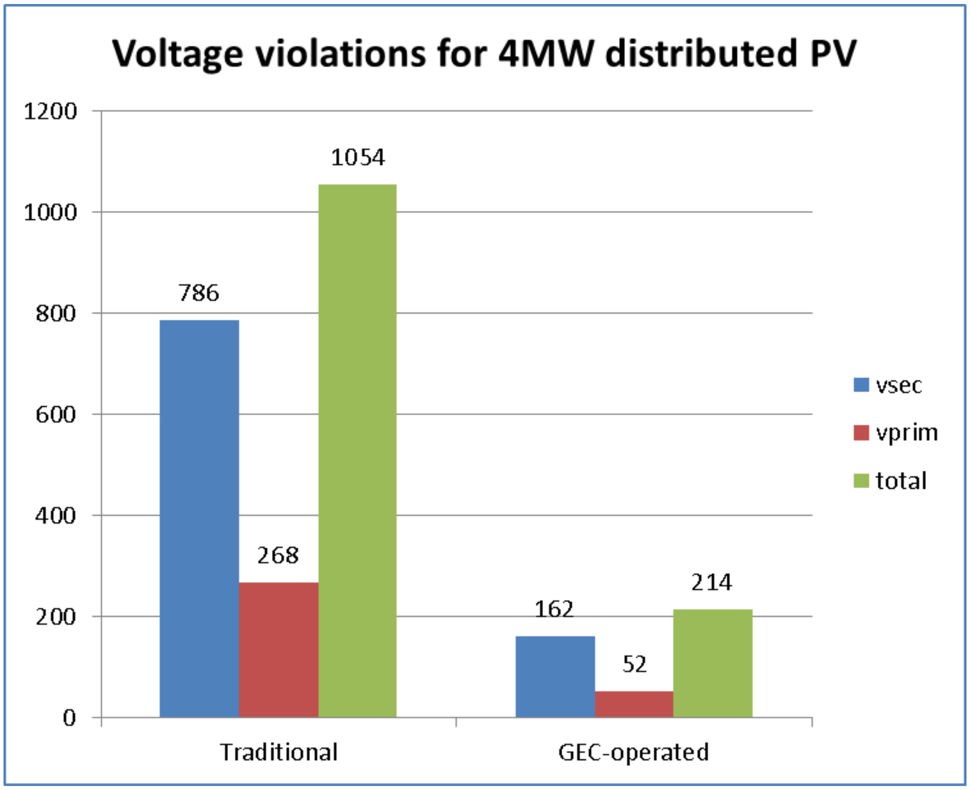


Figure 51. Voltage Violations.

6. SEGIS STAGE 3 CLOSING DEMONSTRATION CONFERENCE

There were several key goals of the SEGIS Demonstration Conference; it was an opportunity to publically display the innovative technology developed through SEGIS funding, in addition to the fact that it was a catalyst to educate and collaborate with key stakeholders: the DOE, DOD, Sandia, utilities, legislators, regulators, financial community, and the media. Through panel discussions, it was a chance for the conference participants to learn from our utility partners about real-world experiences and grid reliability challenges of large scale PV integration.

Attendees became familiar with practical knowledge of how SEGIS technology solves real-world problems and an understanding of the value-add for utilities and owners of SEGIS enabled PV systems.

6.1. Conference Agenda

The final SEGIS conference agenda is summarized in Table 2.

Table 2. SEGIS Conference Agenda.

9:30 am	Registration
10:00 am	Welcome Keynote: Ward Bower, Distinguished Member of the Technical Staff, Sandia National Laboratories
10:20 am	Commissioner Jeanne Fox, Positive impact of the solar industry on New Jersey's job market – high tech job creation and manufacturing.
10:40 am	Petra Solar Keynote: Dr. Shihab Kuran, President and CEO
11:00 am	Technology Developed by Petra Solar through SEGIS Program: Joe DeLuca
12:30 pm	Lunch
1:15 pm	SEGIS Technology Demo and Project Field Demo: Petra Solar Team
3:15 pm **3:30 pm**	Break Next Generation SEGIS AC Initiative: Kevin Lynn, Team Lead, Systems Integration, Solar Energy Technologies Program, U.S. Department of Energy
3:50 pm	Utility Panel Discussion: Real-world experiences and grid reliability challenges of large scale PV integration. Panelists include: • Alfredo Z. Matos, VP Renewables and Energy Solutions, Public Service Electric and Gas • Steven Steffel, Senior Supervising Engineer, Atlantic City Electric • David Bates, Project Development Manager, Florida Power & Light Moderator: Assemblyman Upendra Chivukula
5:15 pm	Trends/Market Analysis: MJ Shiao, Solar Analyst, Greentech Media Research
7:00 pm	Networking Reception: One Atlantic, Atlantic City

The ‘Technology Developed’ discussion presented at 11:00 AM by Petra Solar included:

- Distributed PV systems with intelligent interfaces, creating a smart-grid with two-way communication
- Dynamic voltage regulation
- Automated Volt-VAr support
  - Dynamic reactive power injection
- Automatic power curtailment
- Microgrid operation
  - Black-start
  - Seamless transition to/from grid-tie
  - Automatic load shaving
- Easy to understand animations of each of the features and benefits of SEGIS technology
- Practical examples of how the technology solves real-world problems, using cause and effect simulations
- Innovations/Patents as a result of the initiative
- Products developed as a result of the initiative
  - GridWave™ product line

The ‘Utility Panel’ discussion at 3:50 PM presented by PSE&G, ACE and FP&L included:

- Real-world experiences and grid reliability challenges of large-scale PV integration
- Panel discussion (both U.S. and International utilities were invited to participate in the discussion)

The SEGIS Technology Demo (indoor) presented by the Petra Solar team demonstrated the SEGIS technologies developed by Petra Solar using the lab-scale feeder test bed and visuals.

The SEGIS Project Field Demo (outdoor) presented by the Petra Solar team was held at Pepco’s substation yard using 25 SunWave ground-mounted units (5kW system).

6.2. Logistics and Attendance

Petra Solar’s SEGIS Demonstration Conference assembled key stakeholders and technology experts from the DOE, Sandia and the industry, utility executives, Wall Street investors, influential policy makers, leading industry market analysis from Greentech Media Research, and much more.

The conference was held on **Thursday, September 29th, 2011** at the following location:

Pepco Holdings, Inc.
Atlantic Regional Office
5100 Harding Highway
Mays Landing, New Jersey 08330

6.3. Invitations and Conference Registration

Petra Solar created a website for the conference, with agenda, hotel and travel details and the list of speakers (http://www.segisconference.com /).

Invitees included:

- Utility
  - Key Petra Solar customer accounts, domestic and international
- Governmental
  - DOE
  - DOD
  - Sandia
  - New Jersey Governor & Lt. Governor
  - New Jersey EDA
  - Regulatory
  - New Jersey BPU
  - California PUC
- Media
- Financial/Investment
- Industry organizations
  - EPRI
  - EPA
  - NJTC

6.4. Conference Logistics

The conference was held at the facility of one of Petra Solar's utility partners, Pepco Holdings, Inc. At the Pepco facility, 25 SunWave units were installed in a 5kW ground-mount array. This afforded a terrific venue for a real-life demonstration of the SEGIS technology, as well as the opportunity to hear from Pepco as to why this technology will help them solve actual issues they are experiencing with high penetration of PV on some of their feeders in the Atlantic City area.

6.5. Media

Petra Solar worked with GreenTech Media as a media partner for the event. One of the GreenTech Media analysts spoke about the industry trends. After the conference, Petra Solar worked with GreenTech Media to offer webinars on the topics discussed at the conference to further promote the technology and extend the educational benefits of the conference.

Conference collateral

Petra Solar collaborated with Sandia on posters and handouts for the event.

6.6. Demonstration Plans

6.6.1. Voltage Optimization and Smart-Tie Functions

A typical 12kV/10MVA feeder was scaled to 120V/5kVA with typical impedance and loading profile. The test bed included loads and PV inverters and was intended to show the effect on voltage regulation/distribution losses in three different cases:

- No PV
- Tradition current-source PV
- GEC-operated PV

The test bed (Figure 52 and Figure 53) was also used to demonstrate the islanding and Smart Switch functionality. Battery-sourced inverters were added to the setup to achieve this goal.

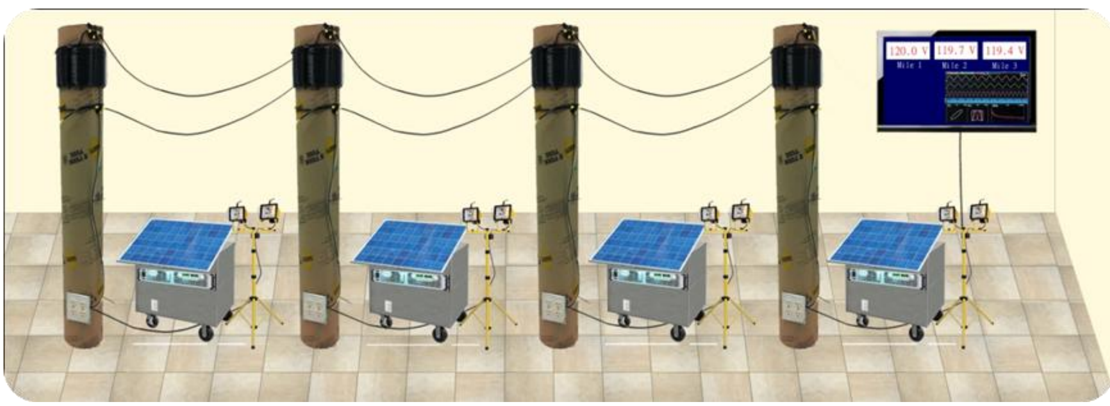


Figure 52. Voltage Optimization Demonstration Layout.

Figure 53. Actual Voltage Optimization Demonstration Layout.

6.6.2. Field Demonstration of Legacy, Smart-Tie and Islanded Operation

The field demonstration was planned to showcase a 5kW utility installed PV mini-field with 2-4kW of supplementary battery back-up. The demonstration showcased legacy mode operation, LVRT operation, "Islanded Mode" operation, and re-synchronization to the grid. Due to the limitations in the ability to manipulate the grid at the utility test yard, Smart-tie and Flex-tie operations were showcased (Figure 54 and Figure 55).

Figure 54. Field Demonstration of Legacy, Smart-Tie and Islanded Operations.

(a)

(b)

Figure 55. Actual Field Demonstration.

7. IMPACTS FOR THE UTILITY, CUSTOMER AND PV APPLICATIONS FUTURE

The SEGIS initiative is expected to have significant positive impacts in many years to come throughout the electric utility ecosystem as solar energy generation penetration increases. The benefits of these impacts are expected to accrue to both utilities and their customers.

SEGIS-developed capabilities will directly address many of the issues incurred from PV solar intermittency. Solar intermittency, the variation in output power from PV resources, is due to changes in solar input based on time of day and, more importantly, due to shading from clouds. It may also be due to shading from nearby objects in the case of distributed arrays (e.g., residential rooftop arrays). This intermittency can produce conditions of overvoltage in the case of having high solar irradiance with low load, as may occur at midday as cloud cover suddenly moves off of PV arrays when residential loads are low. Conversely, under-voltage conditions may occur when clouds suddenly shade PV resources while utility infrastructure is under high load.

For utilities, SEGIS-developed capabilities will enable Volt-VAr compensation and "Watt droop" power curtailment to be used to manage these issues in automated fashion. These, and related capabilities (e.g., power ramp rate control) will allow utilities to embrace the use of PV solar on their systems without concern for grid stability. In fact, the same capabilities may be extensible outside of PV solar applications to support general grid issues stemming from distribution and transformer losses and to support grid capacity issues from dynamically variable loads and new technologies such as electric vehicle charging. The team developed a new product definition dubbed the VARbox as a cost-effective method for scaling-up Volt-VAr capability for voltage regulation support.

For the consumer, the benefit is having a more reliable and efficient grid, which translates to sustained customer satisfaction, and the ability for consumers to apply PV solar, electric vehicle charging, and other renewable energy sources to their homes and businesses leads to increased satisfaction. Through the application of SEGIS capabilities, these distributed resources also translate to a more robust electric grid.

The Petra Solar team created a number of technical and marketing publications in an effort to educate the public on the advantages and the potential of technology developed under the SEGIS initiative. These publications were presented in technical conferences and they include [15] [16] [17].

7.1. Applications

Voltage Regulation Support

The voltage regulation support through management of device real and reactive power output may be used for Conservation Voltage Reduction.

- Automated reactive power control, or Volt-VAr;

Volt-VAr management is particularly effective for reactance-dominated circuits (high X/R ratios). It is therefore intended as a means to “flatten” the voltage profile across a distribution feeder. This technique is effective for large deployments with considerable capacity relative to the feeder size.

- Automated real power control, or Volt/Watt;
  Volt/Watt management is effective for resistance-dominated circuits (low X/R ratios). It is therefore intended as an extreme measure to relieve voltage rise across secondary lines (service drops).

Provide Voltage Readings

Provide accurate measurements of service voltage (at the secondary circuit) to supervisory systems. This reduces the requirement for safety margins, and allows for better optimization of voltage profiles at lower risk of breaching voltage quality standards.

Microgrids and Feeder Islanding

Enable creation of microgrids that are capable of:

- Operating as part of the larger EPS
- Forming an intentional island to support local loads
- Performing seam-less transitions between these modes

This capability is useful for a wide spectrum of users. It will provide the commercial and residential consumer with the ability to utilize the PV installation for supporting the load during grid outages. Utilities can apply this concept on a feeder level to provide continuous electricity supply for neighborhoods unaffected by faults in other parts of the system. The military can utilize micrografts to rapidly set up and operate forward operating bases. This also applies to relief organizations as they set up basic infrastructure in emergency zones.

7.2. Value Added

Petra Solar’s advanced renewable energy technologies for grid stabilization and optimization developed under the SEGIS initiative includes:

1. Distributed PV systems with “Intelligent Interfaces”
2. Automated voltage regulation, achieved through:
   - Dynamic reactive power (VAr) injection
   - Automated active power curtailment
3. Power ramp rate management
4. Low Voltage ride through
5. Microgrid operation and management

Table 3 summarizes the SEGIS features and benefits.

Table 3. SEGIS Features with Benefit and Value.

Feature	Benefits	Value
1. Distributed PV Systems with Intelligent Interfaces	1. Reduced T&D losses 2. No infrastructure upgrades 3. Reduced O&M 4. Energy security 5. Increased energy harvesting 6. Smart-grid creation, with two-way communication	• Energy production • Generation capacity • Distribution loss reduction • Reactive power control to improve grid stability • Environment (carbon credits) • Disaster recovery • Reduced cost of siting, permitting and interconnection costs
2. Automated Voltage Regulation • Dynamic reactive power (VAr) injection • Automated active power curtailment	1. Mitigates over voltage and under voltage conditions on the grid due to intermittency of PV, which can result in: a. Stress on utility equipment and resultant issues/shortened life b. Consumer outages / outage minutes c. Higher consumer electric bills due to higher voltage on the grid d. Shortened life of consumer appliances 2. Mitigates today's reduction in approval by utilities for PV interconnections into their electric grid due to intermittency issues. 3. Enables PV to be deployed without limit. 4. Enables utilities to use solar power for frequency regulation. 5. Improves system stability and	• Mitigation of additional utility equipment and stress on existing equipment to manage intermittency due to high PV penetration • Reduction in customer interruptions thus avoiding costs of unserved energy and penalties • Reduction in consumer electric bills due to higher voltage than necessary on the grid • Improved power quality resulting in reduction premature failures of both consumer and utility equipment

	thus enables high transfer capability on the transmission system (thus more economic trade) 6. Improves power quality	
3. Power Ramp Rate Management	Controls rate of ramp up of active power, enabling grid stability	• A similar value to voltage regulation
4. Voltage Ride Through (LVRT)	In the case of nuisance tripping scenarios: • Avoids loss of PV generation due to hiccups in grid voltage • Avoids turning PV generation on/off and thus destabilizing voltage levels on grid	• A similar value to voltage regulation plus • Mitigation of loss of PV generation
5. Microgrid Operation and Management	Energy security Increased grid reliability and elimination of blackouts, especially for critical facilities Increased de-centralization of power generation	• Reduction in customer interruptions (outages, brownouts, etc.), thus avoiding costs of unserved energy and penalties Consumers and businesses in the U.S. pay at least $150 billion per year in costs due to power outages. Smart microgrids' reliability significantly reduces these costs • Energy security

7.3. Numbers of U.S. Jobs Discussion

Petra Solar can demonstrate the positive impacts that investment in solar technology innovation through the SEGIS initiative has had on economic development and job creation.

Petra Solar's development of distributed AC Module technology with two-way smart-grid communications was funded in part by the SEGIS initiative. Public Service Electric & Gas (PSE&G), the largest utility in New Jersey, found this technology to be very attractive, and as a result Petra Solar is now installing its SunWave AC Module systems under a contract with PSE&G. This 40MW installation is the largest distributed solar electric project being deployed in the world today, and has created jobs at all levels of the supply chain, including research and development, manufacturing and assembly, installation and maintenance, finance, legal, and marketing. This is in addition to indirect benefits to the economy.

Petra Solar alone has grown from 15 employees in the spring of 2009 to 170 employees at the end of 2010. The company has developed its own innovative modular assembly line for balance-of-system type solar manufacturing of SunWave systems at its headquarters in New Jersey. Over 60 installation jobs have also been created for the rapid rollout of the system.

In keeping with the company's commitment to return ratepayer and taxpayer support, the company will create new manufacturing facilities in jurisdictions in which it does significant business. As a result, major contracts with utilities are expected to result in the creation of jobs to staff local manufacturing operations.

Adding to the growth of jobs at Petra Solar is the development of its Network Operations Center (NOC). The NOC serves as Petra Solar's command center where the company uses its IntelliView smart energy software platform, developed through SEGIS funding, to remotely monitor and control all solar and smart-grid assets in the field, both in the U.S. and around the world. Petra Solar has staffed the NOC with a highly trained technical staff for 24/7 support and operations services. Utilities can use Petra Solar's NOC services offering options from support of their SunWave deployment to full remote 24/7 operations where Petra Solar is the first line of defense in managing, monitoring, and troubleshooting their smart-grid system.

7.4. Long Term Standardizations

The development of adequate standards is critical for the future of the PV industry; this is highlighted by the need for utility control over distributed assets. Standardization is required at various levels.

Standardized communications are necessary for the effective scaling of utility supervision of distributed assets. This has driven the team's direction to ZigBee network as an emerging standard for last-mile communications.

Microgrid functionality requires interoperability of PV, energy storage, and load scheduling systems together with building the EMS. Alignment of feature definition and capabilities of DG inverters is critical. Petra Solar has supported and contributed to various initiatives at standardization, notably the Smart Inverter Communication Initiative led by EPRI [18].

Harmonization of active, non-intentional detection techniques is required to allow various inverters to cooperate in detecting unplanned islanding of a common circuit. Petra Solar has chosen to implement the Sandia Frequency Shift (SFS) method for islanding detection, which was designed with a particular focus on scalability to large groups of inverters.

8. SUMMARY AND CONCLUSIONS

With support from the SEGIS initiative partnerships, cost-shared funding and technical assistance from Sandia National Laboratories, the project met the following goals:

- GEC controls were updated on both the 120 and 240V platforms, and the nuisance tripping issues previously experienced by early SEMs were addressed and corrected.
- UL1741 and IEEE 1547 SEM parameters were optimized to improve adherence to these standards.
- The Smart Switch was developed and implemented in the lab and is ready for field testing.
- Grid impact studies were conducted and theoretical results derived to illustrate the impact of Petra Solar's GEC controls on high penetration PV into the grid; a 5kW mockup system was successfully tested to ensure readiness for field deployment. Also a field demonstration system was installed at a local utility's test yard in preparation for the SEGIS conference.
- An NMS (network management system) to better manage distributed solar PV and other distributed energy resources was developed.
- A SEGIS Demonstration Conference, which included technology demonstration, was held at Pepco Holdings, Inc., on September 29, 2011. This highly successful event was attended by nearly 100 people including technology experts from DOE and Sandia, as well as utility executives, Wall Street investors, influential policy makers, stakeholders, leading industry market analysis from Greentech Media Research, and others.

Work continues on components and circuits that were developed during the three stages of the SEGIS contract. Goals of the continued work include higher efficiency of the conversion processes, inclusion of new integrated circuits that will improve reliability and reduce costs, and development of new applications that use the "power-on-a-pole" hardware technologies but expand into areas that enhance the "Virtual Power Plant" (VPP) concepts.

9. REFERENCES

[1] Bower, W., Ropp, M., “Evaluation of Islanding Detection Methods for Photovoltaic Utility-interactive Power Systems”, International Energy Agency Photovoltaic Power Systems Implementing Agreement, Task V; Grid Interconnection of Building-integrated and Other Dispersed Photovoltaic Power Systems, Report IEA PVPS T5-09: 2002, Feb., 2002.

[2] “Solar Energy Grid Integration Systems: Program Concept Paper,” Sandia National Laboratories, October 2007.

[3] Hussam Al-Atrash, Nasser Kutkut, and Issa Batarseh, “The AC PV Module: A New Trend in Distributed Photovoltaic Generation Systems”, IEEE Energy2030, Atlanta, Georgia, 17-18 November 2008.

[4] J.H.R. Enslin, “Network Impacts of High Penetration of Photovoltaic Solar Power Systems,” IEEE PES GM 2010-001626, USA.

[5] IEEE 1547 Standard: http://www.ieee.org/portal/innovate/search/search_result.html?key=1547

[6] A. Engler, “Control of Parallel Operating Battery Inverters,” in PV Hybrid Power Systems, 2000, Aix en Provence, France.

[7] J. Guerrero et al., “Output impedance design of parallel-connected UPS inverters,” in Industrial Electronics, 2004 IEEE International Symposium on, 2004, pp. 1123-1128 vol. 2.

[8] R. Lasseter et al., “Integration of Distributed Energy Resources: The CERTS Microgrid Concept,” Consortium for Electric Reliability Technology Solutions, LBNL-50829, April 2002.

[9] Z. Ye et al., “Facility Microgrids,” General Electric Global Research Center, subcontract report NREL/SR-560-38019, May 2005.

[10] H. Alatrash, A. Mensah, E. Mark, G. Haddad and J. Enslin, “Generator Emulation Controls for Photovoltaic Inverters”, submitted to IEEE PES Transactions on Smart Grid, 2011.

[11] UL 1741 Standard: http://ulstandardsinfonet.ul.com/scopes/1741.html

[12] Petra Solar website: www.petrasolar.com

[13] Cooper Power Systems website: http://www.cyme.com/software/cymdist/

[14**]** Manitoba HVDC Research Centre website: https://pscad.com/services/consulting/software_and_tools/index.cfm

[15] J.H.R. Enslin, H. Alatrash, “Distribution Network Impacts of High Penetration of Distributed Photovoltaic Systems”, 21st International Conference on Electricity Distribution, Frankfurt, 6-9 June 2011.

[16] H. Alatrash, A. Mensah, E. Mark, R. Amarin, and J. Enslin, “Generator Emulation Controls for Photovoltaic Inverters”, 14th European Conference on Power Electronics and Applications - EPE 2011 -, Birmingham, United Kingdom, 30 Aug. - 1 Sep., 2011.

[17] H. Alatrash, R. Amarin, J. Enslin, “Mitigating Distribution Network Impacts Using Smart Grid Enabled Distributed Photovoltaic Systems”, Building Integrated PV Systems International workshop, Delft University of Technology, the Netherlands, 11/12 April 2011.

[18] “Standard Language Protocols for PV and Storage Grid Integration: Developing a Common Method for Communicating with Inverter-based Systems,” Electric Power Research Institute, May 2010.

APPENDIX A - SUNWAVE POLE-MOUNT SOLUTIONS

PETRA SOLAR

SunWave™ Pole-Mount Solutions

Smart Utility-Grade Solar Energy Solution

120 V/60 Hz

Overview

Petra Solar's SunWave solutions offer solar energy generation, smart grid communications and control, and electric grid reliability capabilities with certified, utility-grade robustness. SunWave systems bring solar online faster, enabling meaningful energy generation utilizing existing assets and time-tested deployment strategies.

The SunWave solution mounts quickly and safely to utility distribution and streetlight poles to deliver power directly to the electric grid. Systems consist of a high efficiency solar module and a Smart Energy Module (SEM™) with smart grid communications capability, mounted to a utility-grade rack system that is compatible with wood, metal, fiberglass and concrete poles.

This turnkey "mount and play" solution is designed to be easily installed by linemen and utility crews on utility poles in under 30 minutes. The system is certified to the requirements of UL1741, and the 2008 US NEC.

Configuration

The SunWave system includes:

- SunWave AC Module (solar module plus SEM)
- SunWave Communicator®
- Energy Portal software
- Rack and grid connection cable

Smart Energy Module

The SEM optimizes and manages solar energy production on an individual solar module basis, providing energy harvests averaging more than 10% greater than traditional solar solutions and supports a wider variety of configurations. The SEM also meters energy that is output to the electric grid and safely disconnects the output in the event of a grid fault or disconnect (UL1741 compliant).

Petra Solar's SEM does more than simply provide utilities with visibility into solar energy production. The SEM provides an added benefit of visibility into the distribution grid, and means to mitigate grid secondary performance issues. Each SEM measures the voltage of the electric grid, enabling utility visibility of secondary grid voltage over an area as wide as the solar deployment. SEMs also have the capability to produce reactive power (VAR) to help mitigate voltage or power factor instability on the grid.

Communications

Petra Solar provides smart grid communications for SunWave systems using ZigBee® wireless mesh networking supported by cellular, Ethernet, or WiMax backhaul networks. The scalable communications system allows individual monitoring and control of each SunWave AC Module. When coupled with the Energy Portal, this system also enables remote management of geographically dispersed SunWave units as a "virtual power plant." SunWave communications also support future-proofing of the system through remote upgrade capabilities to leverage future applications and comply with emerging standards; and can be expanded to support integration with other smart grid management solutions.

Key Communication Features

SunWave solutions deliver the following capabilities on an individual AC Module basis:

- Energy generation monitoring
- Health and status diagnostics
- Remote system configuration and software upgradability
- Grid voltage measurement
- Manage reactive power (VAR)
- Smart grid expansion capable

Solar module dimensions
66.14" x 39.40" max
(168.0 cm x 100.0 cm) max

Smart Energy Module (SEM)

SEM120™ 120V/60Hz

Electrical Specifications	Min	Typ	Max
DC Power Input (W)*	200		240
AC Reactive Power Output (VAR)			±200
AC Output Voltage (V)	106	120	132
AC Output Frequency (Hz)	59.3	60	60.5
Current THD (%)			< 5
Power Factor (at 0 VAR Output)			> 0.99
CEC SEM Efficiency (%)	93		
RMS Output Current (A)			1.67
Operating Temperature (°C)	-40		85
Temperature Derating Above 65°C Ambient (W/°C)			-2.5

*Based on PV solar module type

General Specifications and Compliance	
Smart Grid Communication	ZigBee®/IEEE 802.15.4
Solution Weight*	77-87 lbs. (35-40 kg)
Weather Resistance	NEMA4/IP56
Safety/Grid Connection Certification	UL1741, IEEE1547
Standard Warranty	10 Years Limited (SEM),
	Pass through (PV Solar Module)

PETRA SOLAR
300-G Corporate Court, South Plainfield, NJ 07080
Phone: +1.732.379.5566 Fax: +1.908.755.0369
utilities@petrasolar.com www.petrasolar.com

SunWave™ Pole-Mount Solutions

Smart Utility-Grade Solar Energy Solution

230 V/50 Hz

Overview

Petra Solar's SunWave solutions offer solar energy generation, smart grid communications and control, and electric grid reliability capabilities with certified, utility-grade robustness. SunWave systems bring solar online faster, enabling meaningful energy generation utilizing existing assets and time-tested deployment strategies.

The SunWave solution mounts quickly and safely to utility distribution and streetlight poles to deliver power directly to the electric grid. Systems consist of a high efficiency solar module and a Smart Energy Module (SEM™) with smart grid communications capability, mounted to a utility-grade rack system that is compatible with wood, metal, fiberglass and concrete poles.

This turnkey "mount and play" solution is designed to be easily installed by linemen and utility crews on utility poles in under 30 minutes.

Configuration

The SunWave system includes:

- SunWave AC Module (solar module plus SEM)
- SunWave Communicator®
- Energy Portal software
- Rack and grid connection cable

Smart Energy Module

The SEM optimizes and manages solar energy production on an individual solar module basis, providing energy harvests averaging more than 10% greater than traditional solar solutions and supports a wider variety of configurations. The SEM also meters energy that is output to the electric grid and safely disconnects the output in the event of a grid fault or disconnect.

Petra Solar's SEM does more than simply provide utilities with visibility into solar energy production. The SEM provides an added benefit of visibility into the distribution grid, and means to mitigate grid secondary performance issues. Each SEM measures the voltage of the electric grid, enabling utility visibility of secondary grid voltage over an area as wide as the solar deployment. SEMs also have the capability to produce reactive power (VAR) to help mitigate voltage or power factor instability on the grid.

Communications

Petra Solar provides smart grid communications for SunWave systems using ZigBee® wireless mesh networking supported by cellular, Ethernet, or WiMax backhaul networks. The scalable communications system allows individual monitoring and control of each SunWave AC Module. When coupled with the Energy Portal, this system also enables remote management of geographically dispersed SunWave units as a "virtual power plant." SunWave communications also support future-proofing of the system through remote upgrade capabilities to leverage future applications and comply with emerging standards; and can be expanded to support integration with other smart grid management solutions.

Key Communication Features

SunWave solutions deliver the following capabilities on an individual AC Module basis:

- Energy generation monitoring
- Health and status diagnostics
- Remote system configuration and software upgradability
- Grid voltage measurement
- Manage reactive power (VAR)
- Smart grid expansion capable

Solar module dimensions
66.14" x 39.40" max
(168.0 cm x 100.0 cm) max

Smart Energy Module (SEM)

SEM230™ 230V/50Hz

Electrical Specifications	Min	Typ	Max
DC Power Input (W)*	200		240
AC Reactive Power Output (VAR)			±200
AC Output Voltage (V)**	208	230	262
AC Output Frequency (Hz)	47	50	52
Current THD (%)			< 5
Power Factor (at 0 VAR Output)			> 0.99
CEC SEM Efficiency (%)	91.5		
RMS Output Current (A)			1.0
Operating Temperature (˚C)	-40		85
Temperature Derating Above 65˚C Ambient (W/˚C)			-2.5

*Based on PV solar module type
**Range may be more constrained by grid connection standards

General Specifications and Compliance	
Smart Grid Communication	ZigBee®/IEEE 802.15.4
Solution Weight*	77- 87 lbs. (35-40 kg)
Weather Resistance	NEMA4/IP56
Safety/Grid Connection Certification	G83, AS4777, AS/NZS 3100, AS/NZS 3000
Standard Warranty	10 Years Limited (SEM)
	Pass through (PV solar module)

C US

PETRA SOLAR
300-G Corporate Court, South Plainfield, NJ 07080
Phone: +1.732.379.5566 Fax: +1.908.755.0369
utilities@petrasolar.com www.petrasolar.com

APPENDIX B - SUNWAVE ROOF AND GROUND-MOUNT SOLUTIONS

PETRA SOLAR

SunWave™ Smart Solar Energy Solutions

SunWave™ Roof and Ground-Mount Array Solutions

10% Greater Energy Harvest than Traditional Arrays

120 V/60 Hz

Overview

Petra Solar's SunWave array solutions offer solar energy generation, smart grid communications and control, and electric grid reliability capabilities with certified, utility-grade robustness for use in rooftop and ground-mount configurations. SunWave systems bring solar online faster, enabling meaningful energy generation in more configurations in less time.

The SunWave solution centers around a solar AC Module that mounts quickly and safely to rooftop and ground-mount arrays to deliver power directly to the electric grid or behind the meter. AC Modules consist of a high efficiency solar module and a Smart Energy Module (SEM™) with smart grid communications capability.

Configuration

A complete SunWave roof or ground-mount solution includes:

- SunWave AC Module (solar module plus SEM)
- SunWave Communicator®
- Energy Portal software
- Rack and cable system

Smart Energy Module

The SEM optimizes and manages solar energy production on an individual solar module basis, providing energy harvests averaging more than 10% greater than traditional solar solutions and supports a wider variety of configurations. The SEM also meters energy that is output to the electric grid and safely disconnects the output in the event of a grid fault or disconnect.

Petra Solar's SEM does more than simply provide utilities with visibility into solar energy production. The SEM provides an added benefit of visibility into the distribution grid, and means to mitigate grid performance issues. Each SEM measures the voltage of the electric grid, enabling utility visibility of secondary grid voltage over an area as wide as the solar deployment. SEMs also have the capability to produce reactive power (VAR) to help mitigate voltage or power factor instability on the grid.

Communications

Petra Solar provides smart grid communications for SunWave systems using ZigBee® wireless mesh networking supported by cellular, Ethernet, or WiMax backhaul networks. The scalable communications system allows individual monitoring and control of each SunWave AC Module. When coupled with the Petra Solar Energy Portal, this system also enables remote management of geographically dispersed solar arrays. SunWave communications also support future-proofing of the system through remote upgrade capabilities to leverage future applications and comply with emerging standards; and can be expanded to support integration with other smart grid management solutions.

Key Communication Features

SunWave solutions deliver the following capabilities on an individual AC Module basis:

- Energy generation monitoring
- Health and status diagnostics
- Remote system configuration and software upgradability
- Grid voltage measurement
- Manage reactive power (VAR)
- Smart grid expansion capable

SunWave™ AC Module

Technical Data

Solar module dimensions
66.14" x 39.40" max
(168.0 cm x 100.0 cm) max

Smart Energy Module (SEM)

SunWave AC Module

SEM120™ 120V/60Hz

Electrical Specifications	Min	Typ	Max
DC Power Input (W)*	200		240
AC Reactive Power Output (VAR)			±200
AC Output Voltage (V)	106	120	132
AC Output Frequency (Hz)	59.3	60	60.5
Current THD (%)			< 5
Power Factor (at 0 VAR Output)			> 0.99
CEC SEM Efficiency (%)	93		
RMS Output Current (A)			1.67
Operating Temperature (°C)	-40		85
Temperature Derating Above 65°C Ambient (W/°C)			-2.5

*Based on PV solar module type

General Specifications and Compliance	
Smart Grid Communication	ZigBee®/IEEE 802.15.4
AC Module Weight*	42-52 lbs. (19-24 kg)
Weather Resistance	NEMA4/IP56
Safety/Grid Connection Certification	UL1741, IEEE1547
Standard Warranty	10 Years Limited (SEM)
	Pass through (PV solar module)

C SP US

PETRA SOLAR

300-G Corporate Court, South Plainfield, NJ 07080
Phone: +1.732.379.5566 Fax: +1.908.755.0369
utilities@petrasolar.com www.petrasolar.com

SunWave™ Roof and Ground-Mount Array Solutions

10% Greater Energy Harvest than Traditional Arrays

230 V/50 Hz

Overview

Petra Solar's SunWave array solutions offer solar energy generation, smart grid communications and control, and electric grid reliability capabilities with certified, utility-grade robustness for use in rooftop and ground-mount configurations. SunWave systems bring solar online faster, enabling meaningful energy generation in more configurations in less time.

The SunWave solution centers around a solar AC Module that mounts quickly and safely to rooftop and ground-mount arrays to deliver power directly to the electric grid or behind the meter. AC Modules consist of a high efficiency solar module and a Smart Energy Module (SEM™) with smart grid communications capability.

Configuration

A complete SunWave roof or ground-mount solution includes:

- SunWave AC Module (solar module plus SEM)
- SunWave Communicator®
- Energy Portal software
- Rack and cable system

Smart Energy Module

The SEM optimizes and manages solar energy production on an individual solar module basis, providing energy harvests averaging more than 10% greater than traditional solar solutions and supports a wider variety of configurations. The SEM also meters energy that is output to the electric grid and safely disconnects the output in the event of a grid fault or disconnect.

Petra Solar's SEM does more than simply provide utilities with visibility into solar energy production. The SEM provides an added benefit of visibility into the distribution grid, and means to mitigate grid performance issues. Each SEM measures the voltage of the electric grid, enabling utility visibility of secondary grid voltage over an area as wide as the solar deployment. SEMs also have the capability to produce reactive power (VAR) to help mitigate voltage or power factor instability on the grid.

Communications

Petra Solar provides smart grid communications for SunWave systems using ZigBee® wireless mesh networking supported by cellular, Ethernet, or WiMax backhaul networks. The scalable communications system allows individual monitoring and control of each SunWave AC Module. When coupled with the Petra Solar Energy Portal, this system also enables remote management of geographically dispersed solar arrays. SunWave communications also support future-proofing of the system through remote upgrade capabilities to leverage future applications and comply with emerging standards; and can be expanded to support integration with other smart grid management solutions.

Key Communication Features

SunWave solutions deliver the following capabilities on an individual AC Module basis:

- Energy generation monitoring
- Health and status diagnostics
- Remote system configuration and software upgradability
- Grid voltage measurement
- Reactive power (VAR)
- Smart grid expansion capable

SunWave™ AC Module

Solar module dimensions
66.14" x 39.40" max
(168.0 cm x 100.0 cm) max

Smart Energy Module (SEM)

SunWave AC Module

SEM230™ 230V/50Hz

Electrical Specifications	Min	Typ	Max
DC Power Input (W)*	200		240
AC Reactive Power Output (VAR)			±200
AC Output Voltage (V)**	208	230	262
AC Output Frequency (Hz)**	47	50	52
Current THD (%)			< 5
Power Factor (at 0 VAR Output)			> 0.99
CEC SEM Efficiency (%)	91.5		
RMS Output Current (A)			1.0
Operating Temperature (°C)	-40		85
Temperature Derating Above 65°C Ambient (W/°C)			-2.5

*Based on PV solar module type
**Range may be more constrained by grid connection standards

General Specifications and Compliance	
Smart Grid Communication	ZigBee®/IEEE 802.15.4
AC Module Weight*	42-52 lbs. (19-24 kg)
Weather Resistance	NEMA4/IP56
Safety/Grid Connection Certification	G83, AS4777, AS/NZS 3100, AS/NZS 3000
Standard Warranty	10 Years Limited (SEM)
	Pass through (PV solar module)

C SP US

PETRA SOLAR
300-G Corporate Court, South Plainfield, NJ 07080
Phone: +1.732.379.5566 Fax: +1.908.755.0369
utilities@petrasolar.com **www.petrasolar.com**

APPENDIX C - SUNWAVE COMMUNICATOR

PETRA SOLAR

SunWave™ Smart Solar Energy Solutions

SunWave Communicator®

Enabling Adaptability and Control of the Smart Grid

Overview

The SunWave Communicator® serves as the hub for an advanced communications architecture. It features two-way communications to each smart grid device connected to it, allowing both individual and system monitoring and control.

Enabling connectivity to remote, distributed assets using technology best suited to the device and applications requirements, the SunWave Communicator is an integral part of the smart grid network.

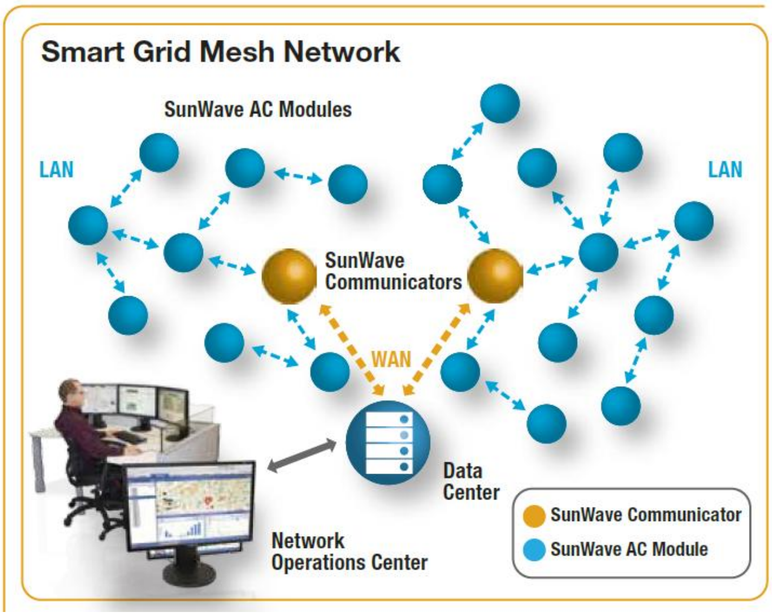
Much more than a communications gateway, it also provides the intelligence in any smart grid. By enabling key decision making processes at this level, utilities can benefit from increased grid reliability and efficiency.

With a variety of WAN interface options and a self healing reliable LAN mesh network, the SunWave Communicator provides a holistic approach to managing the electric grid. As part of the SunWave system, it enables the intelligent energy system to improve grid management by putting much needed data into the hands of utility companies. This is achieved through the continuous monitoring of the system performance, utilizing operational power flow parameters, real-time analysis and status updates. The SunWave system enables decision-making processes based on the data from these critical assets.

The standards-based modular architecture provides interoperability capabilities with other smart grid applications, and leverages the network investment across additional applications and devices such as: Distribution Automation, Demand Response, Advanced Metering Infrastructure and Home Area Networks.

Key Features

- Enables smart grid interoperability
- Provides smart grid backbone for distributed PV resources
- Enables monitoring and reporting of critical data, including energy generation
- Aggregates reports of operational status to the operations center
- Provides health status and diagnostics data
- Automated alerts
- Self healing LAN mesh network
- Secure communications – 128 Bit AES encryption
- NEMA4 enclosure
- Variety of mounting options



SunWave AC Modules automatically discover one another, intelligently and dynamically choosing the optimal communication path to a SunWave Communicator.

LAN	
Technology/Standard	802.15.4/ZigBee®
Frequency	2.4 GHz
Modulation	Direct Sequence Spread Spectrum (DSSS)
Network Configuration	Self-Healing Mesh
Transmit Output Power	
North America & Australia	63 mW (+18 dBm)
International	10 mW (+10 dBm)
RF Data Rate	250 kbps
Receiver Sensitivity	-102 dBm
Security	128 Bit AES Encryption Link and Network Keys
Antenna Gain	2 dBi
No. of Channels	15
WAN	
Technology	Cellular/EVDO/1xRTT/ HSDPA/EDGE/GPRS/ Wi-Fi/Gobi
Security	SSL tunnels, SSHv2, FIPS 197 (serial port) VPN-IPsec with IKE/ISAKMP, multiple tunnel support, DES, 3DES, up to 256 bit AES Encryption, VPN Pass-through, GRE Forwarding
Management	HTTP/HTTPS web interface, password access control, IP service port control
Compliance / Agency	
North America	FCC 47 CFR PT 15-B UL 60950-1 CSA C22.2 #60950-2
Global (passed)	IEC 60950-1 IEC 60950-22 IEC 60529 Cenelec EN 55024
Global (pending)	IEC 61000-6-4 C-Tick, A-Tick

Power	
Average Operating Current	< 0.1A
Supply Voltage	
North American	100 - 140 VAC
International	100 - 240 VAC
Power Consumption Idle (W)	3.9 W at 120 VAC
Power Consumption Max (W)	13.4 W at 120 VAC
Surge Protection	
North American	10 kA Inominal, 36 kA Ipeak
International	20 kA Inominal, 50 kA Ipeak
Environmental	
Operational Temperature Range	-35 °C to +70 °C
Storage Temperature Range	-40 °C to +85 °C
Relative Humidity	5 - 95% (Non-condensing)
Mechanical	
Dimension (L x W x H)	12" x 10" x 6" (31 cm x 25 cm x 15 cm)
Weight	10 lbs. (4.5 kg)
Mounting Options	Wood pole, metal pole, concrete pole, rooftop
Internal Flash Storage	> 1GB

PETRA SOLAR
300-G Corporate Court, South Plainfield, NJ 07080
Phone: +1.732.379.5566 Fax: +1.908.755.0369
utilities@petrasolar.com **www.petrasolar.com**

APPENDIX D - GRIDWAVE

PETRA SOLAR

Grid Reliability and Efficiency Solutions

GridWave™

Smart Energy Solutions

GridWave solutions extend the functionality of Petra Solar's SunWave™ smart energy offerings with capabilities supporting grid reliability and efficiency. GridWave solutions enable distribution utilities to proactively manage grid effects caused by renewable generation intermittency such as sudden overvoltage or undervoltage conditions as well as supporting existing grid infrastructure by reducing switching frequency of on-load tap changers, voltage regulators and capacitors.

GridWave solutions, based on technology developed in coordination with the U.S. Department of Energy's Solar Energy Grid Integration Systems program, are established on the concept of generator emulation which captures the inertial behavior, as well as finite and controlled impedance of a synchronous generator, to facilitate stable grid management. Providing a superset of functionality to UL 1741 operation, GridWave solutions enable utilities to move to next-generation grid reliability functionality while providing for safe return to standard UL 1741 modes. In doing so, GridWave solutions open the door for utilities to proactively manage next-generation standards benefits while maintaining required compliance standards.

GridWave Smart Energy solutions are offered as extended firmware capability to the Petra Solar SunWave Smart Energy Module (SEM™) as part of a complete solar Smart Energy solution. Three levels of GridWave functionality are offered: Flex-tie™, Smart-tie™ and Smart-tie™ Microgrid.

Flex-tie
Targeted grid reliability management

The Flex-tie solution provides an excellent avenue to evaluate and target GridWave capabilities. The Flex-tie offering comprises all of the major GridWave features but provides them as manual, operator-driven capabilities. This allows for a clear understanding of cause and effect of each feature and ensures complete control if the operator is unfamiliar with the effects of an automated management system. Additionally, specific grid issues may be targeted on as needed basis prior to deployment of automated functionality.

The Flex-tie package includes:

- AC output power curtailment (manual)
- Reactive power (VAR) injection (manual)
- Voltage operating-window setpoints
- Frequency operating-window setpoints
- Voltage ride-through controls
- Power ramp rate management

Smart-tie
Automated voltage regulation for grid reliability

The Smart-tie solution is the principal component of the GridWave management solutions. Smart-tie functionality adds automated voltage regulation operation to GridWave through volt-VAR management and AC output power curtailment. As part of an overall grid voltage optimization system including standard utility practices such as using voltage regulators and capacitor banks, Smart-tie solutions complete the system by managing rapid voltage changes and solar-induced conditions at the grid secondary.

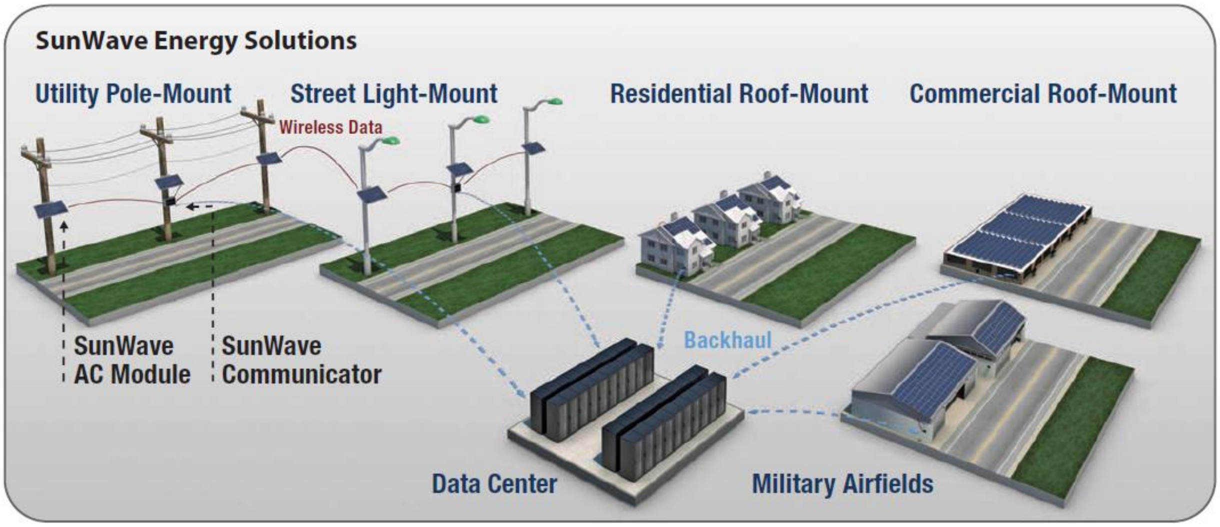
The Smart-tie package includes:

- All Flex-tie features
- Reactive power (volt-VAR) injection (automated)
- AC output power level curtailment (automated)

Smart-tie Microgrid
Automated microgrid management

Smart-tie Microgrid solutions take Smart-tie operation to the next level, enabling full microgrid (intentional islanding) operations. In a microgrid, GridWave-enabled Petra Solar SunWave solutions

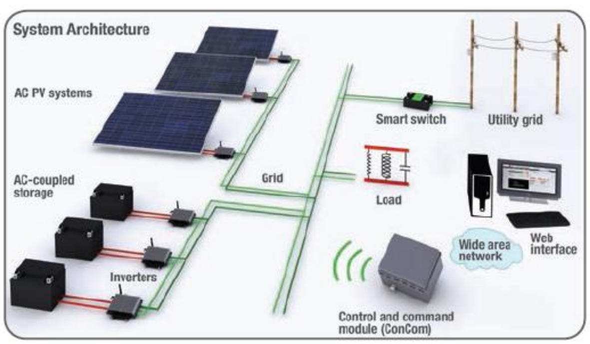
GridWave™



are capable of bringing up the grid from a complete off state (black start) and managing the microgrid load across all GridWave devices. Additionally, if the microgrid is capable of grid-tie through a smart switch, Smart-tie Microgrid devices are able to automatically synchronize with grid frequency and voltage for seamless connection, with similar autonomy for smooth disconnect from the grid.

The Smart-tie MicroGrid package includes:

- All Smart-tie features
- Microgrid black start
- Support for seamless transition to and from grid-tie
- Automated load sharing (among GridWave compatible devices)



Petra Solar's Microgrid Architecture
Collaborative work with the SEGIS program at the U.S. Department of Energy

Grid Management Platform

GridWave capabilities are supported through the Grid Management System (GMS) of the Petra Solar Energy Portal. This secure web-based platform enables GridWave system set-up and management as well as reporting of system status. Fully integrated with the Petra Solar Energy Management System (EMS) and optional Network Management System (NMS), the Petra Solar Energy Portal comprises a complete solar virtual power plant solution.

Key Benefits of Voltage Regulation

Volt-VAR Management and Power Curtailment

- Mitigate over voltage and under voltage conditions on the grid due to intermittency of PV, which can result in:
  - Stress on utility equipment which shortens life
  - Consumer interruptions and associated costs
  - Shortened life of consumer appliances
- Enables PV to be deployed without limit
- Enables utilities to use solar power for frequency regulation
- Improves system stability and thus enables high transfer capability on the transmission system
- Improves power quality

Volt-VAR Management

Volt-VAR management capability within GridWave solutions incorporates fixed reactive power (VAR) injection and automated volt-VAR management.

Fixed VAR

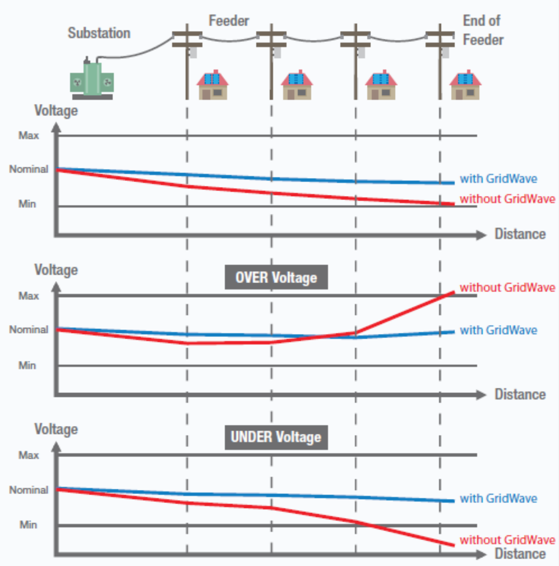
GridWave solutions support the injection of user-specified fixed reactive power to the full capacity of device operation, both leading and lagging. When commanding fixed VAR, GridWave limits real power output as needed to achieve the requested VAR output.

Automated Volt-VAR

Automated volt-VAR operation provides voltage regulation support by sinking reactive power if the line voltage is higher than the selected maximum voltage and by sourcing reactive power if the line voltage drops below the selected minimum voltage. No operator intervention is required other than to configure the applicable voltage range as percentages of nominal line voltage from 80% to 110%.

Automated volt-VAR management enables seamless voltage regulation supporting a wide variety of grid conditions.

Automated Volt-VAR Benefits



Power Curtailment

GridWave solutions support user-specified manual and automated power curtailment that minimizes over-generation to prevent power reliability issues.

Fixed Power Curtailment

GridWave solutions support fixed power curtailment, limiting power output to a fixed maximum as a percentage of system maximum from 0% to 100%.

Automated Power Curtailment

Automated power curtailment manages potential over-voltage situations based on temperature and frequency. Temperature-based power curtailment is always enabled, derating the power output when the operating temperature exceeds 65° C. Frequency-based automated power curtailment may be enabled and disabled as desired. Frequency-based automated power curtailment will limit real output power to manage voltage increases due to increasing grid frequency.When operating in conjunction with automated volt-VAR, automated power curtailment is only employed when the overvoltage condition is beyond the capacity of the automated volt-VAR function.

Voltage Window

GridWave solutions supports user-specified valid voltage windows within which the device operates when connected to an energized grid. Essentially, this capability allows a GridWave-enabled device to operate within user-selected voltage windows (wider, narrower, or overlapping UL 1741 voltage window requirements). UL 1741 specifies two ranges of operating voltage limits; normal and fast-acting. Grid voltage excursions outside the normal (narrower) limits cause disconnection of the device after a specified number of cycles. A wider excursion outside of the fast-acting limits causes a faster disconnection. GridWave solutions follow the same model, but allow the reconfiguration of these limits.

Voltage window parameters are expressed as a percentage of the nominal operating voltage at the point of interconnection. The narrower “normal” window may be adjusted from 80% to 120% of nominal voltage, and the wider “fast-acting” window may be adjusted from 20% to 120% of nominal voltage.

GridWave™ Features continued

Frequency Window

GridWave solutions support user-specified valid frequency windows within which the device shall operate when connected to an energized grid. Essentially, this capability allows a GridWave-enabled device to operate within different frequency windows (wider, narrower, or overlapping UL 1741 window requirements). Frequency window ranges are 57Hz to 63Hz for 60Hz nominal systems and 47Hz to 53Hz for 50Hz nominal systems.

Voltage Ride-Through

Voltage ride-through enables continued operation of GridWave- enabled devices for a user-specified duration within a user-specified voltage limit rather than immediately disconnecting from the grid (as per UL 1741). Generally, low-voltage ride-through (LVRT) is the key functionality enabling, for example, grid connection to be maintained as a tree falls across a line momentarily, and then falls to the ground. High-voltage ride-through is also a capability.

The voltage ride-through window is fixed (0% to 120%) of nominal voltage. The user defines the duration for which the voltage ride-through function will be enabled in the range of 0 to 300 seconds (5 minutes). Within this window, the device will continue to operate and smoothly return to normal operation if line conditions permit within the specified duration.

Smart Microgrid

A microgrid is a stand-alone local electrical power system which may be interconnected to the utility grid. Microgrids support electrical loads and may support electric generation capabilities in the form of solar energy, fossil fuel generators or others, and may also incorporate storage in one or more forms (e.g., batteries). Together these elements form a self-sufficient electric grid and, if interconnected to the utility electric grid, become distributed generation and storage resources from the utility's perspective. During microgrid operation, the microgrid does not exchange real or reactive power with the utility grid. Therefore, no utility grid interconnection requirements are applicable.

GridWave-enabled devices use automated volt-VAR and power curtailment capabilities to maintain voltage and frequency within the microgrid, even under varying load. The nominal voltage and frequency settings can be modified by the microgrid operator in order to maintain voltage and frequency at the desired values.

In addition to managing microgrid voltage and frequency, GridWave microgrids support black start capability, the ability to start the microgrid from a completely off status when not connected to the utility grid. As part of this capability,GridWave will manage the sharing of loads across GridWave-enabled devices. Additionally, GridWave devices support seamless disconnect from, and connection to, the utility grid by fully synchronizing voltage and current before smart switch operation.

Key Benefits of Voltage Ride Through

- Avoids loss of PV generation due to transients in grid voltage
- Avoids turning PV generation on/off and thus destabilizing voltage levels on grid

Key Benefits of Smart Microgrid

- Facilitates energy security
- Increases grid reliability and reduces customer interruptions (outages, brownouts) especially for critical facilities
- Increases de-centralization of power generation

PETRA SOLAR

300-G Corporate Court, South Plainfield, NJ 07080
Phone: +1.732.379.5566 Fax: +1.908.755.0369
utilities@petrasolar.com **www.petrasolar.com**

Preliminary Product Brief

APPENDIX E – ILLUMIWAVE

PETRA SOLAR

Intelligent Streetlight Controller

IllumiWave™

Intelligent lighting control for energy efficiency and cost savings

Overview

Municipalities and other providers have the responsibility to supply street lighting for their service territories. However, the costs of energy consumption, maintenance and operations of these devices are considerable. Entities are seeking ways to increase their overall savings and drive energy efficiency and conservation measures at the same time. The Petra Solar IllumiWave™ smart lighting energy management solution is designed to address these needs.

The IllumiWave intelligent lighting control system provides ON/OFF control of streetlights using traditional photo controls (dawn-dusk sensor) enhanced with two-way communications on the Petra Solar designed smart grid network. The IllumiWave device mounts on streetlights using a twist-lock installation in a standard compliant three-prong socket. In conjunction with light sensing, users can remotely schedule lights to turn on or off at predetermined times for additional savings. Alerts on bulb outages, energy consumption data and reports are managed via the IntelliView™ Lighting Control System (LCS). The LCS is a secure web-based communications module of Petra Solar's robust IntelliView Smart Energy Management system.

IllumiWave System Advantages

The SunWave Smart Solar solution, with an integrated smart grid communication network, is the backbone for smart energy applications such as IllumiWave streetlight control systems. The patented pole-mount system allows customers to mount SunWave systems on wood, concrete and metal poles. Many of these poles are collocated with streetlights or at least within the same general vicinity.

When a SunWave system is deployed, it forms a mesh communications network, which intelligently routes data from each unit back to a secure data center. With access to the IntelliView portal, users can remotely command and control all smart energy applications on the smart grid network including SunWave solar systems and IllumiWave intelligent lighting controls.

With IntelliView LCS users can manage lights by defining groups and implement schedules for energy efficiency according to individual requirements. The system's dashboard provides alert notifications of bulb outages and energy consumption reports. This information reduces the customer call-in volume, thus reducing operational costs. In addition to energy efficiency and conservation measures, LCS can leverage the built-in two-way communications capability to react to load control and disaster events.

Key Features

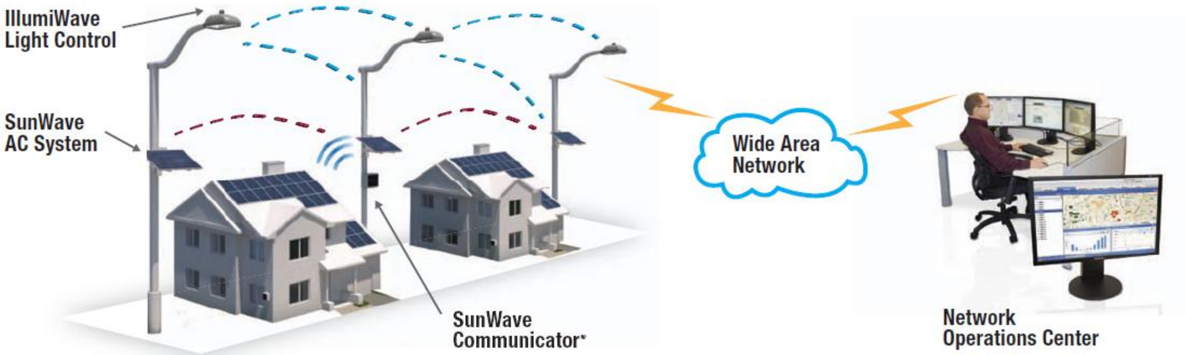
Significant Energy Cost Savings with Energy Efficiency Benefits

- Reduce operational and capital expenses
  - Reduce energy consumption costs by turning lights on/off during off-peak hours
  - Dramatically reduce outage population and customer service calls
  - Reduce truck rolls
  - Prolong life of light
  - Materials replacement savings
- Leverage Petra Solar smart grid deployment
  - Integration with SunWave Smart Solar Energy systems
  - IllumiWave system forms its own mesh communicators network
  - IllumiWave system leverages SunWave Smart Grid network for redundancy
- Remote management and control
  - Individual units
  - By group
- ON/OFF remote control for off peak hours
  - Works in conjunction with and independent of dawn-dusk sensors
- Scheduling
  - Pre-programmed schedule based on recurring or one-time events
- Accurately report energy savings
  - Measurement of actual kilowatts consumed
- Load control and demand response integration
- Optional dimming functionality*

*Depending on lighting technology

IllumiWave™

Network Architecture – SunWave & IllumiWave Systems



IllumiWave Lighting Control Device:

- Three-prong NEMA twist-lock receptacle
- Photosensing using measured light to automatically turn on/off light
- Accepts remote commands to turn on/off light based on schedules
- Dimming option
- Forms mesh network between each IllumiWave device

Petra Solar Designed Smart Grid Network

- Two-way communications
- Mesh network formed from IllumiWave devices connects to SunWave Communicator® (gateway)
- SunWave Communicator connects IllumiWave system to IntelliView LCS module

IntelliView Lighting Control System (LCS) Module

- Remote command and control capabilities
- ON/OFF dimming actions based on: schedules, groups and events
- Telemetry reporting (kWh)
- Bulb status
- Alerts
- Reports
- Integrates with Network Management System

Technical Data/Specifications	Value
Power consumption	105 – 305 VAC, 50/60 Hz
Transmit power	100 MW
Receive sensitivity	-95 dBm
Data rate	250 kbps
Surge protection	320 Joule (13,000 Amps)
Operating light levels	1.5 fc +/- 0.1 fc
Photosensor	Encapsulated phototransistor (upward facing)
Ambient temperature	-40 °C to +70 °C
Moisture resistance	95% RH
FCC	Testing and certified FCC Part 15

Drivers for Energy Efficiency Implementations

Having access to control the energy consumption of thousands of streetlights every day can give a customer tremendous savings. However, it is necessary to identify components which affect the energy consumption and both direct and indirect associated costs.

By having automated alerts sent to operations centers on just bulb outages, organizations can take a proactive approach to handling outage events. Many who rely on the traditional reporting by customers can derive indirect operational savings from reductions in call center ticket handling. Organizations can also schedule their maintenance truck rolls based on the automated outage data, leading to improved operational efficiencies. Since the bulbs can be scheduled to be in an on-state for shorter periods of time each day, the general life of the bulb can be increased and that results in savings on materials replacement and also annual maintenance costs.

Carbon dioxide (CO_2) emissions is another indirect savings which must be factored when analyzing energy efficiency and conservation measures. There are considerable environmental benefits associated with energy reductions and are a responsive measure to eco-efficiency and global climate change.

Streetlight Controls Impact on Savings

If each streetlight (or even a percentage of them) is equipped with controls to cut back on energy consumption, there would be a significant savings to customers. Additionally, goals and tagets for the reduction of greenhouse gases could be met from streetlights efficiencies annually.

The following chart summarizes the dollar value which can be realized from deploying IllumiWave smart lighting energy management solutions.

Assumptions	Values
No. of streetlights	50,000
No. of lights per pole	1
Cost of energy ($/kwh)	0.15*
No. of hours ON (with dawn dusk sensor only)	12
No. of hours (every other light OFF)	6
Maintenance saving per light (annually)	$9.00**

Cost Savings Annual – Light Source Comparison*

	With IllumiWave	Without IllumiWave	With IllumiWave	Without IllumiWave	With IllumiWave	Without IllumiWave	With IllumiWave	Without IllumiWave
	LED		**Induction**		**HID**		**HPS**	
Wattage/Device (w)	57		80		100		150	
Remote Lighting Control and Monitor	Yes	No	Yes	No	Yes	No	Yes	No
Annual								
Energy Consumption (kwh)	9,362,250	12,483,000	13,140,000	17,520,000	16,425,000	21,900,000	24,637,500	32,850,000
Energy Reduction (kwh) Savings	**3,120,750**	–	**4,380,000**	–	**5,475,000**	–	**8,212,500**	–
Energy Consumption Cost	$1,404,338	$1,872,450	$1,971,000	$2,628,000	$2,463,750	$3,285,000	$3,695,625	$4,927,500
Energy Reduction ($) Direct Savings	**$468,113**	–	**$657,000**	–	**$821,250**	–	**$1,231,875**	–
Maintenance Indirect Savings	$425,000**	–	$425,000**	–	$425,000**	–	$425,000**	–
Total Direct and Indirect ($) Savings	**$893,113**	–	**$1,082,000**	–	**$1,246,250**	–	**$1,656,875**	–

*Does not include materials replacement and installation savings when deployed with the SunWave AC system.
**Values varies for each customer.

APPENDIX F – SMART ENERGY SERVICES

PETRA SOLAR

Smart Energy Services

Petra Solar Smart Energy Services

Network Operations Center Services
and IntelliView™ Network and Energy Management Platform

Increase efficiency and reliability with Petra Solar's Network Operations Center and IntelliView management portal and services

Overview

Petra Solar's smart energy services feature data analytics coupled with highly skilled management of critical energy systems. This premiere offering is comprised of the Network Operations Center (NOC) services and IntelliView™ – Petra Solar's intelligent energy management platform. This powerful combination allows customers to collect useful data along with operations and support services to manage their smart grid, including renewable energy, energy efficiency and grid reliability systems.

Network Operations Center Services

Petra Solar's highly skilled technical staff, integral to the Network Operations Center (NOC), provides critical support and operations for the smart grid network and smart energy systems, enabling optimal operations of the system and network.

The Petra Solar NOC services are available in packages to meet varying customer needs - from support of SunWave, GridWave, and IllumiWave smart energy systems to the option for full remote 24/7 operations of Petra Solar designed smart grid networks. Customers can leverage the expertise of the Petra Solar trained technical staff to be the first line of defense in managing, monitoring and troubleshooting the system.

This model allows utilities to focus on other key functions of their operations, while deriving full benefits from their investment in the Petra Solar designed smart grid system.

Network Operations Center Key Features

- Highly trained technical staff
- Service levels:
  - Operations or
  - Support
- Remote monitoring
- Troubleshooting
- Problem resolution
- Energy management services
- Grid reliability verification
- State-of-the-art facilities
- Secure monitoring and data hosting using industry-standard implementation
- Physical security to NOC location
- Military-grade pass card access and biometric finger scan
- Monitored CCTV
- Data security
  - Remote data center
  - Secure VPN
  - SL
  - Firewall and router
- Redundant data storage and back-up
- Back up power

Network Operations Services Matrix

Service	Support	Operations	Service	Support	Operations
IntelliView license	•	•	Remote monitoring		•
Hosting services	•	•	End-to-end testing		•
Data storage	•	•	Triaging		•
Secure VPN to data center	•	•	Troubleshooting		•
Technical support	•	•	O&M dispatch		•
Provisioning	•	•	Energy settlement		•
Configuration management	•	•	Reporting		•
Field deployment verification	•	•	RMA		•
			User access administration	•	

IntelliView

The Petra Solar IntelliView platform combines smart grid network management with energy management services for the suite of Petra Solar smart energy solutions:

- SunWave smart solar energy solutions
- GridWave grid reliability and efficiency solutions
- IllumiWave smart streetlight energy management and efficiency solutions

The IntelliView smart energy platform provides critical analysis of smart grid application data to enable remote command and control of large distributed energy systems.

IntelliView places data for all deployed remote assets on Petra Solar designed smart grid networks into the hands of the customer. Additionally, the processing of myriads of data points in a useful manner empowers the user to effectively operate systems, pinpoint issues, receive alerts and create reports.

With a two-way communications network to support all deployed systems, not only is the operational data (telemetry) important, but so is the communications network related data. With the ability to view the status and health of the network, it assures optimal connectivity of all systems.

IntelliView's modular design creates the platform for additional data-analytic modules, coupling critical network management with smart energy applications. The robust platform is scalable to future smart grid applications, including energy efficiency, energy conservation, grid reliability and smart microgrids.

IntelliView is comprised of several modules that work in unison to enable management of the smart grid network and smart energy systems on that network.

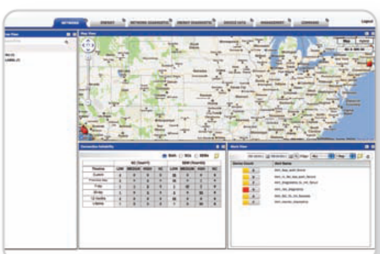
Network Management System (NMS)

A key enabler of remote managing of all elements of the communications network

The Network Management System (NMS) is the foundation module of IntelliView. With NMS, users have a dashboard view of all elements of the communications network. Alerts, performance summaries, and mesh networking diagnostics are provided for problem identification and resolution on an exception basis.

The NMS module allows the user to configure the network, and ensure maximal system up-time. Therefore, when monitoring core assets (such as the SunWave system), the user has the ability to get the necessary data for reporting or troubleshooting in an efficient manner. Additional modules in IntelliView are added with respect to the devices deployed.

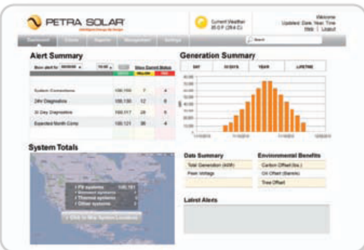
Each device with built-in communications, is displayed on an interactive map, and users can readily visualize network connectivity, status and issues.

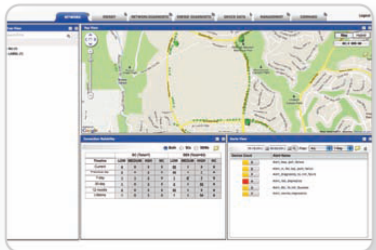


A dashboard view allows management-by-exception by displaying connection summaries, and trace the path of the mesh network via a Radial View.

IntelliView Services Key Features

- Manage network remotely to support
  - Renewable energy systems
  - Grid reliability
  - Energy efficiency
- Isolate and/or overlap network layer from added on applications
  - NMS
  - Plus: EMS, GMS*, LCS*
- Manage by exception – focus on issues only
- Reports on network and system health
- View historical data enabling:
  - Troubleshooting analysis
  - Trending
  - Forecasting
- Secure web hosting
- Secure updates and patches
- Continuous database Replication (RAID)
- Database backup (Including remote)
- Branding customizing
- Management dashboards And reports
- Training & User Manuals





Energy Management System (EMS)*

A centralized view of a virtual power plant

Modules enable a centralized view of a virtual power plant consisting of a large installed base of SunWave smart solar systems distributed over a broad geographical area. The user can perform remote monitoring, command and control capabilities and energy generation reporting.

With distributed generation systems, when data is aggregated in an intelligent manner, it is most useful to the user and familiar, looking more like a power plant. Therefore, in like fashion to the NMS, the EMS provides management by exception features, where expected energy values can be compared to the actual values on an on-going basis. This provides the ability to quantify pre-determined periodic values of energy generation and quickly identify systems which may not be functioning as expected. The EMS features a dashboard view where energy generation can be correlated to geographic locations on a map view, and performance issues are identified and addressed in the alerts and performance summaries.

Grid Management System (GMS)*

A secure web-based platform for GridWave™ smart energy solutions

This IntelliView module enables GridWave system set-up and management as well as reporting of system status. Fully integrated with the EMS and NMS, IntelliView enables the essential remote operations capabilities of a complete solar virtual power plant solution.

Data analytics and command and control is made possible by management by exception, grouping, scheduling and setting up profiles for the systems deployed. Giving system operators the flexibility of grouping data in a logical manner similar to the grid architecture, takes the complexity out of dealing with myriads of data points, and efficiently support grid reliability.

Lighting Control System (LCS)

Remote energy efficiency and conservation management for IllumiWave™ streetlight controller

This module enables users to control when streetlights are turned on or off, in addition to dimmed, and seamlessly coordinate with traditional dusk-dawn sensors. Lights can be managed individually or grouped, commanded actions can be schedules on periodic, one time or event basis.

By having alerts generated for issues such as bulb outages, the burden on call-centers is reduced and customers are able to effectively schedule maintenance work based on priority and geographic locations, since all deployed systems and alerts are displayed on a map. Such data allows pro-active scheduling of preventative maintenance. By viewing the energy consumption, the user can report their energy costs, and quantify savings from their investment.

*Upcoming modules in IntelliView

Preliminary Product Brief

PETRA SOLAR

300-G Corporate Court, South Plainfield, NJ 07080
Phone: +1.732.379.5566 Fax: +1.908.755.0369
utilities@petrasolar.com www.petrasolar.com

DISTRIBUTION:

Internal Distribution

1	MS-0352	Jay Johnson	Org-00718, jjohns2@sandia.gov
1	MS-0717	Randy Shibata	Org-10245, rtshib@sandia.gov
2	MS-0717	Carolyn David	Org-10245, cdavid@sandia.gov
1	MS-0721	Marjorie Tatro	Org-06100, mltatro@sandia.gov
3	MS-0734	Lisa Sena-Henderson	Org-06111, ldhende@sandia.gov
1	MS-0734	Bruce Kelley	Org-06632, jbkelle@sandia.gov
1	MS-0735	Ron Pate	Org-06926, rcpate@sandia.gov
1	MS-0951	Jennifer Granada	Org-06112, jegrana@sandia.gov
1	MS-0978	Scott Kuszmaul	Org-05946, sskuszm@sandia.gov
5	MS-1033	Sig Gonzalez	Org-06112, sgonza@sandia.gov
3	MS-1033	Charles Hanley	Org-06112, cjhanle@sandia.gov
1	MS-1033	Armando Fresquez	Org-06112, afresqu@sandia.gov
1	MS-1033	Abe Ellis	Org-06112, aellis@sandia.gov
1	MS-1033	Josh Stein	Org-06112, jsstein@sandia.gov
3	MS-1104	Juan Torres	Org-06120, jjtorre@sandia.gov
1	MS-1104	Rush Robinette	Org-06110, rdrobin@sandia.gov
1	MS-1108	Michael Hightower	Org-06111, mmhight@sandia.gov
1	MS-1108	Ray Finley	Org-06111, refinle@sandia.gov
1	MS-1108	Jeff Carlson	Org-06111, jjcarls@sandia.gov
1	MS-1108	Jennifer Stinebaugh	Org-06111, jstineb@sandia.gov
1	MS-1108	Jason Stamp	Org-06111, jestamp@sandia.gov
1	MS-1108	Marvin Cook	Org-06111, macook@sandia.gov
1	MS-1140	Ross Guttromson	Org-06113, rguttro@sandia.gov
1	MS-1315	Jeff Nelson	Org-01131, jsnelso@sandia.gov
1	MS0899	RIM-Reports Management	09532 (electronic copy)

External Distribution

Akhil, Abbas (2)	Renewable Energy Ventures 1727 Soplo Rd. SE Albuquerque, NM 87123	aakhil@comcast.net
Alatrash, Hussam (1)	Petra Solar, Inc. 300-G Corporate Court South Plainfield, NJ 07080	Hussam.alatrash@petrasolar.com
Amarin, Ruba (1)	Petra Solar, Inc. 300-G Corporate Court South Plainfield, NJ 07080	Ruba.Amarin@petrasolar.com

Ball, Greg (1)	BEW Engineering 2303 Camino Ramon Suite 220 San Ramon, CA 94583	Greg.Ball@dnv.com
Balog, Robert (1)	PhD.-P.E; Assistant Professor Dept. Electrical and Computer Eng. Texas A&M University 216P Zachry Engineering Center TAMU 3128 College Station, TX 77843-3128	rbalog@ece.tamy.edu
Bower, Ward (10)	Consultant SEGIS Project Manager 13108 Hidden Valley NE Albuquerque, NM 87111	wibower@centurylink.net
Casey, Leo (1)	SatCon 25 Drydock Avenue 7th Floor Boston, MA 02210	Leo.casey@satcon.com
Click, Dave (1)	Florida Solar Energy Center University of Central Florida 1679 Clear Lake Road Cocoa, FL 32922	daveclick@fsec.ucf.edu
Coddington, Michael (1)	National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3305	michael.coddington@nrel.gov
Davis, Kris (1)	Florida Solar Energy Center University of Central Florida 1679 Clear Lake Road Cocoa, FL 32922	kdavis@fsec.ucf.edu
DeLuca, Joe (1)	Petra Solar, Inc. 300-G Corporate Court South Plainfield, NJ 07080	Joe.deluca@petrasolar.com
Enslin, Johan (1)	University of North Carolina Director EPIC 9201 University City Blvd., Charlotte, NC 28223-0001	jenslin@uncc.edu
Gardow, Eva (1)	First Energy 300 Madison Ave, Morristown, NJ	egardow@firstenergycorp.com
Haddad, Ghaith (1)	Petra Solar, Inc. 300-G Corporate Court South Plainfield, NJ 07080	Ghaith.haddad@petrasolar.com
Hamaoui, Ronald (1)	Petra Solar, Inc. 300-G Corporate Court South Plainfield, NJ 07080	Ronald.hamaoui@petrasolar.com

Herig, Christy (1)	Segue Consulting 3201 34th St. South St. Petersburg, FL 33711	cherig@tampabay.rr.com
Hoque, Aminul (1)	EPRI, Power Delivery 942 Corridor Park Boulevard, Knoxville, Tennessee 37932	mhuque@epri.com
Key, Tom (1)	EPRI, Power Delivery 942 Corridor Park Blvd. Knoxville, Tennessee 37932	tkey@epri.com
Kroposki, Benjamin (1)	National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3305	benjamin.kroposki@nrel.gov
Kuran, Mohammad (1)	Petra Solar, Inc. 300-G Corporate Court South Plainfield, NJ 07080	mohammad.kuran@petrasolar.com
Kuran, Shihab (5)	Petra Solar, Inc. 300-G Corporate Court South Plainfield, NJ 07080	shihab.kuran@petrasolar.com
Le, Minh (1)	US DOE EERE –Solar Energy Technologies Program U.S. Department of Energy 1000 Independence Ave SW, EE-2A Washington, DC 20585	minh.le@ee.doe.gov
Lynn, Kevin (2)	US DOE EERE -Lead for Systems Integration Solar Energy Technologies U.S. Department of Energy 1000 Independence Ave SW - EE-2A Washington, DC 20585	Kevin.lynn@ee.doe.gov
Mark, Evlyn (1)	Petra Solar, Inc. 300-G Corporate Court South Plainfield, NJ 07080	Evlyn.mark@petrasolar.com
Mills-Price, Michael (1)	PV Powered/Advanced Energy 20720 Brinson Blvd, Bend OR. 97708	michael.mills-price@aei.com
Moaveni, Houtan(1)	Florida Solar Energy Center University of Central Florida 1679 Clear Lake Road Cocoa, FL 32922	hmoaveni@fsec.ucf.edu
Ozpineci, Burak (1)	Oak Ridge National Labs Power Electronics and Electric Machinery Research Group 2360 Cherahala Boulevard Knoxville, TN 37932	burak@ornl.gov

Ramamoorthy, Ramesh(1)	US DOE EERE - Program Manager Solar Energy Technologies Program U.S. Department of Energy 1000 Independence Ave SW; EE-2A Washington, DC 20585	Ramamoorthy.ramesh@ee.doe.gov
Razon, Alvin (1)	US DOE EERE - CTR - Contractor for Solar Energy Technologies Program U.S. Department of Energy 1000 Independence Ave SW; EE-2A Washington, DC 20585	alvin.razon@ee.doe.gov
Reedy, Bob (1)	Florida Solar Energy Center 1679 Clearlake Rd, Cocoa, FL 32922	reedy@fsec.ucf.edu
Ropp, Mike (3)	Northern Plains Power Technologies 807 32nd avenue Brookings, SD 57006-4716	michael.ropp@northernplainspower. com
Rustom, Khalid (1)	Petra Solar 300-G Corporate Court South Plainfield, NJ 07080	Khalid.Rustom@petrasolar.com
Senkowicz, Eric (1)	Florida Reliability Coordinating Council (FRCC) The Towers at Westshore 1408 N. Westshore Blvd., Suite 1002, Tampa, Florida 33607-4512	esenkowicz@frcc.com
Shaffer, Alan (1)	Lakeland Electric 502 E Lemon St, Lakeland, FL 33801	alan.Shaffer@lakelandelectric.com
Smirnow, John (1)	SEIA 575 7th St. NW; #400 Washington, DC 20004	jsmirnow@seia.org
Smith, Merrill (1)	US DOE OE - Program Manager Office of Electricity Delivery and Energy U.S. Department of Energy 1000 Independence Ave SW; OE-10 Washington, DC 20585	merrill.smith@hq.doe.gov
Stuby, Rick (1)	Petra Solar, Inc. 300-G Corporate Court South Plainfield, NJ 07080	Rick.stuby@petrasolar.com
Thomas, Holly (1)	DOE Golden Field Office 1617 Cole Blvd. Golden, CO 80401	holly.thomas@go.doe.gov

Ton, Dan (4)	US DOE OE - Program Manager, Office of Electricity Delivery and Energy Reliability Smart Grid Research U.S. Department of Energy 1000 Independence Ave SW; OE-10 Washington, DC 20585	dan.ton@hq.doe.gov
Wright, Chris (1)	Florida Power & Light 700 Universe Blvd. Juno Beach, FL 33408	Chris.Wright@fpl.com
Xu, Dr. Yan (1)	Oak Ridge National Labs (ORNL) P.O. Box 2008 Oak Ridge, TN 37831	xuy3@ornl.gov
Yuan, Guohui (1)	US DOE EERE-CTE - Contractor for Solar Energy Technologies Program U.S. Department of Energy 1000 Independence Ave SW ; EE-2A Washington, DC 20585	guohui.yuan@ee.doe.gov
Zgonena, Timothy (1)	Underwriters Laboratories 333 Pfingsten Road Northbrook, IL 60062.	timothy.p.zgonena@us.ul.com

Sandia National Laboratories