Delivering High Value Electricity With Smart Distributed PV Generation

A Petra Solar Whitepaper

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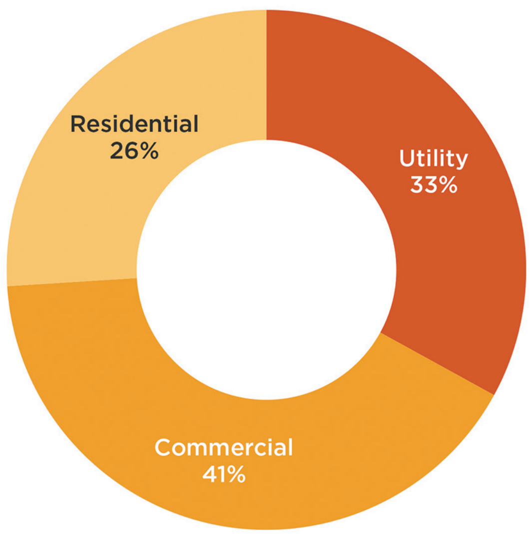
1 GROWING GLOBAL DEMAND FOR DISTRIBUTED SOLAR GENERATION

As the cost of solar photovoltaic (PV) generation drops due to the expansion of manufacturing and industry experience, two trends are beginning to emerge: first, the growth of distributed PV generation as a significant contributor to electricity generation, and second, the opportunity for solar PV to promote and support the developing smart grid. According to GTM Research, annual global PV installations have surged by nearly 74% per year over the past five years, moving from just 2.5 GW in 2007 to 26.7 GW at the end of 2011, and are expected to continue to grow to over 58 GW by 2016. Last year, more than two-thirds of PV capacity was installed in residential and commercial applications, demonstrating PV's rising presence as a distributed resource. While much of the recent attention for solar PV is placed on large multi-MW solar farms, rooftop and other distributed PV systems are forecasted to account for more than half of the market in the next five years.

Figure 1-1: Market Segmentation of Global PV Installations, 2011



Source: GTM Research

As the number of installations continues to increase, grid operators are growing increasingly worried that intermittent and uncontrolled distributed PV generation can destabilize the electricity grid. However, new technologies and smart features can mitigate the destabilizing effect of PV. In fact, widespread adoption of smart distributed PV can increase the efficiency of maintaining the grid, especially when bolstered with smart grid features.

Petra Solar, a solar and smart grid technology company, has taken distributed PV generation to the next level through PV module-level smart grid and optimization solutions. Through the use of proprietary power electronics attached to every solar module, Petra Solar's SunWave™ installations simultaneously optimize the performance of the system and provide essential monitoring and operational services for utilities and system operators. We demonstrate in this whitepaper that smart distributed PV can eliminate nuisances caused by high-penetration PV while providing a savings of $0.024/kWh to $0.176/kWh through advanced grid features.

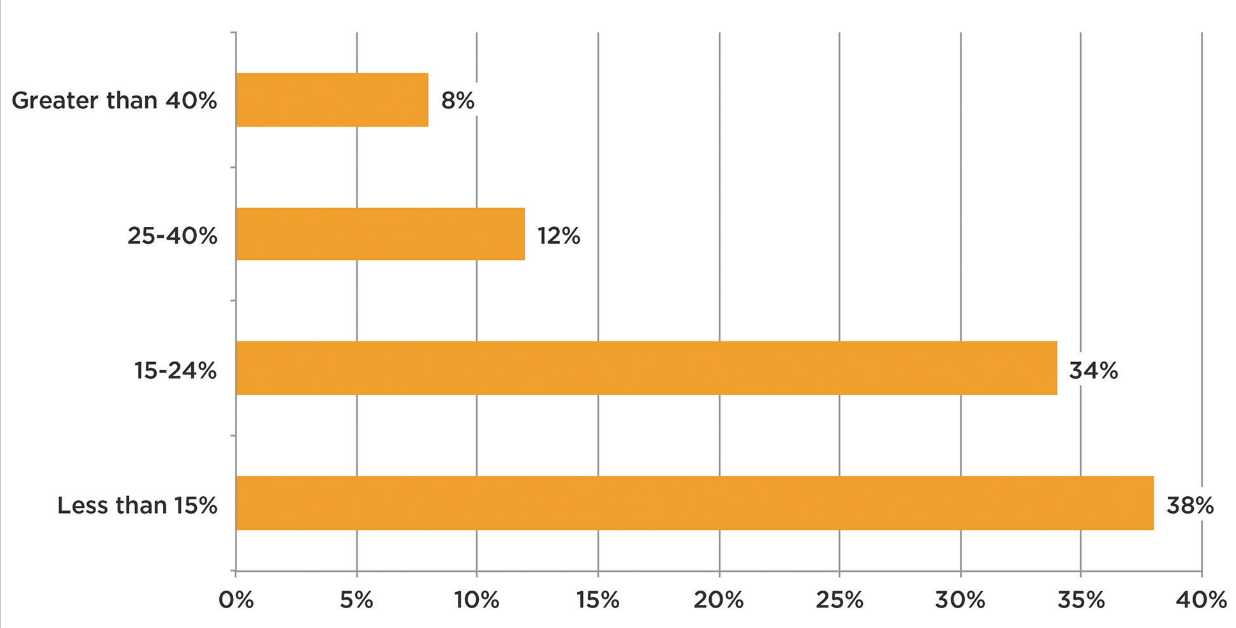
Figure 1-2: Petra Solar's GridWave™ system installation at Atlantic City Electric proactively managing grid effects on feeders that exhibit voltage fluctuation issues in the presence of solar intermittency.

Source: Petra Solar

2 SMART PV SOLUTIONS FOR HIGH PENETRATION PV

Low levels of PV installations are nearly invisible to grid operators, who see only reduced demand on the distribution grid. Higher levels of penetration can begin to cause problems, as PV generation is normally an uncontrolled generator and is an inherently intermittent resource. According to a recent study by Accenture, 38% of surveyed U.S. utilities believed their grids would require upgrades once PV penetration levels hit 15%.

Figure 2-1: Accenture Survey of Utilities: "At what percentage penetration will the grid face challenges or require upgrade in order to handle high-penetration PV?"



Source: Accenture

Partly driven by new standards and by the need to increase the value of generation for PV, inverter and power electronics suppliers have introduced a number of features to mitigate the effects of high-penetration PV, including low voltage/fault ride-through, power factor control, and power curtailment. The most common features provided by this new generation of smart inverters are discussed in the following sections.

2.1 Staying Connected with Low Voltage/Fault Ride Through

In order to prevent PV systems from generating power during grid faults, grid connection standards often force PV systems to disconnect when voltages and frequency deviate from strictly defined specifications. However, in high-penetration situations, temporary fluctuations in grid voltage or frequency that cause connected PV systems to drop offline can exacerbate grid events by increasing generation-load imbalance. As a result, in high-penetration environments, grid operators often implement requirements for low voltage, or fault, ride-through capabilities, which dictate that systems stay connected for a pre-determined number of cycles based on the magnitude of the fault.

This prevents further deterioration of grid conditions as multitudes of PV systems disconnect and attempt to reconnect at the same time. If the fault does not clear within a certain amount of time, the PV system disconnects and waits for grid presence before reconnecting.

2.2 Preventing Over-Voltage and Over-Frequency through Power Curtailment

During periods when generation outpaces electricity demand, grid frequencies and line voltage begin to rise, which can create disruptions and damage sensitive equipment connected to the grid. Historically, generation has only been located upstream of load, meaning that most operators are only concerned with low voltage scenarios at the end of distribution lines. However, high-penetration PV generation located throughout the distribution line can cause grid voltages to exceed compliance levels.

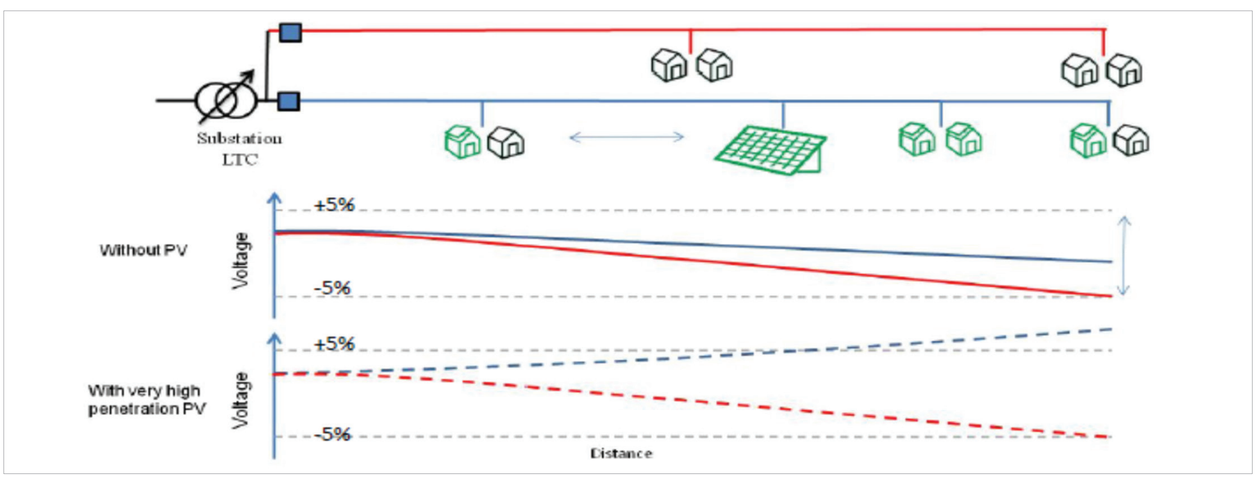
Smart inverters can automatically detect the rise of grid frequencies and voltages. By scaling back power generation, solar energy systems can bring frequencies in line with regulatory requirements. Curtailment can be determined automatically through standard set points (e.g., in the German VDE-AR-N-4105 low-voltage grid code) or through remote utility control.

2.3 Controlling Voltage Levels through Power Factor

In addition to balancing generation and load of real power (watts), grid operators must account for reactive power (VAR) on the system, which is generated and absorbed by capacitive and inductive elements in the system. By controlling and balancing reactive power, grid operators are able to influence the voltage on a distribution line or throughout the system.

Historically, PV inverters have been set to generate with a unity power factor. However, in high-penetration scenarios, PV inverters can operate at non-unity power factor to compensate for reactive power and keep line voltages in compliance. For example, German BDEW technical guidelines call for the control of power factor between 0.95 leading/lagging to support grid voltages depending on local conditions.

Figure 2-2: Potential Effect of Distributed PV on Feeder Voltage

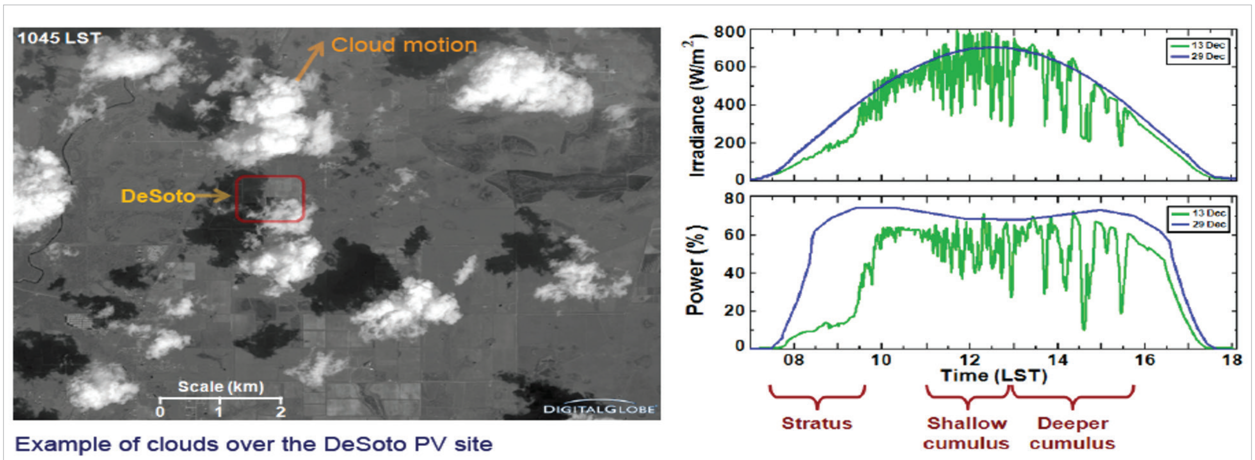


Source: NREL

3 EXTENDING THE VALUE OF DISTRIBUTED GENERATION THROUGH SMART PV

One of the largest challenges for grid operators and utilities is the intermittent behavior of PV generation. While day-to-day PV generation is predictable, more detailed forecasting, which forms the basis of grid planning and stability, is a far more difficult challenge. Cloud coverage and rapid changes in solar resources can cause MW-scale drops in PV generation within seconds. While innovations like local weather forecasting or storage may help with intermittency, these solutions can come at a prohibitive cost. Distributed generation mitigates the effect of intermittency by spreading generation sites across a large geographical area.

Figure 3-1: Intermittency of PV Generation due to Cloud Coverage



Source: Windlogics

Furthermore, distributed generation has the potential to offset transmission and distribution equipment needed to deal with new load behavior (e.g., electric vehicles) and rising electricity demand (e.g., congestion). Petra Solar's solution for modular smart solar generation expands on the traditional notion of distributed solar as individual solar systems with smart grid capabilities located throughout the utility's territory on utility assets like distribution poles in addition to building roofs and solar fields, allowing a utility to directly control distributed generation in its territory. With Petra Solar's IntelliView™ platform, utilities can virtually manage hundreds of thousands of discrete solar modules as if they were a singular utility power plant while still exploiting the benefits of distributed generation.

Most grid requirements for advanced grid integration are reactionary in nature, with smart inverters responding to an unplanned or out-of-specification grid event. However, smart PV inverters are capable of transforming high penetration PV into grid assets rather than a potential nuisance. For example, by capturing the inertial behavior as well as finite and controlled impedance of a synchronous generator, Petra Solar's Smart Energy Module GridWave™ capability provides dynamic Volt/VAR behavior and grid voltage control, improving the overall efficiency of the system. Vendors and utilities indicate that grid operators could leverage five VA for every controlled VAR, meaning a distribution feeder or grid system would theoretically only need 20% penetration of smart PV to realize voltage control. By reducing grid voltages, utilities can lower the overall amount of generation required to power the grid ('conversation voltage reduction,' or CVR). A Snohomish PUD study estimated that a 1% reduction in system voltage levels would reduce overall load consumption by 0.33% to 1.1% with an average around 0.75%.

In addition, distributed solutions owned or operated by the utility can also increase the value of PV systems beyond generation. With smart distributed generation assets on the grid, the utility can monitor grid health beyond existing equipment. For example, Petra Solar's 40 MW of utility-pole installations in New Jersey for PSE&G provide voltage and frequency readings downstream from traditional substation monitoring. Utilities can therefore react more nimbly and even anticipate potential grid events. By increasing the value of the electricity generation though smart grid features like dynamic Volt/VAR control and advanced monitoring, solar can aid the utility in outage detection and restoration and help utilities better control voltages to minimize losses and peak demand, thereby offsetting solar's higher initial costs compared to conventional energy sources.

Figure 3-2: Petra Solar SunWave™ Installation in New Jersey on Utility Distribution Poles

Source: Petra Solar

4 CASE STUDY: QUANTIFYING THE TRUE VALUE OF SMART PV GENERATION

The added benefit of avoided transmission and distribution upgrades, optimization of distribution O&M, and load reduction through conservation voltage reduction and demand response increases the economic benefit of solar to the degree that it can be monetized. By calculating the total operational cost of energy generation ("levelized cost"), we can evaluate solar generation's true cost-competitiveness with conventional generation.

In the comparison in Figure 4-1, the cost of conventional generation is evaluated along with the costs and savings associated with various forms of PV generation, using U.S.-based costs and performance available as a reference. Regions with higher solar resource and lower costs will see lower levelized costs for PV and possibly a more favorable comparison to conventional energy sources. In addition to the levelized cost of electricity generation, other factors such as the recovery of transmission and distribution (T&D) upgrades are considered as well.

As shown in Figure 4-1, the levelized cost of smart distributed PV generation ($0.20/kWh) is higher than the cost of oil generation ($0.201/kWh), but oil also has to factor in the additional cost of building transmission and distribution equipment (T&D), to the tune of $0.049/kWh. Thus, the total cost for oil generation is $0.25/kWh versus smart distributed solar generation's $0.20/kWh.

In addition, using smart distributed PV nets savings by optimizing the operations and maintenance of the distribution grid ($0.01/kWh savings), deferring T&D upgrades and equipment ($0.033/kWh savings) and finally avoiding the generation of conventional sources through demand response and conservation voltage reduction. If smart distributed PV helps grid operators offset natural gas, then the benefit is only $0.024/kWh. However, if oil generation is offset, the load reduction savings skyrocket to $0.133/kWh. Thus, by offsetting oil generation, smart distributed PV can save a total of $0.176/kWh, meaning the net cost of smart distributed PV can be as low as $0.024/kWh. By avoiding natural gas generation, smart distributed PV would still garner $0.067/kWh savings, for a net cost of $0.133/kWh (versus natural gas generation at $0.085/kWh).

Figure 4-1: Cost and Savings of Various Forms of Electricity Generation

UNINCENTIVED COST & SAVINGS BY GENERATION TECH.		SMART DISTRIBUTED PV		DISTRIBUTED PV	CENTRAL PV	OIL	NATURAL GAS
Costs (in ¢/kWh)	Generation	20.0		15.6	12.7	20.1	5.1
	T&D	0.0		0.0	4.1	4.9	3.4
	Total Costs	20.0		15.6	16.8	25.0	8.5
Savings (in ¢/kWh)	O&M Optimization*	-1.0		-	-	-	-
	T&D Deferment**	-3.3		-3.3	-	-	-
	Load Reduction***	Avoiding Oil	Avoiding NG	-	-	-	-
		-13.3	-2.4				
	Total Savings	-17.6	-6.7	-3.3	0.0	0.0	0.0
Net Unincentivized Cost (in ¢/kWh)		2.4	13.3	12.3	16.8	25.0	8.5

*** IMPROVING DISTRIBUTION O&M (Smart Distributed PV)**

By creating a network of grid monitoring devices, distributed PV systems can provide utilities and grid operators quicker and more granular access to voltage and frequency levels throughout their territory and thus, mitigate outages and improve maintenance schedules.

Assumption: 5% improvement in distribution O&M costs.

**** T&D DEFERMENT**

By generating electricity adjacent to demand, distributed PV resources can reduce the use of expensive transmission and distribution capital equipment. Certainly poles and wires are a component, but equipment intended to mitigate congestion and grid events are included as well. With the ability to reduce intermittency effects, smart inverters can defer more capital equipment than passive PV.

Assumption: 50% capacity credit for upfront solar kW rating.

***** LOAD REDUCTION**

By reducing the guesswork involved in delivering energy from the substation to the customer, smart inverters can help utilities react more quickly to changing demand and reduce the overvoltage at the substation resulting in reduced fossil fuel demand.

Assumption: 5x leverage of smart PV capacity; 2% load reduction through demand response and conversation voltage reduction; savings = avoided cost of fuel generation.

Source: GTM Research, Petra Solar

While upfront solar costs still have to decrease significantly to be cost-competitive with inexpensive natural gas, in regions with high electricity costs, the cost of solar has reached parity with conventional generation, and if smart grid features of smart distributed PV can be monetized, the economics are further improved. Furthermore, the reduction of fossil fuel use in existing generators provides a further hedge against potentially volatile fuel prices and increases the value of smart PV generation on the grid.

LCOE Calculation Assumptions: Based on WACC of 10%; inflation/escalator of 3%; capital costs for smart distributed PV ($3.5/W), distributed PV ($2.75/W), central PV ($2/W), oil and natural gas ($1/W) based on 2012 U.S. overnight costs; assumes 20 year PPA tenure; fuel costs for natural gas at $2.5/MMBTU and oil at $80/barrel; solar irradiance fixed at 5.5 kWh/kW/yr.

5 CONCLUSION: UNLOCKING SOLAR'S POTENTIAL THROUGH SMART PV

As the capacity of PV generation increases, grid operators will increase the requirements for PV grid integration. Available features such as low-voltage ride-through, power factor control and frequency-based power curtailment help to mitigate local issues created by high-penetration PV. While these features are more common in large-scale PV systems, small commercial inverters complying with German and Italian grid standards must implement some of these features, as well. While current advanced inverter features will help mitigate potentially destabilizing effects of high penetration PV, further development and utilization of smart PV technology, such as Petra Solar's GridWave™ extensions to its SunWave™ Smart Energy Module, will help drive the economics of solar.

Utilizing smart PV generation can result in net savings of 33.5% to 88% through the combination of distribution O&M optimization (i.e., the ability for utilities to manage distribution grid assets more efficiently with smart PV), T&D deferment from distributed generation, and load reduction (as described previously). As the cost of smart PV technology drops and the price of fossil fuel rises, these savings will help PV reach parity with conventional fuel sources faster than passive PV generation.

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