NREL
NATIONAL RENEWABLE ENERGY LABORATORY

DISTRIBUTED SOLAR PV FOR ELECTRICITY SYSTEM RESILIENCY

POLICY AND REGULATORY CONSIDERATIONS

ABSTRACT

Distributed solar photovoltaic (PV) systems have the potential to supply electricity during grid outages resulting from extreme weather or other emergency situations. As such, distributed PV can significantly increase the resiliency of the electricity system. In order to take advantage of this capability, however, the PV systems must be designed with resiliency in mind and combined with other technologies, such as energy storage and auxiliary generation. Strengthening policy and regulatory support could encourage deployment of PV systems designed for resiliency and improve public access to power during emergencies.

This paper specifies the goals of power resiliency and explains the reasons that most distributed PV systems as installed today are technically incapable of providing consumer power during a grid outage. It presents the basics of designing distributed PV systems for resiliency, including the use of energy storage, hybrid fuel-use and microgrids.[1] The paper concludes with policy and regulatory considerations for encouraging the use of these distributed system designs.

Electricity System Resiliency Focuses on:

- **Prevention** of power disruption
- **Protection** of life and property dependent on electricity service
- **Mitigation** to limit the consequences of a power disruption
- **Response** to minimize the time needed to restore service
- **Recovery** of electricity supply.

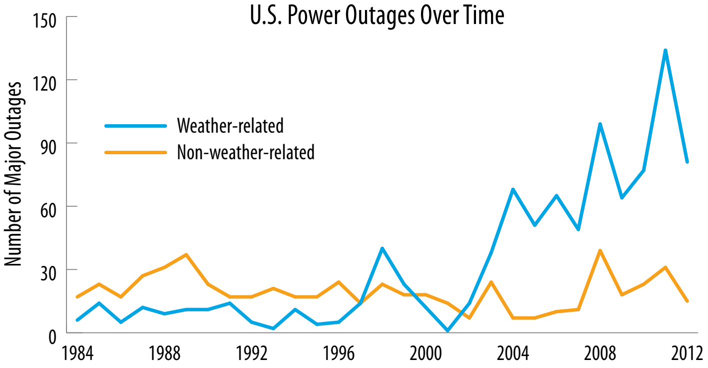


Figure A. Major weather-related power outages—those affecting ≥50,000 customers—increased dramatically in the 2000s *(Kenward and Raja 2014)*

THE NEED FOR RESILIENCY

As shown in Figure A, the number of weather-related power disruptions has grown significantly within the past decade. Severe weather is now the leading cause of power outages in the United States (Kenward and Raja 2014; EOP 2013). Sustained weather-related outages impact daily life, health and safety support services, communities, and the economy, with inflation-adjusted cost estimates of $18 billion to $70 billion per year, on average (Campbell 2012). Electricity losses associated with Hurricane Sandy (2012) are estimated to have resulted in $27 billion to $52 billion in economic losses from lost wages, spoiled inventory, grid damages, and other sources. According to the Edison Electric Institute, the economic impact of blackouts caused by natural disasters can be significantly higher than the cost of system repairs (Johnson 2005).

Electric utilities and local, state, and federal governments understand the urgency for prompt electric system restoration, but are often constrained by limited resources during emergencies. Increasing the grid's resiliency can reduce the time and resources needed to supply power to critical facilities—such as hospitals, shelters, and wastewater treatment facilities—and return the entire system to normal operations.

---

[1] As defined by the Department of Energy, microgrids are a group of interconnected loads and distributed energy resources with clearly defined electrical boundaries that act as a single controllable entity with respect to the grid, and can connect and disconnect from the grid to enable them to operate in both grid-connected or island mode.

**NREL is a national laboratory of the U.S. Department of Energy,
Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.**

Why don’t most existing rooftop PV systems provide power when the grid is down?

For a solar PV system to provide electricity during a utility power outage, it must be designed to function as a standalone system that can isolate itself from the grid, continue power production, and store excess generation for later use.

For safety reasons, current operating standards require that grid-connected solar PV systems automatically disconnect from the grid during a power outage. Most of these systems are not designed to function as both a grid-connected and a standalone system. Instead, they disconnect from the grid and completely cease power production during a system outage. In addition, most PV systems in place today are not coupled with batteries or an auxiliary power source (such as a diesel generator) to allow them to provide continuous power to a load.

Designing a PV system for standalone operation and adding batteries and/or an additional generating resource allows it to produce power even when the grid is down, offering resiliency during an emergency.

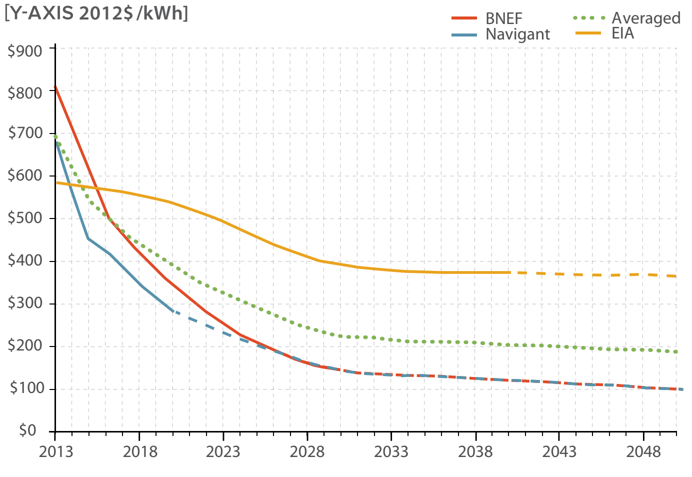
DESIGNING PV SYSTEMS TO PROVIDE ENERGY RESILIENCY

Deploying solar PV technology in conjunction with energy storage, in combination with auxiliary generating sources, or within a microgrid allows solar to contribute to the resiliency by providing localize power when the grid is down. The roles of these supporting technologies and applications are covered below.

Electricity Storage

Given the variable nature of renewable energy resources, including solar, energy storage is a necessary component for a distributed PV system to provide reliable power during a grid outage. Batteries are the most commonly used and well-suited storage technology for small, distributed solar PV applications, although other types of storage may be available for utility-scale systems.

Batteries are integrated with solar PV panels through the inverter. The inverter must be able to automatically select between charging the batteries, providing electricity to the on-site load, and/or feeding electricity onto the grid. The function that is selected at any moment depends on electricity demand from the on-site load, the grid status, battery status, and the available solar resource. When the grid goes down, the inverter must isolate the PV system from the grid, while continuing to supply the on-site load with electricity from the solar panels and/or storage unit. The system must also be capable of isolating all local load from the grid, to avoid creating a grid fault.



(DASHED LINES REPRESENT EXTRAPOLATIONS)

Figure B. Battery price projections. The cost of electricity storage capacity is typically given in $/kWh, while the cost of electric power delivered from storage is usually amortized over thousands of charge-discharge cycles and presented in cents/kWh. *Source: The Economics of Grid Defection (RMI 2014). Courtesy of Rocky Mountain Institute. Used with permission.*

To date, the major barrier to the deployment of energy storage devices in conjunction with PV systems has been cost. But battery prices have declined notably in recent years. One study indicates that the incremental cost of adding batteries to a residential PV system in California declined at an average rate of 11% per year between 2007 and 2013 (NYSERDA 2013), and costs are expected to continue dropping (see Figure B). Based on analysis by Rocky Mountain Institute, PV systems with storage will be cost-competitive with grid power in some locations within this decade (RMI 2014).

Lower battery prices, increased demand for backup power, and uncertainty in the future cost of grid power are all stimulating interest in distributed energy storage (Ammon 2013). Other possibilities receiving attention include using electric vehicles as multi-use storage units and reusing vehicle batteries for solar applications.

In conjunction, more focus is being placed on optimizing the economic viability of energy storage by identifying the most cost-efficient system size for solar applications. Rather than aiming to capture all excess generation from a PV system, the battery unit is sized to match the on-site demand for electricity with the on-site supply of electricity as closely as possible (Doelling 2014). When systems are designed to supply emergency backup power, load shedding to limit electricity use to critical loads reduces the size (and cost) of the battery unit. Batteries may also be used to help a PV system ride through a utility outage long enough for auxiliary generation to come online, or to help auxiliary fuel supplies last longer.

Another means of making storage more economical for the PV system owner is to compensate owners for the benefits that storage provides to the broader electricity system and to society. Storage may add value through the provision of:

- Ancillary services to the grid, such as voltage control,
- Demand-side management to smooth peaks in the load on the utility system,
- Improved power quality (e.g., batteries can smooth the variable output of a PV system),
- Electricity to critical facilities during major power outages
- An increased ability to integrate high levels of distributed generation onto the electricity system (GTM 2014; Roberts 2013).

When PV system owners can realize these values, either through market mechanisms or through government incentives, the cost-effectiveness of storage improves. Even with today's battery prices, if storage owners receive payments for services, such as frequency regulation, a PV system with storage could more than offset the added cost of the batteries. The potential to avoid losses that can result from power outages is another incentive to invest in storage (see Case Studies B and E, the examples of Midtown Community School and Princeton University).

Several state governments are encouraging small-scale, distributed storage adoption through deployment targets, incentive programs, and regulatory adjustments. California is providing incentives for the development of advanced storage associated with distributed energy through the Self-Generation Incentive Program (CPUC 2014a). Storage procurement targets have been set for load serving entities (AB2514), and the California Public Utility Commission (CPUC) has been directed to consider methods to place appropriate value on the services that storage provides. To remove interconnection barriers to storage, the CPUC issued clarification on the issue, specifying that customer-side storage associated with generating systems that are eligible for net-metering should be treated as an "addition or enhancement" to the system, and are exempt from additional interconnection application fees, supplemental review fees, costs for distribution upgrades and standby charges (CPUC Decision 14-05-033 2014b). In a separate proceeding, the CPUC is making updates to Rule 21, which lays out interconnection procedures, in order to standardize the processes for projects involving storage (CPUC 2014c).

Florida's SunSmart Schools and Emergency Shelters Program has installed 115 10-kW PV systems with storage at Florida's schools to create emergency shelters. The program was initially funded by the American Recovery and Reinvestment Act of 2009 (ARRA), through the Florida Department of Agriculture and Consumer Services, and has since received additional funding from private and public utilities. The program has also provided teachers with opportunities for professional development and has taught students about alternative energy and disaster preparedness through an inquiry-based curriculum (NREL 2014; FSEC 2014).

Text Box 1: German incentives for energy storage with distributed solar systems

Since May 2013, the German government has incentivized the installation of storage units in association with new or existing distributed solar PV systems. The €50 million program is funded by emissions trading revenue. German PV system owners can take advantage of low interest loans for the purchase of storage units up to 30 kW, and receive rebates that cover up to 30% of the installed cost. The incentive is available for adding storage to both existing and new solar installations (BSW Solar n.d.; Bayar 2013; Mayer 2013).

The program aims to address the cost barrier that has inhibited the adoption of storage with PV systems (Ammon 2013). However, even with the government rebate, there has been limited growth in the deployment of storage. Low participation in the early months of the incentive program has been attributed to delays in the program rollout, insufficient information for suppliers and customers, and remaining economic barriers beyond the incentives (Doelling 2014).

Rising residential retail electricity rates in Germany and reductions in the cost of solar are expected to spur interest in storage over the coming years. As retail rates rise above the price system owners pay to generate solar power (and are paid for the solar electricity they feed onto the grid), storing excess solar generation for later use in the home becomes more economically attractive. Typical German residential retail rates are currently between €0.22-0.29/kWh, whereas the "feed-in tariff" paid for solar energy fed onto the grid is currently €0.13-0.14/kWh. System owners that receive the higher tariffs offered during the earlier years of the feed-in tariff program, when installing solar systems was more costly, have less economic incentive to add storage to their solar systems (Fares 2014; Bayar 2013). The relatively new charge for self-consumed solar power, designed to ensure that self-generating customers contribute to public funding for the country's transition to clean energy, also impacts the economics of adding storage (Parnell 2014).

The New Jersey Clean Energy Program is developing a solicitation program for storage projects that are integrated with renewable energy generating systems, prioritizing projects that serve critical facilities during electricity system emergencies (NJCEP 2014; Hotchkiss et al. 2013). And the New York State Energy Research and Development Agency (NYSERDA) and ConEdison (ConEd) offer incentives for battery storage projects that help reduce demand during peak periods, thus contributing to electricity system stability (ConEd 2014). Information on the German incentives for storage with residential solar systems is given in Text Box 1.

Community Energy Storage

Community energy storage (CES) brings together many of the benefits of customer-owned storage with those of utility-scale ownership and operation, and is receiving increasing attention in relation to distributed solar generation (ESA 2014). CES is different from storage associated with individual distributed energy systems, because a CES unit serves all customers connected to a particular distribution area (Roberts 2013; Carlson 2011).

Community energy storage. *Image courtesy of eCAMION.*

Similar to the backup capabilities of customer-owned storage, CES units can isolate one portion of the distribution system and provide service to an entire feeder during an outage on the broader grid. The units can be sized from several kilowatts of capacity up to several megawatts, and may offer economies of scale over customer-owned storage.

CES is generally thought of as a utility-owned and operated storage model, although community-owned feeder-level storage units are conceivable. Utility ownership of community-level storage allows utilities to provide potentially greater reliability benefits to all utility customers, integrate the cost of storage into the utility rate-base, and ease the integration of higher levels of distributed generation.

Considerations for regulators wanting to encourage the development of CES include the establishment of standardized specifications for the storage systems and their interconnection with the utility system. American Electric Power (AEP), the utility that has thus far spear-headed the CES model, has published the open-source "Functional Specifications for CES", which outlines connection, control, communication and other proposed standards for the deployment of CES (AEP 2014). Other organizations, such as the National Institute of Standards and Technology and the IEEE are also working on clarifying standards for CES units (IEEE P2030.2 Working Group; IEEE 1547).

Other considerations include the rate structure and metering requirements for customers with a distributed generation system. Questions to be asked include: Can self-generating customers use the CES to store the excess generation from their own systems for later use, as if it were on the customer side of the meter? What are the details of the pricing structure for distributed PV owners and for non-solar customers that benefit from a CES? What is the required metering configuration? (See Text Box 2 for more discussion on this topic.)

Case Study A: CES provides backup power and helps integrate PV in the Borrego Springs Microgrid Demonstration Project

A neighborhood in the city of Borrego Springs, in San Diego County, California is a working example of how distributed solar systems and CES can improve reliability. The town, which is in a relatively remote location, is supplied power via a single transmission line that is at risk for disruptions caused by weather-related events. The town is part of a microgrid pilot project, funded by the U.S. Department of Energy, San Diego Gas and Electric, the California Energy Commission, and other partners to improve reliability of electricity supply. Members of the community installed a total of 700 kW of distributed rooftop solar capacity. CES units were added at the substation and distribution circuits, along with communication and control technologies. A handful of residents had invested in residential-sized battery storage, which was integrated into the system. Residents were also enlisted to participate in a price-driven load management program that used automated price signals sent to home area networks (HANs) to manage loads such as pool pumps, electric vehicles, and thermostats.

The distributed generation, storage units, and control technologies that make up the community's microgrid have provided power during planned and weather-related outages, and successful islanding of neighborhood distribution circuits has been demonstrated on multiple occasions. Experience with the project to date indicates the potential to use the microgrid to re-energize the distribution system after an outage; this capability would represent a new functionality of microgrids and a significant contribution to resiliency. (Klemun 2014; LBNL 2014).

Impacts of Rate Structures on the Use of Distributed Solar with Storage

The rate structure, retail prices, and compensation for PV generation can all influence the use and economics of storage. Solar PV system production coincides fairly well with daily utility system peak demand, when utility generation costs are highest. Customers that are under a time-of-use (TOU) rate structure are incentivized to use their solar generation when prices for grid electricity are highest. In some cases, storage may prove economical if it better allows the customer to use stored solar energy when grid prices are highest. Customers that are subject to demand charges may find it economical to use storage for load shifting by charging batteries with solar and using that power to avoid triggering demand charges. Under the typical residential net metering rate structure, there is little or no economic incentive for a PV system owner to divert power to a battery to be used later, unless reliability is a concern. So, in general, solar PV with associated storage encourages the use of grid power during off-peak hours, which could help to smooth the overall utility system load curve and reduce the need for peaking generation from centralized facilities.

Text Box 2: Distributed Solar with Energy Storage: Where did those electrons come from?

As interconnection policies and incentives for energy storage gain attention, it has become apparent that it is important to be able to distinguish whether an energy storage unit is being charged with electricity generated by a distributed solar system or with grid power.

Energy arbitrage refers to the practice of storing electricity during periods with low energy prices and discharging it at periods with high energy prices. Customers with solar systems may install battery units with the intent of saving excess electricity from their solar system. But the same batteries could also be charged using electricity from the grid. This means that, in the absence of controls, electricity could be purchased from the grid, stored, and sold back to the grid for a higher price than it was purchased. Without metering controls, it is impossible to confirm whether the electricity being discharged from the battery originated from the grid or from the customer's solar panels. In California, this issue was addressed by requiring specific metering configurations to track the flow of electricity to and from the battery and solar system (CPUC Decision 14-05-033 2014b).

A related issue is with regards to whether a storage unit associated with a distributed solar system is eligible to receive incentives that are designed to encourage solar development, if the batteries are charged, to some degree, with grid-supplied power. In 2013, the Internal Revenue Service confirmed that the cost of storage units connected to distributed PV systems is, indeed, eligible for the Federal investment tax credit (ITC). However, customers must track what percentage of the electricity used to charge the battery comes from the grid over the first five years. Reductions in the tax credit apply when the percentage falls below a certain threshold, with no credit available if the percentage is below 75% (IRS Notice 2013-29).

With higher retail rates and lower compensation for PV generation, different behavior is encouraged. As explored in Text Box 1, in Germany, retail rates are higher than the compensation for excess solar generation fed onto the grid. As such, owners of solar systems with battery storage are incentivized to divert excess solar power to their storage units to be used when solar generation does not meet on-site load. This rate structure encourages increased self-sufficiency in distributed system owners, who can benefit from reducing the use of grid power during all times of day (Fares 2014). As such, the system load curve would not change shape as a result of PV systems with associated storage.

In short, if policymakers are inclined to encourage the deployment of distributed storage systems for the purpose of developing the resiliency of the electricity system, careful attention should be paid to the way that the electricity rate structures and incentives encourage certain behaviors and usage patterns, how these patterns may impact the system load curve, and the potential effects on utility revenue streams.

Solar-Diesel Hybrid Systems

Solar PV panels can be combined with auxiliary generators fueled by natural gas, gasoline, or diesel to provide electricity during catastrophic power disruptions to help extend diesel fuel supplies and free it up for other uses. A solar-diesel hybrid generation system consists of solar PV panels, a traditional diesel generator, an inverter, and often an energy storage unit.

During normal operation, the solar system feeds excess electricity onto the grid, as do many of today's distributed solar systems. But if the grid goes down, the system can continue to function as a 'planned island system,' providing emergency backup power (IEEE 1547.4). A controller combines the available solar generation with additional diesel-powered generation to serve the intended load. While installation costs are higher than traditional backup systems, the solar panels produce power during non-emergencies and can pay for themselves through reductions in building electricity costs, as well as providing further value during emergencies. Several case studies highlighting the benefits of solar-diesel hybrids for backup are provided in the following case studies of Midtown Community School, T-Mobile's communication towers, and Princeton University.

Case Study B: Midtown Community School installs hybrid solar-diesel system with storage

Hurricane Sandy, which hit the east coast in 2012, disrupted electricity service to many cities for days or weeks before repairs could be made. Without electricity, emergency shelters often depend on diesel-powered backup generators to supply light and heat. Due to the size and impact of Hurricane Sandy, diesel fuel for backup generators and emergency vehicles was in desperately short supply, and floodwaters often made it difficult to get available fuel to where it was needed. In many cases, diesel generators were themselves covered in floodwaters.

Midtown Community School in Bayonne, New Jersey, however, had a constant supply of electricity throughout the event, thanks to its hybrid solar-diesel generating system, installed in 2004. The school served as a community shelter during Hurricane Sandy as a result of this system. The local school district had worked with Advanced Solar Products to develop a system that would allow the 272 kW of existing solar panels on the school to provide power during a grid outage. The inverter was modified and a diesel generator was added. The system was manually 'islanded' during Hurricane Sandy to provide electricity to the school when the broader grid was down. When the sun is shining, the diesel generators idle at low levels, resulting in a drastic reduction in fuel consumption and reserving valuable supplies (Dumont 2012).

Case Study C: T-Mobile uses solar-hybrid systems to improve resiliency of communications

T-Mobile is installing solar PV to replace or augment its diesel emergency generators, reducing emissions and saving fuel costs while providing emergency backup for communications services. To test the viability of the switch to solar, the company replaced some diesel generators with solar systems for a 16-week trial. Results indicated significant potential savings in fuel costs, and T-Mobile now plans to extend the deployment of solar for backup power to its cell towers on a national scale. Even in cases in which a switch to solar is not practical, combining solar and diesel can increase the length of time diesel reserves last during an emergency, and free up limited fuel supplies for other uses. As the technology included in antennas and radios evolves, less power will be needed at each tower, increasing the viability of solar for these applications (DC Solar 2014; Tweed 2013; 2K Solar n.d.).

Microgrids

A microgrid is a combination of electricity generation, wires, communications and control technologies, and energy storage, which are able to operate both in a grid-connected fashion and independently, in an island mode. Microgrids are fully customizable to specific end-user needs, and offer the opportunity for improved reliability, cost-efficiency, and environmental benefits (Klemun 2014).

In the past, microgrids have been of interest primarily for military bases and remote communities, but the application of microgrids is rapidly evolving. Cities, communities, and public institutions represent the next phase of microgrid adopters, largely driven by resiliency concerns. Five U.S. states[2] have passed laws or announced investment programs to establish microgrids for reliability purposes. Critical facilities such as hospitals, wastewater treatment facilities, and schools are already targeted for microgrid development, but this is likely to extend to privately owned services, such as gasoline fueling stations and grocery stores.

Distributed energy generation is increasingly part of new microgrid development, particularly in cases in which reliability is a key concern. Incorporating distributed solar systems into microgrids adds value to the microgrid and allows additional value to be drawn from the solar system. In some cases, improved integration of high levels of distributed renewable energy generation resources is a driver for the development of microgrids. Energy storage and control technologies—key features of microgrids—provide voltage control services that facilitate high levels of variable generating resources on a distribution network. And, on the other hand, microgrids enable solar PV to provide reliability benefits through the provision of demand response and grid services.

Barriers, most of which are regulatory in nature, inhibit microgrid growth. Microgrids typically require the use of existing lines or the construction of new power lines within the defined zone, which may infringe on utility franchise rights. Microgrid operation may involve the exchange of power between parties or the transmission of power across streets or public areas, which could make operators subject to public utility regulation. The lack of clarity regarding interconnection rules and who pays for necessary equipment or network upgrades is another major barrier. Standards for interconnection procedures and costs would relieve these uncertainties and facilitate deployment. Finally, the facilitation of new financing models for developers of microgrids would help overcome the barrier of high upfront costs and provide the option of microgrids to a broader number of end users.

---

[2] Texas (HB1831 & 4409); Connecticut (Public Act 12-148 Microgrid Pilot Program); New Jersey (TransitGrid and Hoboken microgrid projects); Massachusetts (municipal resilience program); New York (microgrid competition).

Case Study D: Solar-powered microgrid for resiliency in Vermont

The country's first 100% solar-powered microgrid is being constructed on a repurposed landfill to increase energy resiliency for the town of Rutland, Vermont. The community experiences frequent storm-related power outages and was one of the hardest hit areas of the state during Hurricane Sandy. The innovative project includes 2.5 MW of solar capacity and 4 MW of battery storage, enough to supply 365 homes with electricity during normal weather conditions, or power the public shelter during emergency situations. Both lithium ion and lead acid battery technologies are included in the design in order to take advantage of the different cycling qualities of each. Green Mountain Power, the local electricity provider, is developing the project with support from the Department of Energy and other partners. The utility expects to gain valuable experience that it can apply in other locations of its territory. In addition to backup power, the project's storage capacity will provide additional value through quick-responding frequency regulation services for the grid (CESA 2014).

Case Study E: Princeton University microgrid with solar and diesel generation

Princeton University has developed a microgrid that includes a 5 MW backup diesel generator, 5.4 MW of solar PV capacity, chillers, and thermal energy storage, among other technologies. The university's goals in its development included cost reduction and emission reduction. Under normal circumstances, the microgrid is connected to the broader utility system. The on-site generation is used to reduce the amount of electricity purchased during peak demand periods and avoid capacity charges. Frequency regulation services are sold into the regional transmission organization's (RTO) ancillary service market, which adds further economic benefit. The resiliency benefits of the microgrid were proven, and brought the microgrid into the public eye, after Hurricane Sandy. When disruptions were detected on the main grid during the storm, operators disconnected the microgrid and successfully supplied critical power to the campus, providing services to students and avoiding millions of dollars of research-related losses (Klemun 2014; Princeton University 2014; Wood 2014).

REGULATORY AND POLICY CONSIDERATIONS

There are many reasons that existing distributed solar energy systems are not designed to provide resiliency and backup power when the grid is down. There are also numerous supporting technologies that allow distributed solar energy to play a role in resiliency, and the case studies in this paper provide examples of where solar has proven this ability.

Through an understanding of the value that solar brings to the table, the necessary supporting technologies, and the deployment barriers that still exist, regulators and policymakers can support the development of distributed PV to build a more resilient energy system.

The regulatory and policy considerations for supporting the use of distributed solar for increased resiliency are summarized in the bullets below:

- Create rate structures or incentive programs such that system owners can be compensated for the variety of benefits and services provided by energy storage associated with distributed solar energy.
- Support the development of distributed solar PV systems that can operate independent of the electrical grid in emergency situations, particularly at critical facilities.
- Clarify rate structures for owners of PV systems that are capable of being grid-interactive and standalone (hybrid).
- Clarify interconnection procedures for distributed PV systems with storage.
- Clarify rate structures and interconnection procedures for CES and associated distributed PV systems.
- Enable a variety of ownership structures and financing mechanisms for CES.
- Identify critical locations that would benefit from microgrid development.
- Clarify interconnection procedures and utility upgrade costs related to microgrids.
- Allow for third-party participation in the development of microgrids that incorporate utility systems within that microgrid.

In conclusion, distributed solar PV technology can be developed, incentivized, and encouraged to increase electricity system resilience during and after grid outages.

ACKNOWLEDGMENTS

This paper was funded through the Department of Energy's SunShot initiative. Special thanks go to the many colleagues who provided useful feedback during its development, and in particular the efforts of Lori Bird, Francisco Flores-Espino, Paul Schwabe, Eliza Hotchkiss, Michael Coddington (NREL), and Glen Andersen (National Conference of State Legislatures).

For additional information and questions, please contact Joyce McLaren (NREL) at *joyce.mclaren@nrel.gov*.

REFERENCES

2K Solar. (undated.) "T-Mobile Cell Site Now Powered by the Sun." Accessed August 2014: *http://www.2ksolar.com/t-mobile-cell-site-now-powered-by-the-sun/*.

American Electric Power (AEP). (2009). *Functional Specification for Community Energy Storage Unit. Revision 2.2*. Columbus, OH: American Electric Power. Accessed August 2014: *http://www.dolantechcenter.com/Focus/DistributedEnergy/docs/CESUnitSpecifications_rev2_2.pdf*

Ammon, M. (2013). "Solar Energy Storage: Opening up New Customer Potential in Existing Buildings." Accessed June 2014: *http://www.solarenergystorage.org/en/energiespeicher-kundenpotentiale-im-bestand-erschliesen/*.

Bayar, T. (March 28, 2013). "Solar Storage Market Set for Rapid Growth." *Renewable Energy World.* Accessed October 2014: *http://www.renewableenergyworld.com/rea/news/article/2013/03/solar-storage-market-set-for-rapid-growth?cmpid=rss*.

BSW Solar. (undated). "Solarstromspeicher." Accessed October 2014: *http://www.solarwirtschaft.de/speicherprogramm*.

California Public Utilities Commission (CPUC). (2014a). *2014 Self-Generation Incentive Program Handbook.* Accessed July 2014: *https://www.selfgenca.com/documents/handbook/2014*.

CPUC. (2014b). *Decision 14-05-033. Decision regarding net energy metering interconnection eligibility for storage devices pair with net energy metering generation facilities*. Issued May 23, 2014.

CPUC. (2014c). *Issues, Priorities and Recommendations for Energy Storage Interconnection: Staff Proposal*. San Francisco, CA: CPUC.

Campbell, R.J. (2012). Weather-Related Power Outages and Electric System Resiliency. Washington, D.C.: Congressional Research Service.

Carlson, N. (2011). *Detroit Edison's Advanced Implementation of Community Energy Storage Systems for Grid Support*. DE-OE0000229. Albuquerque, NM: Sandia National Laboratory. *http://www.sandia.gov/ess/docs/pr_conferences/2011/4_Carlson_Detroit_Edison.pdf*.

Clean Energy States Alliance (CESA). (2014). *ESTAP Webinar: A Solar Storage Microgrid for the Energy City of the Future*. Webinar. August 22, 2014. *http://www.cesa.org/webinars/estap-webinar-a-solar-storage-microgrid-for-the-energy-city-of-the-future/*.

Con Edison (ConEd). (2013). "Demand Management Incentives." *http://www.coned.com/energyefficiency/demand_management_incentives.asp*.

Cullen, N.; Thornycroft, J.; Collinson, A. (2002). *Risk Analysis of Islanding of Photovoltaic Power Systems within Low Voltage Distribution Networks*. Report IEA PVPS T5-08. Paris, France: International Energy Agency. Accessed August 2014: *http://www.hme.ca/gridconnect/IEA_PVPS_Task_5-08_Risk_Analysis_of_Islanding_of_PV_Systems.pdf*.

DC Solar. (January 16, 2014). "T-Mobile Saves Over $17,000 In Fuel Costs Alone." Accessed May 29, 2014: *http://www.dcsolardistribution.com/t-mobile-saves-over-17000-in-fuel-costs-alone/*.

Doelling, R. (March 17, 2014). "Storage Systems Incentives Only have a Short-term Effect on Demand." Solar Energy Storage. Accessed August 2014: *http://www.solarenergystorage.org/en/speicherforderung-nur-kurzfristig-nachfragewirksam/*.

Dumont, J. (December 27, 2012). "Solar Backup System Powers through Hurricane Sandy with Sunny Centrals." *SMA Inverted*. *http://www.smainverted.com/2012/12/27/solar-backup-system-powers-through-hurricane-sandy-with-sunny-centrals/*.

Energy Storage Association (ESA). (2014). "Community Energy Storage." *http://energystorage.org/energy-storage/technology-applications/community-energy-storage*.

Executive Office of the President. (2013). *Economic Benefits of Increasing Electric Grid Resilience to Weather Outages*. Washington, D.C.: Executive Office of the President. Accessed August 2014: *http://energy.gov/sites/prod/files/2013/08/f2/Grid%20Resiliency%20Report_FINAL.pdf*.

Fares, R. (2014). "German, U.S. Home Energy Storage Incentives Offer Divergent Visions for the Smart Grid." *Plugged In blog, Scientific American*. Accessed August 2014: *http://blogs.scientificamerican.com/plugged-in/2014/08/05/german-u-s-home-energy-storage-incentives-offer-divergent-visions-for-the-smart-grid/*.

Florida State Energy Center (FSEC). (2014). "SunSmart E-Shelters Program." *http://www.fsec.ucf.edu/en/education/sunsmart/index.html*.

GTM Research. (2014). *Distributed Energy Storage 2014: Applications and Opportunities for Commercial Energy*. Accessed August 2014: *http://www.greentechmedia.com/research/report/distributed-energy-storage-2014*.

Hotchkiss, E.; Metzger, I.; Salasovich, J.; Schwabe, P. (2013). *Alternative Energy Generation Opportunities in Critical Infrastructure: New Jersey*. NREL/TP-7A40-60631. Golden, CO: National Renewable Energy Laboratory. Accessed July 2014: *http://www.nrel.gov/docx/gen/fy14/60631.pdf*.

IEEE 1547. (2003). *Standard 1547-2003 - IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems.*

IEEE P2030.2 Working Group. (2013). *Draft Guide for the Interoperability of Energy Storage Systems Integrated with the Electric Power Infrastructure.*

Johnson, B.W. (2005). *After the Disaster: Utility Restoration Cost Recovery*. Washington, D.C.: Edison Electric Institute. Accessed August 2014: *https://www.efis.psc.mo.gov/mpsc/commoncomponents/viewdocument.asp?DocId=4048185*.

Kenward, A.; Raja, U. (2014). *Blackout: Extreme Weather, Climate Change and Power Outages*. Princeton, NJ: Climate Central. Accessed July 2014: *http://assets.climatecentral.org/pdfs/PowerOutages.pdf*.

Klemun, M. (2014). *North American Microgrids 2014: The Evolution of Localized Energy Optimization*. GTM Research.

Lawrence Berkeley National Laboratory (LBNL). (2014). "Microgrids at Berkeley Lab: Borrego Springs." Lawrence, CA: Lawrence Berkeley National Laboratory. Accessed August 2014: *http://building-microgrid.lbl.gov/borrego-springs*.

Massachusetts Governor's Press Office. (January 14, 2014). "Governor Patrick Announces $50m for Comprehensive Climate Change Preparedness Initiatives." Accessed July 2014: *http://www.mass.gov/governor/pressoffice/pressreleases/2014/0114-climate-change-preparedness-investment.html*.

Mayer, J. (May 8, 2013). "State Incentive Program is Launched For Solar Storage Systems." Solar Energy Storage. *http://www.solarenergystorage.org/en/staatliche-forderung-von-solarstromspeichern-gestartet/*.

National Renewable Energy Laboratory (NREL). (2014). *Issue Brief: A Survey of State Policies to Support Utility-Scale and Distributed-Energy Storage*. NREL/BR-7A40-62726. Golden, CO: National Renewable Energy Laboratory. Accessed October 2014: *http://www.nrel.gov/docs/fy14osti/62726.pdf*.

New Jersey's Clean Energy Program. (2014). "Energy Storage." Accessed August 2014: *http://www.njcleanenergy.com/renewable-energy/programs/energy-storage*.

New York Governor's Press Office. (January 7, 2014). "Governor Cuomo Announces Broad Series of Innovative Protections; Vice President Biden Credits Governor Cuomo's Storm Plan as A Model for Future Recovery Efforts." Accessed August 2014: *http://www.governor.ny.gov/press/01072013-cuomo-biden-future-recovery-efforts*.

New York State Research and Development Authority (NYSERDA). (2013). *Residential Solar Energy Storage Analysis*. Prepared by DNV KEMA. Albany, NY: NYSERDA.

Parnell, J. (January 23, 2014). "Germany approves solar self-consumption levy." PV Tech. Accessed August 2014: *http://www.pv-tech.org/news/germany_approves_solar_self_consumption_levy*.

Princeton University. (2014). "The Princeton Energy Plant." Facilities: Princeton University. *http://www.princeton.edu/facilities/info/energy/energy_plant/*.

Roberts, B. (2013). "Substation-Scale and Community Energy Storage." IEEE. Accessed August 2014: *http://smartgrid.ieee.org/january-2013/739-substation-scale-and-community-energy-storage*.

Rocky Mountain Institute (RMI). (2014). *The Economics of Grid Defection: When and Where Distributed Solar Generation plus Storage Competes With Traditional Utility Service*. Snowmass, CO: RMI.

Tweed, K. (2013). "Why Cellular Towers in Developing Nations Are Making the Move to Solar Power." *Scientific American*. Accessed August 2014: *http://www.scientificamerican.com/article/cellular-towers-moving-to-solar-power/*.

Wood, E. (2014). "Princeton University's Microgrid: How to Partner, Not Part from the Grid." Microgrid Knowledge. Accessed October 2014: *http://microgridknowledge.com/princeton-universitys-microgrid-partner-part-central-grid/*.

Photos credits (page 1, left to right):
Photo from iStock 13737597; by Dennis Schroeder, NREL 19893;
Photo from iStock 12123595; Photo by Toyota Motor Sales, USA, NREL 16933;
by Debra Lew, NREL 20528, Photo by Dennis Schroeder, NREL 19163

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

NREL/BR-6A20-62631 • November 2014

NREL prints on paper that contains recycled content.