RESILIENT POWER

Solar+Storage 101: An Introductory Guide to Resilient Power Systems

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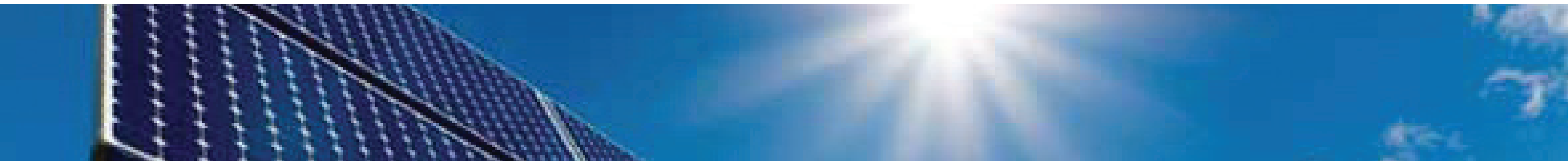

ABSTRACT

This paper is one in a series of reports and white papers Clean Energy Group will publish over a three-year period on the topic of Resilient Power. Resilient Power is the ability of a community to provide clean, reliable energy in the face of power outages, an increasingly regular event due to severe weather. New resilient power technologies can provide electricity during outages, and also at other times so communities benefit fully from clean reliable energy.

Clean Energy Group's Resilient Power Project, a joint effort with Meridian Institute, is designed to help states and municipalities with program and policy information, analysis, finance tools, technical assistance, and best practices to speed the deployment of clean, resilient power systems in their communities. An important focus of the project is to help vulnerable and low-income communities deal with power outages due to severe weather events, as they have suffered disproportionately in damaging storms like Superstorm Sandy and Hurricane Katrina. Installing clean energy technologies such as solar and storage in multi-family housing, assisted living centers, fire stations, and schools that serve as shelters can protect people from harm, reduce pollution, and create community-driven decision making. This series of reports describes the continuing efforts of Clean Energy Group to make resilient power a major part of disaster planning and energy policy, work that is now showing results in new state and local programs to fund resilient power across the country. But much more needs to be done.

Acknowledgements

This paper is a product of Clean Energy Group and part of a series of reports issued through the Resilient Power Project, a joint project of Clean Energy Group and Meridian Institute. This project works to expand the use of clean, distributed generation for critical facilities to avoid power outages; to build more community-based clean power systems; and to reduce the adverse energy-related impacts on poor and other vulnerable populations from severe weather events. This project has been generously funded by The JPB Foundation, The Kresge Foundation, and The Surdna Foundation. The views and opinions expressed in this report are those of the authors' alone.

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INTRODUCTION

Why Solar+Storage?

Whether wildfires in the West, hurricanes in the East, ice storms in the North, tornadoes in the Plains and Midwest, or severe storms and flooding across the country, extreme weather is causing more numerous and costly power outages with each passing year. This troubling reality has led federal, state, and local governments, as well as many business owners and facility managers, to the realization that there is a dire need for a more resilient, distributed approach to the current centralized U.S. power system.

Many organizations are beginning to explore the benefits of self-generation and more robust solutions for emergency backup power. Instead of relying solely on a centralized delivery system, where large, remote power plants are responsible for powering many thousands of customers and electricity delivery can be knocked offline by no more than a downed tree branch or unfortunate squirrel, individuals and organizations are beginning to take control of their own energy future. Combining solar photovoltaics (PV) with energy storage (solar+storage) is poised to play a pivotal role in this shift towards energy empowerment and the ongoing transition to more distributed and resilient power systems.

Historically, diesel-powered generators have been considered the standard for supplying emergency power in the event of power outages. Unfortunately, this dependence on diesel generators has left many in the dark when power is needed most (see box, The Failure of Diesel Generators, on page 11).

Because backup generators sit idle most of the time, inadequate maintenance and testing often lead to failure when disaster strikes. And, unlike renewable energy sources, the power provided by diesel generators is typically limited by the amount of fuel that can be stored on-site. This is especially true during extreme weather events, when obtaining additional fuel may be extremely difficult or impossible due to widespread lack of power and limited resource availability. Because of this, even if diesel generators do work properly in an emergency, they may become useless during an extended power outage.

With steadily dropping costs in both solar and energy storage technologies, solar+storage has become a viable and more reliable choice for emergency power. Not only do solar+storage systems have the ability to provide power indefinitely when the grid is unavailable, they can also cut costs and generate revenue during the 99.9% of the time when the grid is functioning normally. In many cases, these savings and revenue streams can drastically reduce the payback period of an energy storage system.

While solar+storage may not be the perfect solution for every resilient power project, its versatility and scalability make it ideal for many facilities, especially those located in urban and residential environments where space may be at a premium. A number of facilities that provide crucial services in times of emergency are good candidates for solar+storage; the list includes schools, community centers, assisted living facilities, and multifamily housing units. (See Case Studies starting on page 16: Florida SunSmart Emergency Shelters Program and Scripps Ranch Community Recreation Center).

These buildings often have relatively modest critical loads that are well-suited for the technology. The needs of more advanced projects, such as business complexes and microgrids,[1] can also be met by large-scale solar+storage applications. (See Case Studies: Konterra Solar Microgrid Storage System and Stafford Hill Solar Farm and Microgrid).

How to Use this Guide

This guide was created by Clean Energy Group's Resilient Power Project to provide a basic technical background and understanding of solar+storage systems. It is meant as a starting point for project developers, building owners, facility managers, and state and municipal planners to become familiar with solar+storage technologies, how they work, and what's involved in getting a new project off the ground.

The guide first explores how a solar+storage system generally works and the basic layout of system configurations. It then takes a closer look at the components involved and necessary considerations for grid interconnection. A brief checklist is included at the end of the paper to help developers get started when planning a new solar+storage project.

It should be noted that the focus of this guide is on grid-interactive solar+storage systems installed behind the customer's meter and designed to provide resilient power, though much of the information is equally applicable to stand-alone systems and shorter duration storage applications.

HOW DOES SOLAR+STORAGE WORK?

The Basics

While renewable power technologies like solar photovoltaics (PV) have the ability to generate electricity independent of the central grid, solar PV system owners are often surprised to find their building is without power when the grid goes down, even when the sun is shining.

This is because the majority of PV systems currently installed are grid-tied (*Figure 1*), sometimes referred to as grid-direct systems, and lack both energy storage capacity and islanding capability. For safety reasons, these systems are configured to shut down when the grid goes down; if they did not, they could send power back up grid distribution lines undergoing repair, endangering utility line workers.

In a grid-tied system, the grid acts like a battery with unlimited storage capacity. Any excess energy produced by the solar array on the customer's side of the meter gets fed directly into the central grid, and when there is a need for more power than the customer's solar array is producing, the additional load is served by power drawn from the grid. In areas where net metering policies are in place, utility customers get a credit for the energy they export to the grid, which can then be applied to times when additional energy is required.[2] This is a great system, until the grid goes down.

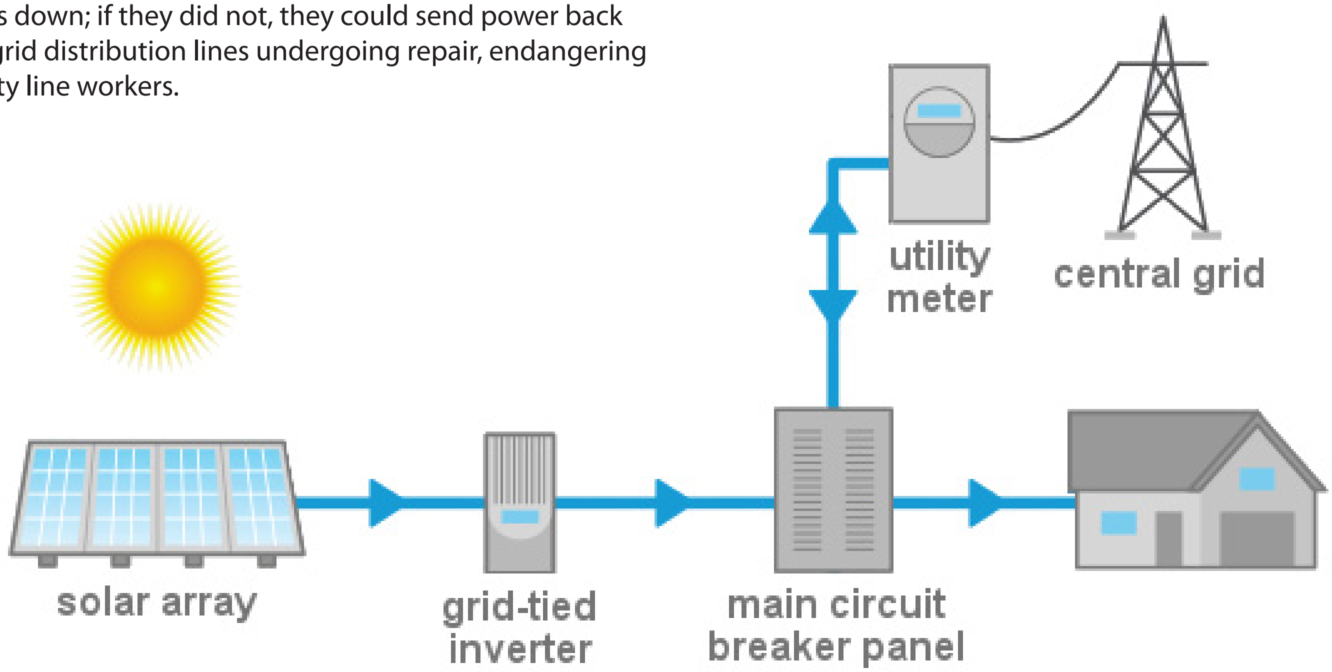


Figure 1: Grid-tied solar system

Resilient solar+storage systems differ from the solar system described above in two important ways.

First, they include islanding equipment, typically consisting of a switch that physically isolates the system from the larger grid when the grid goes down.

Second, they include a battery to store excess solar-generated electricity when the sun is shining, and release it to power the host facility at night or when clouds cause a drop in PV output.

Adding energy storage capacity to a solar system (*Figures 2 and 3*) ensures that the system can continue to provide continuous reliable power even when the grid is down. When the grid is up and running, the solar system will still function just as it always has: meeting local demand, sending excess power to the grid, and drawing electricity from the grid when needed. If the grid becomes unavailable, due to severe weather or any other sort of unexpected failure, the solar system will still perform pretty much as it always has.

The only significant difference is that instead of exporting to and importing power from the grid, power will be sent to and pulled from the system's on-site battery. With a properly sized system and careful consideration of critical loads,[3] the solar+storage system has the potential to continue providing power indefinitely.

This switching back and forth between grid and storage is typically all handled automatically. As soon as the grid goes down, the solar+storage system detects the failure and disconnects from the central grid. This is known as islanding, which basically means that the solar+storage system and any buildings it is powering will function autonomously from the central grid, essentially becoming an independent microgrid.

Islanding is a necessary precaution in order to ensure the safety of utility employees dispatched to restore functionality to the central grid. When the grid is back online, the solar+storage system will reestablish the connection and begin working with the grid as if nothing had ever happened.

The key difference in how solar+storage works as opposed to a backup generator is that, along with being there to meet the occasional need for emergency power, a solar+storage system can provide additional benefits year round. The most obvious solar+storage benefit comes from offsetting electricity purchased from a utility with self-generated solar power, which lowers the facility's utility bills. Less familiar are the other beneficial services a storage system can provide.

Storage has the ability to significantly reduce a building's peak demand, which can add up to significant savings in areas with high utility demand charges.[4] And in certain regions, such as the PJM Interconnection, energy storage can bid into the ancillary services market. This market includes high value services like quick-response frequency regulation services, which grid operators use to balance supply and demand.[5] Facilities located in areas with time-of-use (TOU) rate structures may also be able to reduce costs by using stored energy to supply electricity during peak rate periods when electricity prices are highest, and using solar or energy from the grid to charge batteries at off-peak times when rates are low.

There may be other energy markets as well where storage owners can sell services, such as demand response and capacity reserves. The markets available to the energy storage owner will vary depending on where the system is located, and the value that can be captured in these markets will depend on a number of variables, including system location and size.

Some energy storage companies help coordinate participation in these markets, either as a paid service or revenue sharing partnership, with the system owner or through retaining full ownership of the storage system. In some instances, this arrangement can deliver the benefits of resilient power to a facility at little to no additional cost (see Case Study: Konterra Solar Microgrid Storage System).

The size and complexity of solar+storage systems can range from a single array and battery bank in a single-family home to multiple arrays and a variety of storage technologies in a multi-building microgrid, but there are two basic configurations that form the basis of nearly all solar+storage installations: DC-coupled systems and AC-coupled systems.

DC-Coupled Systems

There are two sides to every solar+storage system: a direct current (DC) side and an alternating current (AC) side.

DC electricity flows in one direction and cannot efficiently "step up" or "step down" voltages with transformers for delivering electricity across long distances. Solar modules generate electricity in direct current, and storage devices typically charge and discharge using direct current.

AC, on the other hand, alternates between positive and negative directions and can be stepped up or stepped down by transformers with ease and efficiency. This permits the transmission of power at high voltages even when long distances are involved. AC is the kind of current that comes out of standard electricity outlets. Generators naturally produce alternating current and most machinery and appliances run on AC power. The central grid functions almost exclusively in AC power.

Power conversions between DC and AC are accomplished by a device called an inverter, which is the component responsible for converting the DC electricity from solar panels and batteries into the AC electricity required to power a building.

Energy storage can be integrated into either the DC or AC side of an installation. The majority of new solar+storage systems, where solar in not already in place, integrates the battery on the DC side, as shown in *Figure 2*.

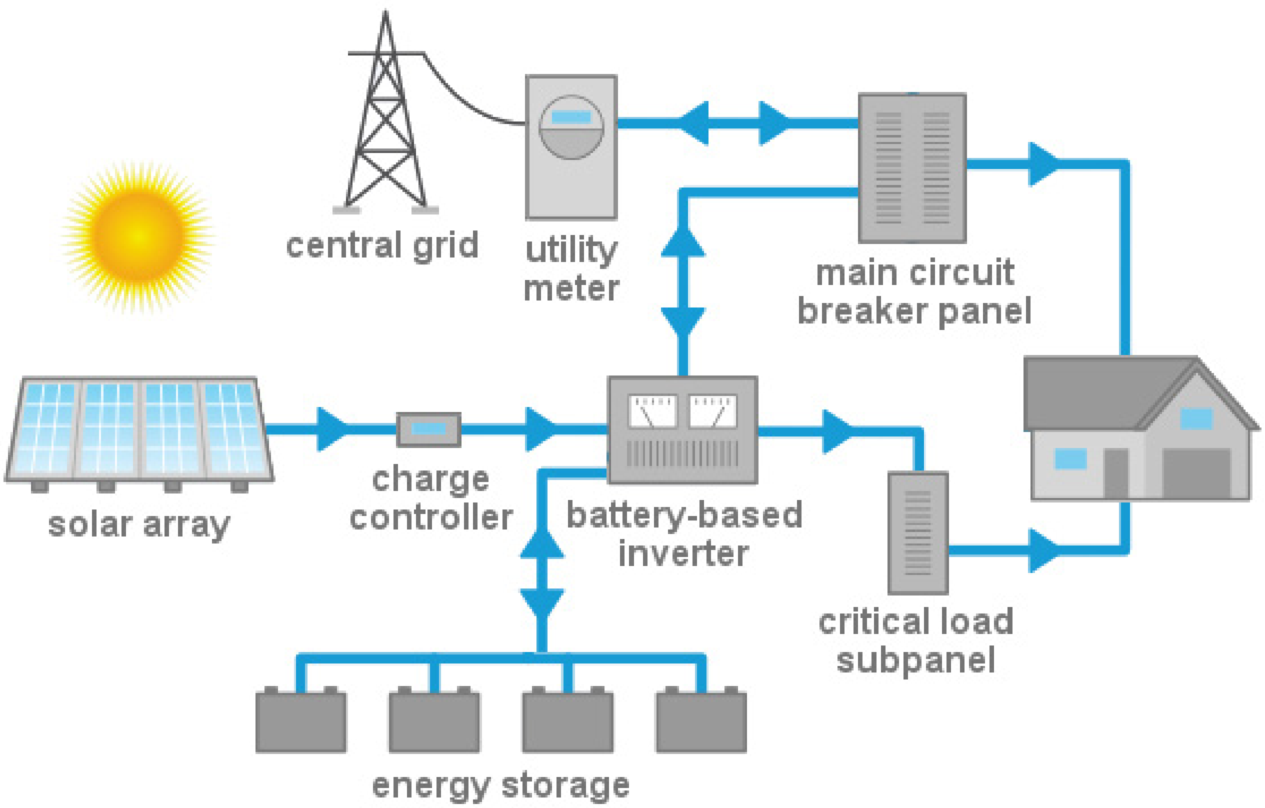


Figure 2: DC-coupled solar+storage system

In these DC-coupled systems, the storage battery is charged directly with DC power generated by the solar array. A device called a charge controller is connected between the solar panels and the battery bank. The charge controller regulates the DC power coming from the solar array and prevents overcharging of the batteries. Overcharging must be avoided as it can result in damage to a battery and potentially pose a safety hazard.

When the grid is available, a DC-coupled system works very much like a standard grid-tied solar system. The battery-based inverter converts DC power to AC to meet facility load demands and exports any surplus electricity to the grid. If the grid experiences an outage, the inverter automatically disconnects from the grid, by activating an internal transfer switch, and continues to supply power to select circuits located on a separate critical load subpanel, which will be discussed in detail in the next section.

When the sun is shining, the solar system will generate electricity to serve loads and charge the batteries. The storage system acts to smooth out any fluctuations in solar generation, providing consistent, continuous power to the loads. The inverter detects when the central grid is back online and automatically reconnects when it becomes available.

The battery-based inverter can also take AC power from the grid and convert it to DC in order to charge the battery when necessary, or as a paid service to the utility to soak up excess electricity supply on the grid. To take advantage of the added benefits such as demand reduction and load shifting, additional components and control software may be required.

DC-coupled systems tend to be preferred for new installations because they generally have lower initial investment costs, due to the solar and battery systems utilizing the same inverter. Also, DC-coupled systems perform with higher battery charging efficiencies and better control coordination than AC-coupled systems.

It is possible to install a DC-coupled solar+storage system when retrofitting an existing solar installation; however, it is more common to install an AC-coupled system in order to utilize existing inverters and wiring.

Small Systems Aggregation

Larger battery systems can sell services such as frequency regulation and demand response to grid operators in certain areas of the country. But what about smaller battery systems less than 100 kW in capacity, such as those sized for residential and small commercial applications?

While these systems may be too small to sell grid services individually, when combined with other small batteries by systems aggregators, they can collectively represent sufficient capacity to enter ancillary services markets. This is being done in several pilot studies using residential and even vehicle batteries. For example, in Annapolis, MD, a system integrator has aggregated 20 5-kW residential solar+storage systems to form a single 100-kW system, which is able to sell services into the PJM market. NRG Energy and the University of Delaware have successfully aggregated a fleet of 12 electric vehicles, collectively representing just over 100 kW, to bid ancillary services into PJM. And in ERCOT, Southwest Research Institute is aggregating a fleet of a dozen electric delivery trucks to sell frequency regulation services to the grid operator. This type of aggregation service is not yet widely available, but is likely to become much more common in the near future.

AC-Coupled Systems

AC-coupled solar+storage systems, shown in *Figure 3*, are ideal for existing solar installations. This is because the existing connection from solar array to grid-tied inverter will not need to be rewired.

However, some grid-tied inverters are more sensitive to changes in AC supply than others, so it is important to research existing inverter specifications prior to adding storage onto a solar system. Some inverter manufacturers do not support the use of their equipment in AC-coupled storage installations.

In an AC-coupled system, the grid-tied solar inverter essentially replaces the charge controller in a DC-coupled system. Both the grid-tied inverter and battery-based inverter are connected directly to a critical load subpanel. The subpanel acts as the point where the two inverters can couple and share energy to meet a facility's electricity needs.

Under normal conditions, when the grid is available, energy from the solar array flows through the grid-tied inverter, which converts solar DC power to AC, and on to the critical load subpanel. Any additional energy not used to power these critical loads moves on through the battery-based inverter to power loads connected to the main circuit breaker panel or is converted back to DC to charge the battery bank when needed. Excess energy is once again exported to the central grid.

In the event of a grid outage, the battery-based inverter automatically disconnects the system from the grid and keeps the grid-tied inverter online by using energy drawn from the battery as a power source. The grid-tied inverter doesn't distinguish whether it is being powered by the grid or the battery and thus continues to operate as normal. Critical loads are now energized through a combination of solar generated power and stored energy flowing through the two inverters.

When power is restored to the grid, the battery-based inverter transfer switch is again triggered, reconnecting the system to the central grid.

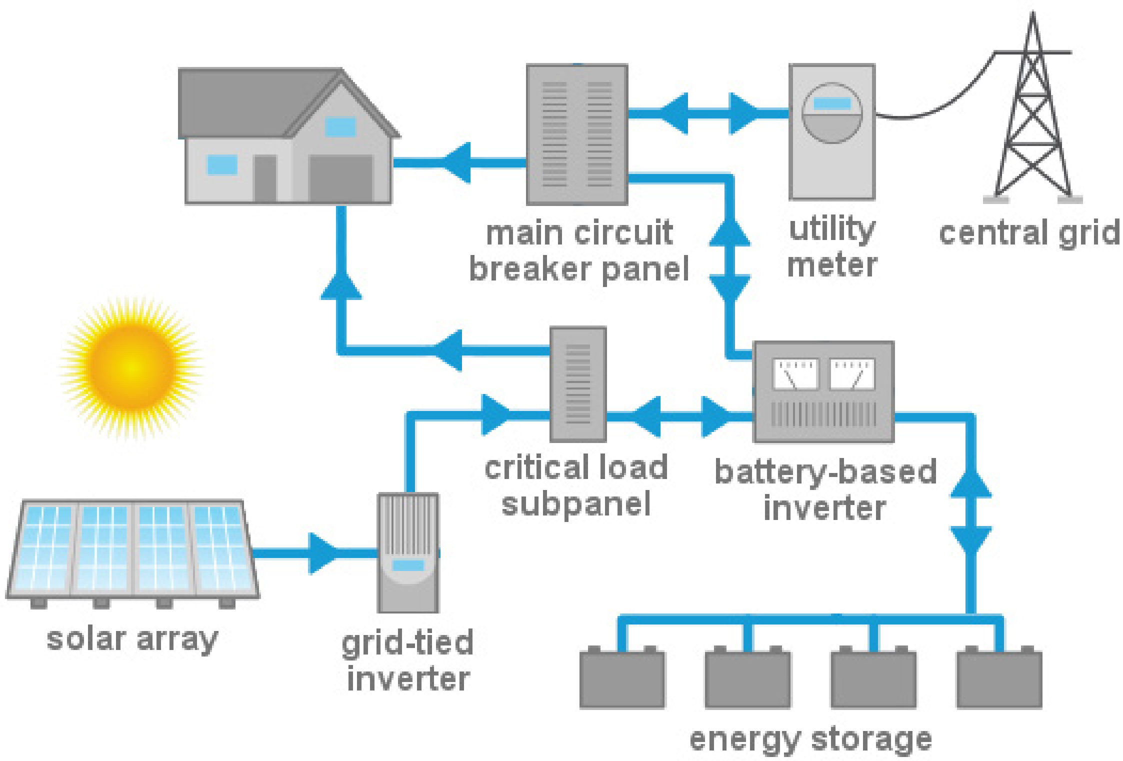


Figure 3: AC-coupled solar+storage system

The battery-based inverter is equipped with a charge controller to prevent battery overcharging. However, in situations where there is a low load and fully charged battery, islanded AC-coupled systems must be designed to control the output power flowing from the grid-tied inverter. The most common control methods are to knock the grid-tied inverter offline, use a diversion load to soak up excess power, or curtail inverter output by direct control signals.

Using a blackout relay to knock the grid-tied inverter offline is the cheaper and less complicated approach and is sufficient for most solar+storage applications. Once the battery is drained enough to accept further charging, the grid-tied inverter is brought back online. Systems with solar generation capabilities much larger than available battery capacity may want to consider using a diversion load. A diversion load is simply an additional load that can perform useful work by utilizing excess solar energy. Devices such as water heaters and space heaters are commonly employed as diversion loads.

Because solar energy in an AC-coupled system must undergo two conversions, DC to AC through the grid-tied inverter and AC back to DC through the battery-based inverter, before being stored in the battery bank, AC-coupled systems typically have lower overall efficiencies than DC-coupled systems. However, there are still some cases when AC-coupled systems are more desirable even for new solar+storage installations.

AC-coupled systems are generally more scalable and more easily expandable than DC-coupled systems, and AC-coupling makes it a fairly simple process to incorporate additional AC backup generators. Incorporating energy storage on the AC side of the system may also be preferred to avoid transmission losses when there is a long distance between the solar array and battery bank, though higher voltage charge controllers have improved performance in DC systems.

Another potential benefit is that the battery-based inverter and the solar PV system's grid-tied inverter act independently in AC-coupled systems, so that maintenance or trouble-shooting on one of the systems doesn't necessarily require shut down of the other system.

In general, DC-coupled systems are the first choice for new installations, as they tend to be less complex and more efficient. AC-coupled systems are the lower-cost approach for retrofits with existing solar systems in place.

Critical Load	**Typical Power Draw (watts)**
Incandescent Bulb (60-watt)	60
Compact Fluorescent Bulb (60-watt equivalent)	18
LED Bulb (60-watt equivalent)	10
Central Air Conditioner	5,000
Room Air Conditioner	1,000
Refrigerator-Freezer	400
Furnace Blower	300-1,000
Portable Heater	1,500
Television	180
Computer	120

Table 1: Sample of residential critical loads with typical rated power draw [6]

WHAT ARE THE REQUIRED COMPONENTS?

The systems shown in *Figure 2* and *Figure 3* are the simplest representations of solar+storage installations. In reality, solar+storage systems may be composed of any number and variety of solar arrays, energy storage technologies, inverters, management systems, and additional backup generators.

But, regardless of complexity, each system will likely follow one of the two simplified designs already discussed and be composed primarily of the same basic core components: a critical load subpanel, solar panels, batteries, and at least one inverter.

Critical Load Subpanel

The critical load subpanel is arguably the most important component to consider when designing a solar+storage system. Which loads to include, and which not to include, will determine the optimal sizing of the rest of the system.

It is usually not practical to design a solar+storage system with the intent to support all of a facility's electrical loads when the grid is down. At this time, installing a battery system large enough to serve all loads is not typically a cost effective solution. This is why it is necessary to install a critical load subpanel that is separate from the main distribution panel. The subpanel is very similar to a main circuit breaker panel, except that it only includes loads deemed critical to a facility during a central power outage. In the event of grid failure, only the loads connected through the critical load subpanel will be supported until power is restored.

Specific critical loads will vary depending on the needs of each facility, but generally include loads such as heating and cooling, emergency lighting, a few outlets, elevators, refrigeration, and water pressure pumps. *Table 1* provides a sample of some common critical loads and their corresponding power needs.

The total expected critical load, the sum of all individual critical loads, can be used as a baseline to specify inverter and battery capacity requirements. In the case where a facility has one or more high-power critical load requirements that may not be well-suited for energy storage applications, an emergency backup generator can be employed to serve these individual loads while the solar+storage system supplies power to the remaining critical loads.

Solar Panels

Solar panels are obviously an integral part of any solar+storage system. Each solar panel, also known as a solar module, is actually composed of a number of small units called photovoltaic (PV) cells. The cells themselves are composed of a semiconductor material, which is most commonly made of silicon. When a particle of light, or photon, hits a PV cell, an electron is knocked free. These free electrons generate a current. It is this current along with the cell's voltage that defines the power that a PV cell can produce.

The combined power of all PV cells in a solar panel will be the rated power output of the solar panel. Peak rated power varies among manufacturers and solar panel designs, but tends to average around 200 watts per panel. Individual panels can then be connected to form a solar array. If an array is composed of 10 solar panels, each with a rating of 200 watts, the entire solar array will have the potential to produced 2000 watts (2 kilowatts) of power. Solar arrays can be located on rooftops, carports, and other structures or they can be stand-alone, ground-mounted arrays positioned in open areas.

There are many different types of solar panels available today. The most common are panels composed of either monocrystalline or polycrystalline silicon cells. The main difference is that monocrystalline cells are cut from a single silicon crystal, so that the entire cell is aligned in one direction; whereas, polycrystalline cells are made up of several bits of pure silicon, meaning that individual crystals may not be perfectly aligned. Monocrystalline cells are very efficient in bright, direct sunlight. And though polycrystalline cells tend to be less efficient in direct light, they can perform better in more diffuse and low light conditions.

There are numerous other solar technologies, such as thin film and hybrid panels, but when it comes down to it, a 10-kilowatt solar PV system will generate a very similar amount of energy regardless of the material it's made of.

The efficiency of the solar panels and system design will ultimately determine how much area is needed to produce the desired power output.

Optimal sizing of a solar array depends on a number of factors. In many cases, array size is limited by the space available for solar panel placement. Ideally, solar panels in the northern hemisphere should point due south in order to maximize energy generation, though more westerly or easterly orientations can work as well and can be better situated to produce electricity at different times of the day. Shading of any part of a solar array should be avoided at all times. If even one cell is shaded, the power output of the whole interconnected array can be significantly impaired.

The inclination, or tilt, of a solar panel is another important consideration. The most efficient inclination occurs when panels are aligned at an angle as close as possible to the location's latitude. Most solar panels are installed with a fixed position. The addition of single or double axis tracking capabilities allows solar panels to alter their orientation throughout the day in order to maximize production along with the changing position of the sun. While these systems have higher efficiencies than fixed-tilt arrays, they are more complex and expensive. Tracking systems are more common in large, utility-scale installations.

When space isn't a determining factor, solar systems are typically sized to meet a facility's average monthly or annual electricity needs. Electricity needs can be estimated by simply examining a facility's electricity bills over a period to calculate average kilowatt-hour usage.

The other crucial factor in sizing a solar system to meet electricity needs is determining how much solar energy a location receives throughout the year. For example, on average Phoenix, AZ receives about 6.6 hours of peak sun per day while Ithaca, NY receives about 3.9 hours of peak sun per day. A derate factor must also be applied to account for all the potential losses in a solar system, such as energy conversion from DC to AC, wiring losses, temperature effects, shading, dust, and age of the system. A derate factor of about 75 percent is typical of most systems.

So, a facility in Phoenix looking to offset 10,000 kilowatt-hours of electricity per year would need a solar array with a rated power of at least:

(10,000 kilowatt-hours per year) /
(6.6 hours per day * 365 days per year * 0.75)
= 5.5 kilowatts

If the same facility was instead located in Ithaca, it would need a solar array with a rated power of at least:

(10,000 kilowatt-hours per year) /
(3.9 hours per day * 365 days per year * 0.75)
= 9.4 kilowatts

This type of calculation can provide a rough initial estimate for the size of solar array a particular facility might require. A number of good online tools are also available to help determine optimal solar array sizing. The National Renewable Energy Lab (NREL) has developed a particularly useful tool called PVWatts (available online at pvwatts.nrel.gov).

The Failure of Diesel Generators

Most of the critical infrastructure that communities depend on in an emergency—fire stations, hospitals, community shelters—rely almost exclusively on diesel generators when the grid goes down. Unfortunately, diesel generators aren't always up to the task when called upon.

In fact, diesel generator failure is a commonly occurring theme when disaster strikes. High-profile failures at hospitals, resulting in life-threatening conditions for vulnerable patients, have been particularly widespread. Superstorm Sandy led to the evacuation of nearly 1,000 patients in New York when generators failed at two of the city's busiest medical centers. Hospitals in New Orleans were crippled after Hurricane Katrina. Irene brought down hospitals in Connecticut. Tropical Storm Allison left Houston hospitals in the dark when generators failed. And failure is not just limited to severe weather. In 2003, a software problem led to massive blackouts across the Northeast, and diesel generators malfunctioned at hospitals throughout the region during the outage. The list goes on and on.

Generators can fail for any number of reasons: malfunctioning switches, overheating, lack of adequate fuel supplies, improper sizing for loads. A key issue with diesel generators is that they spend the majority of their time just sitting there, doing nothing. When a generator sits idle for too long, it tends to break. There are protocols in place for periodic testing of generators, but testing is generally infrequent and does not typically reflect real load conditions. This sporadic testing provides no guarantee that generators will perform properly in an emergency.

Despite their flaws, diesel generators still meet the minimum requirements specified by current backup power supply standards. Because of this, they remain the default choice in emergency power for many facility owners. However, with their inherent limitations and consistently high rates of failure, diesel generators fail to ensure the level of reliable, resilient power that other technologies can provide and that critical facilities demand.

Batteries

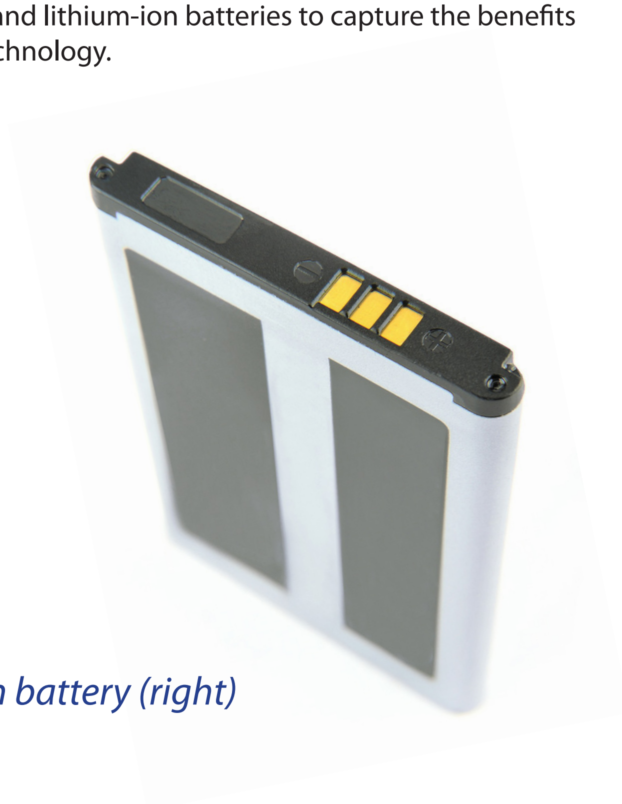
The other main component of a solar+storage system is the energy storage technology, usually a battery. A battery is a device consisting of one or more electrochemical cells that converts stored chemical energy into electrical energy through chemical reactions.

Each cell in a battery has a positive terminal (cathode), a negative terminal (anode), and an electrolyte. The electrolyte allows ions to move between terminals, which generates a current that can flow out of the battery to perform work. While there are many different varieties of batteries with different chemical compositions, the two most common technologies for solar+storage applications are lead-acid and lithium-ion batteries.

Lead-acid batteries have been around since the mid-1800s and remain the workhorse of PV storage applications, though this may change as other technologies continue to evolve. Most people are familiar with the lead-acid batteries found in automobile engines; however, these are not the same as those used in energy storage systems. Car batteries are designed to be almost always at or near full charge, whereas those required for solar storage must be able to withstand frequent deep discharge. These are known as deep-cycle lead-acid batteries. Some of the disadvantages of lead-acid batteries for energy storage applications, such as lower energy density and shorter battery life, are now being addressed with the next generation of advanced lead-acid battery technologies.

Lithium-ion batteries are a much newer and still developing technology. First used for consumer products like laptops and mobile phones, lithium-ion batteries have a far greater energy density than lead-acid batteries, which means that a lithium-ion battery can weigh less and require less space while storing the same amount of energy as a lead-acid battery. The term "lithium-ion" actually refers to a wide array of different chemistries, all of which transfer lithium ions between electrodes during charging and discharging reactions. Primarily due to their use in electric vehicles, the cost of lithium-ion energy storage technologies has been decreasing at a rapid pace in recent years.

Each battery technology has its advantages and disadvantages. Deep-cycle lead-acid batteries are a proven technology that is widely available and relatively inexpensive. On the downside, they are quite large and heavy and tend to have a shorter lifespan than lithium-ion batteries. Lithium-ion batteries are more compact and lightweight and are better suited for frequent cycling. Lithium-ion batteries also typically perform better at low temperatures than lead-acid batteries. For some applications, the increased lifespan and more robust cycling capabilities of lithium-ion batteries will make them a more cost effective choice. As the costs of lithium-ion batteries continue to drop, they are likely to become increasingly cost competitive. Hybrid battery systems are also being deployed that combine the use of lead-acid and lithium-ion batteries to capture the benefits of each technology.



Lead-acid battery (left) and lithium-ion battery (right)

Like solar panels, batteries can be wired together to achieve desired current, voltage, and power ratings. To determine the optimal size of an emergency battery storage system, a facility must know the maximum power needs of critical loads and how much time the battery may be required to supply critical power. If the system will be required to provide critical power for an exceptionally long period of time, the developer may want to consider adding a generator as a third source of power during extended outages.

Two other important factors must be considered when sizing the system: depth of discharge and inverter losses. Batteries can be damaged or have their lifespan significantly shortened if they are discharged too deeply too often. A good rule of thumb for sizing a lead-acid or lithium-ion battery system is to set a maximum depth of discharge of 80 percent. Battery system sizing must also take into account inverter and other losses incurred when DC power from the battery is converted to AC power. Battery system charge/discharge round trip efficiency can typically be assumed to be about 85 percent.

So, for a facility with a total critical load of 2 kilowatts that must be able to supply power for two days, the battery bank will need to have a power rating of at least 2 kilowatts and an energy storage capacity of at least:

(2 kilowatts x 48 hours) / (0.80 depth of discharge x 0.85 inverter efficiency) = 141 kilowatt-hours

Again, this is just a rough estimate of the battery storage system size a facility with these needs might require. Some critical loads may not need to be powered 24 hours a day, allowing for the battery capacity to be reduced. Available battery capacity is also highly dependent on temperature and the rate of discharge.

Lower temperatures and higher rates of discharge will both result in less available battery capacity. Both variables should be considered when designing a system. Ultimately, capacity requirements and the choice of technology may also be limited by real world considerations, such as cost and space available for placement of the battery system.

Inverters

Solar panels generate DC power and batteries discharge DC power; just about everything else in a building runs on AC power. That's where inverters come in.

Inverters can perform a number of useful functions, but their primary role is converting energy between DC and AC currents. There are many inverter manufacturers offering various technologies, but only two basic types are commonly needed in a solar+storage system: grid-tied inverters and battery-based inverters.

If a building only has a solar PV system, it only needs a grid-tied inverter. These inverters are sometimes known as grid-direct inverters. They convert the DC power produced by solar arrays into the AC power used by appliances and distributed across the grid. Grid-tied inverters are required to have anti-islanding protection, which ensures that they will shut down in the event of a power outage. This is why most solar systems don't provide any power when the central grid goes down.

Depending on the number of solar panels involved, a system may have one or many grid-tied inverters. Some solar panels even have their own built-in inverters, called micro-inverters. Micro-inverters typically increase the cost of a system, but can also improve the overall performance of a solar array. A system based on micro-inverters can optimize performance for each individual panel, so that one poorly performing panel won't drag down the performance of the whole array. This can be particularly beneficial when shading or debris can be an issue.

Grid-tied inverters should be sized to effectively pass energy from the PV system to building loads or the grid. If a solar array is rated to produce a maximum 4,000 watts of power, the inverter should be sized accordingly.

If a building is installing a solar+storage system from scratch, with no existing solar system, it may not need a grid-tied inverter, but most systems must have a battery-based inverter. A battery-based inverter can be known by any number of names: grid-interactive, dual-function, hybrid, bi-directional, multi-function. No matter what you call it, it is responsible for converting energy flowing to and from the battery.

DC power from the battery must be converted to AC before it can be used to power loads, and AC power flowing in to charge the battery must first be converted to DC. Unlike the grid-tied inverter, the battery-based inverter includes an automated transfer switch that enables the system to disconnect from the central grid and continue to operate critical loads during a power outage. When the central grid is up and running again, the inverter will automatically switch back to grid-interactive operation. Larger systems with multiple battery banks may require more than one battery-based inverter.

In a DC-coupled system with no grid-tied inverter, the battery will usually be charged directly by the solar array. Because the solar array produces a DC current, no energy conversion is needed. A charge controller connected between the solar array and battery is responsible for regulating the DC transfer of solar energy to the battery in these systems. In some cases, the charge controller is integrated with the DC port of the battery-based inverter.

Battery-based inverters should also be able to handle the energy from a PV system. Additionally, they must be sized with the ability to supply power to all critical loads simultaneously. The battery-based inverter should be appropriately sized to accommodate the larger of the two values. If the array can produce 4,000 watts and critical loads may require up to 5,000 watts, the battery-based inverter should be sized to meet the 5,000 watt need.

Everything Else

A whole lot more goes into making a solar+storage system work than just these few major components.

It takes fuses, circuit breakers, switchgear, cables and wires, mounting hardware, battery enclosures, and safety equipment like earth-grounding and lightning-protection to properly get a system up and running. Added functionality like peak load reduction may require additional management software and hardware. For systems with large loads or extended outage requirements, it may be necessary to incorporate a backup generator.

There are myriad possible equipment combinations and sometimes getting all these pieces to work together can be a challenge. To help avoid compatibility issues, it can be beneficial to use hardware from a single manufacturer whenever possible.

CONNECTING WITH THE GRID

No matter where a building is located, there are interconnection regulations and electrical standards that must be followed when integrating a solar+storage system with the central grid. These requirements ensure that both the solar+storage system owner and utility have followed the approved procedural guidelines for proper interconnection.

Two primary electrical standards apply directly to solar+storage installations:

- UL 1741: Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources[8]
- IEEE 1547: Standard for Interconnecting Distributed Resources with Electric Power Systems[9]

UL 1741 sets forth the anti-islanding requirement in place for grid-tied inverters. It states that, in the event of a power failure on the central grid, any independent power-producing inverters connected to the grid must turn off shortly after the grid outage is detected. It is important to note that this standard applies to only to inverters connected to the grid.

Solar+storage systems must have the capability to disconnect from the grid in the event of failure in order to continue supplying electricity to local critical loads. This disconnect is typically handled by the battery-based inverter. UL 1741 also includes additional performance requirements for interconnected systems such as proper operating voltage, frequency parameters, power quality, and interconnection integrity.

IEEE 1547 lays out a uniform standard for the interconnection of distributed generation systems with the grid. The standard sets forth requirements related to the performance, operation, testing, safety, and maintenance of the interconnection. IEEE 1547 was implemented to create a concrete national standard to facilitate the interconnection of distributed generation projects.

Currently, more than thirty states, plus Washington, D.C. and Puerto Rico, have adopted comprehensive interconnection standards that apply to both small and large solar+storage systems. Ten additional states have standards or guidelines that apply only to smaller, net-metered systems. The Interstate Renewable Energy Council (IREC) has also established a list of best practices for state interconnection standards, which recommends each state implement a clear, transparent policy that streamlines the process and keeps costs and regulations to a minimum.

In general, most small systems can be approved and interconnected fairly quickly. Larger systems may take more time and require a closer review. Experienced contractors should be well versed in the process of submitting interconnection applications to the utility and scheduling any required inspections.

Case Studies of Solar+Storage Systems

Photo credit: Sherri Shields, Florida Solar Energy Center

Florida SunSmart Emergency Shelters Program

As of today, the SunSmart Emergency Shelter Program has installed more than 115 solar+storage systems in Florida schools, supplying over 1 MW of solar generation capacity and providing resilient power to emergency shelters across the state.

Initially funded by the American Recovery and Reinvestment Act of 2009 (ARRA), the program was designed to achieve three primary goals: provide uninterrupted emergency power in the event of grid failure, reduce school electricity costs through the production of solar energy, and function as an interactive scientific learning tool for students and teachers. Through an innovative partnership between the Department of Labor, the State of Florida, the University of Central Florida, the Florida solar industry, and utilities, the program has fully accomplished these goals and continues to be implemented in more schools each year.

Each solar+storage system is composed of a 10-kW SolarWorld PV array, a 25-kWh Sun-xtender lead-acid battery pack, and a 10-kW battery-based Outback inverter. The systems have the capability to sell electricity to the utility during normal operation and supply backup emergency electricity to power critical loads in the designated Enhanced Hurricane Protected Area of each school. Emergency power from the solar+storage systems can be accessed by any emergency response organization and the schools collectively have the capacity to shelter 10,000 to 50,000 people during a disaster.

Not only has the SunSmart Emergency Shelter Program ensured emergency services for thousands in local communities and saved Florida schools hundreds of thousands in electricity costs, it has already introduced more than 50,000 students to solar photovoltaics and renewable energy systems.

Photo credit: Standard Solar, Inc.

Konterra Solar Microgrid Storage System

Maryland's first commercial solar+storage microgrid, one of the first commercial solar microgrids in the nation, came online at Konterra headquarters in October 2013. In addition to 402 kW of solar generation and 500 kW/300 kWh of lithium-ion battery storage capacity, the project includes two EV charging stations and LED parking lot lighting. Konterra, a real-estate developer of mixed-use, sustainable communities, developed the project along with Standard Solar and Solar Grid Storage.

The solar side of the installation, which doubles as a parking canopy, will supply 20 percent of the facility's annual electricity demand. That's equivalent to the energy use of about 57 residential homes. The grid-interactive energy storage side of the project will provide grid balancing services during normal operation and emergency power when the grid is unavailable. The batteries are capable of keeping a critical load of 50 kW online for just over four hours and can recharge as solar energy becomes available.

The project was partially funded through a Maryland Energy Administration "Game Changer" Grant. The battery system, inverter, and related components, however, were provided virtually free of cost by Solar Grid Storage. The company is able to do this by using the battery system to generate revenue, primarily through participating in the grid ancillary services market. Batteries are particularly good at providing quick and accurate response to load balancing and frequency regulation demands, services that are highly valued in the PJM Interconnection ancillary services market.

Such innovative business solutions show that when energy storage is properly valued in a competitive market, resilient power can be implemented at little to no cost to the beneficiary.

Photo credit: Princeton Power Systems

Scripps Ranch Community Recreation Center

The San Diego, CA community of Scripps Ranch faced a problem: periodic blackouts caused by reoccurring wildfires. The solution: solar+storage.

In September 2012, with technical support from Princeton Power Systems, the community was able to transform its recreation center into an emergency command center. The Scripps Ranch Community Recreation Center was equipped with a solar+storage system able to serve as an islandable emergency communication center for fire and police operations during grid disruptions. This small solar+storage microgrid was the first of its kind in Southern California.

The facility already had an existing solar array prior to incorporating energy storage. Because of this, the system utilizes two 100-kW grid-tied inverters to handle solar and battery power conversions. Islanding of the system's 30-kW solar array and 100-kW/100-kWh lithium-ion battery pack during outages is coordinated by a separate component, a Princeton Power Systems Site Controller.

Along with supplying reliable emergency power, the energy storage system cuts costs by reducing peak demand charges and can generate revenue through providing grid support services. Savings from the daily operation of the system reduced the recreation center's energy bill from around $2,000 a month down to nearly zero.

The project was funded through a grant from the California Public Utilities and as part of the U.S. Department of Energy's Solar America Cities program. The project also qualified for a $40,000 rebate from the California Solar Initiative.

Photo credit: Green Mountain Power

Stafford Hill Solar Farm and Microgrid

The Stafford Hill Solar Farm and Microgrid, situated on a closed city landfill in Rutland, VT, is all about firsts. Not only was it the first project of its kind to establish a microgrid powered solely by solar energy and batteries, with no additional source of fuel, it was also the first known solar+storage project in the country to be sited on brownfield land.

The project was developed by the utility Green Mountain Power, in collaboration with Dynapower and GroSolar. It is co-funded by a unique federal-state-NGO partnership including the U.S. Department of Energy's Office of Electricity, the State of Vermont, and the Energy Storage Technology Advancement Partnership (ESTAP), which is managed by Clean Energy States Alliance and Sandia National Laboratories.

The solar farm includes over 7,700 solar panels and is capable of producing 2 MW of power. That's enough meet the energy needs of about 2,000 homes. The massive solar array is complemented by 4 MW of battery capacity, composed of a hybrid system of both lithium-ion and lead-acid battery technologies.

The microgrid will supply resilient power to nearby Rutland High School. The school has been designated as an emergency shelter, supplying critical power when the central grid is down. The city of Rutland has a history of frequent power outages due to severe storms. While the microgrid provides much needed power for the community when disaster strikes, the project will recover costs largely though daily storage-enabled services to the grid, regulating and smoothing supply and demand.

The project marks one big step forward in Green Mountain Power's goal of making Rutland the Solar Capitol of New England and helps the state of Vermont reach its renewable energy goals.

Conclusion

When considering a solar+storage system, it is important to weigh all the associated costs and benefits before moving ahead. Solar+storage may not be the ideal choice for every type of facility.

Large facilities that have year-round heating needs, like hospitals and universities, may be better suited for a combined heat and power (CHP) system. Facilities with brief minute-to-minute power reliability concerns, such as data centers, may benefit more from fuel cell technologies.

But facilities with moderate critical loads, adequate space for solar panel and battery placement, and a need for resilient power when the grid goes down, have the potential to greatly benefit from solar+storage. These could include a broad array of community facilities like affordable housing, assisted living, community shelters, schools, fire stations, and other critical public and private facilities.

A lot of steps are involved in properly developing a solar+storage system. To help get the process started, this paper includes a brief Solar+Storage Project Checklist for new developers. The task may seem daunting at the outset, but careful planning and the assistance of experienced solar and energy storage contractors can help ensure a smooth and successful development process. The time and effort involved will pay off quickly the next time disaster strikes and the lights stay on.

Solar+Storage Project Checklist

☐ Get to know your utility bill

Becoming more familiar with your building's energy needs and utility rate structure is a good first step in thinking about a solar+storage system.

Questions to consider:

- What is your monthly/annual energy use (kWh)?
- Are you subject to subject to demand charges? If so, how much are they ($/kW)?
- Are you on a time-of-use rate structure that may benefit from shifting loads to off-peak periods?

☐ Research utility policies and state and local interconnection standards

Prior to beginning any project, it is important to understand what will be required before the system can be connected to the grid. Reach out to your utility and any experienced solar+storage developers in your area to find out what you're allowed to do and what you'll need to do before grid interconnection.

Questions to consider:

- Is net metering available for your solar+storage system?
- Are there any limitations for adding storage to a net metered solar system?
- What market opportunities are open to your system for possible revenue streams? Frequency regulation? Demand response?
- What are the local zoning and permitting requirements?
- Are there any interconnection issues and/or costs you should be aware of?

The U.S. Department of Energy maintains a list of state interconnection policies and standards, available online at www.dsireusa.org/incentives/index.cfm?SearchType=Interconnection&&EE=0&RE=1.

☐ Evaluate critical loads

Start with the devices that absolutely must have power during an emergency and build out a list from there. Research what the maximum power draw is for each device you'd like to keep running. Power requirements may by specified directly on the device or available online. Then think about how long you'll realistically need to power each device in an emergency situation.

☐ Explore your solar needs and limitations

Investigate any limitations you may have on the placement of solar panels at your facility.

Questions to consider:

- How much roof space is available?
- Is the roof flat or tilted? What angle?
- Can panels be positioned to primarily face south?
- Are there any trees or other structures that might shade the panels throughout the day?
- Are ground-mounted solar panels an option?

Then look at your average electricity needs and find out how much solar energy your location receives during the year. NREL (National Renewable Energy Lab) has developed a very useful tool for planning solar systems called PVWatts, available online at http://pvwatts.nrel.gov/.

Solar+Storage Project Checklist (cont.)

☐ Decide on an energy storage technology

This will most likely involve a decision between lead-acid batteries and lithium-ion batteries. Lead-acid may be a more cost effective choice for systems primarily concerned with emergency backup power. If a system will also be providing peak demand reduction, grid frequency regulation, or load shifting, lithium-ion batteries may be a better choice. Hybrid systems utilizing both technologies are another option to explore.

Once you've decided on the proper technology, you can use your maximum critical load power requirements (kW) and emergency energy supply needs (kWh) to estimate the battery bank size for your system.

☐ Explore your financial options

Now that you have an idea of the size of your system and the revenue streams available, it's time to begin the process of figuring out how to pay for it all. Local solar+storage developers should be able to help you get started in this process.

Questions to consider:

- How much of your system will qualify for the Federal Investment Tax Credit (ITC)?
- Are there any state and/or local incentives that can be applied to the cost of your system?
- Is leasing or third party ownership of solar and/or storage available? Would it be cost beneficial?
- Are Solar Renewable Energy Certificates (SRECs) available in your state?

About Clean Energy Group and the Resilient Power Project

Since 1998, Clean Energy Group, a national nonprofit organization, has worked to expand markets for clean energy technologies, including solar, land-based wind, offshore wind, fuel cells, energy storage, and biomass. In 2002, Clean Energy Group created and now manages a sister organization, Clean Energy States Alliance (CESA), another nonprofit organization that helps state and municipal clean energy funds to work together to deploy tens of thousands of clean energy projects around the country.

As part of our work, Clean Energy Group has advocated for the use of advanced clean energy technologies in critical public and private facilities that need reliable power during power outages. Instead of depending on unreliable diesel generators, Clean Energy Group has advocated for the use of clean, community-driven distributed energy sources like solar+storage to provide energy security and backup power in the event of power emergencies.

In 2013, with support from major foundations and in a joint effort with Meridian Institute, Clean Energy Group launched a new national project—The Resilient Power Project—to advance the deployment of resilient power technologies in states and local communities. The project will help communities to better prepare for, and more quickly recover from, damages caused by power outages, with installations of cleaner distributed energy sources.

Through the Resilient Power Project, Clean Energy Group works to help communities install these systems in critical facilities such as police and fire stations, schools that serve as community shelters, multi-family housing, food banks, wastewater treatment facilities, and other locations that need power to keep communities safe when the grid goes down. The project is especially interested in ensuring that these new protective power technologies are deployed in low income communities, which are particularly vulnerable to grid outages, and are often overlooked when new, innovative technologies are adopted.

The Resilient Power Project provides technical assistance on the technology options available and on financing solutions that can make resilient power installations more affordable. Clean Energy Group also has limited funding available for predevelopment costs associated with near-term clean energy storage projects.

More information about Clean Energy Group and the Resilient Power Project can be found online at www.cleanegroup.org and www.resilient-power.org.

Recent publications:
Ramp Up Resilient Power Finance: Bundle Project Loans through a Warehouse Facility to Achieve Scale
Financing for Clean, Resilient Power Solutions
Resilient Power: Evolution of a New Clean Energy Strategy to Meet Severe Weather Threats
Clean Energy for Resilient Communities: Expanding Solar Generation in Baltimore's Low-Income Neighborhoods

These and additional publications are available online at http://www.cleanegroup.org/ceg-projects/resilient-power-project/publications/.

Recent webinars:
New Initiatives in Community Resilient Power
Energy Storage in FERC Territories
MassDOER Resilient Power Solicitation
Financing Resilient Power
New Jersey's Energy Resilience Bank

These and additional webinars are available online at http://www.cleanegroup.org/ceg-projects/resilient-power-project/webinars/.

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Lewis Milford is president and founder of Clean Energy Group and founder of the Clean Energy States Alliance (CESA), two national nonprofit organizations that work with state, federal, and international organizations to promote clean energy technology, policy, finance, and innovation. For Clean Energy Group, Mr. Milford directs the Clean Energy Finance Project (www.cleanegroup.org/ceg-projects/clean-energy-finance/) and the Resilient Power Project (www.resilient-power.org) as well as other projects involving natural gas and renewable power. Mr. Milford is also a nonresident senior fellow at the Brookings Institution. He works with many public agencies and private investors in the United States and Europe that finance clean energy. Mr. Milford is frequently asked to appear as an expert panelist at energy conferences throughout the United States and Europe. His articles on clean energy have appeared in many publications including The New York Times, The Boston Globe, The National Journal, The Huffington Post, and Solar Today. He has a J.D. from Georgetown Law Center. LMilford@cleanegroup.org

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Endnotes

[1] A microgrid is a localized energy grid with the ability to generate energy on-site and operate effectively independent from the central grid. While a single home with a solar panel and storage capacity is technically a small microgrid, microgrids are often defined as incorporating two or more interconnected facilities.

[2] Most states currently have some form of net metering policy in place. See http://www.dsireusa.org/solar/solarpolicyguide/?id=17 for more information on individual state polices.

[3] Critical loads include any equipment that is crucial to the functional operation of a facility. Common critical loads include lighting, heating/cooling, refrigeration, and power for communication devices.

[4] Demand charges, typically applied to commercial customers, are based on the highest capacity load (kW) a building requires at any point during a given billing period. If a building has a one-time peak of 2,000 kW and the utility demand charge is $5 per kW, the demand charge will be $10,000 for that period.

[5] Frequency regulation services act to either feed electricity into the grid to fulfill unmet demand (battery discharge) or draw power from the grid in order to offset excess generation (battery charge).

[6] Items listed are meant to serve only as an example of possible load values. Actual power ratings may vary significantly depending on individual appliance specifications. Source: visualization.geblogs.com/visualization/appliances/, buildingsdatabook.eren.doe.gov/TableView.aspx?table=2.1.16

[7] Peak sun is a convenient way to convert rated power to energy production and is not the actual number of daylight hours during a day. The daily amount of peak sun varies throughout the year, with more sun in the summer and less in winter, so a PV system will generally produce more energy during summer months. Source: www.solardirect.com/pv/systems/gts/gts-sizing-sun-hours.html

[8] ulstandardsinfonet.ul.com/scopes/scopes.asp?fn=1741.html

[9] grouper.ieee.org/groups/scc21/1547/1547_index.html

[10] See www.dsireusa.org/incentives/index.cfm?SearchType=Interconnection&&EE=0&RE=1 for a complete list of state interconnection rules, regulations, and policies.

[11] www.irecusa.org/wp-content/uploads/2013-IREC-Interconnection-Model-Procedures.pdf

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Clean Energy Group

Clean Energy Group (CEG) is a national, nonprofit organization that promotes effective clean energy policies, develops low-carbon technology innovation strategies, and works on new financial tools to advance clean energy markets. CEG works at the state, national, and international levels with stakeholders from government, the private sector, and nonprofit organizations. CEG promotes clean energy technologies in several different market segments, including resilient power, energy storage, solar, and offshore wind. Above all, CEG also works to create comprehensive policy and finance strategies to scale up clean energy technologies through smart market mechanisms, commercialization pathways, and financial engineering. CEG created and now manages a sister organization, the Clean Energy States Alliance, a national nonprofit coalition of public agencies and organizations working together to advance clean energy through public funding initiatives.

CleanEnergyGroup

Innovation in Finance, Technology & Policy

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