NATIONAL RENEWABLE ENERGY LABORATORY

Valuing the Resilience Provided by Solar and Battery Energy Storage Systems

Placing a value on the benefits provided by solar with storage during grid outages can significantly impact project economics and system design.

Interest is increasing in installing solar photovoltaic (PV) systems combined with battery energy storage to provide backup power during electric grid outages; however, building owners and investors are often unsure how to assign value to the lost power anticipated during an outage. As a result, the resilience benefit that a PV system with storage could provide is typically not accounted for when investigating the cost-effectiveness of a potential project.

This paper explores the impact of resilience on the economics of PV and energy storage systems for commercial buildings. The analysis illustrates that accounting for the cost of electric grid power outages can change the breakeven point for PV and storage system investment. In other words, valuing resilience can make PV and energy storage systems economical in cases when they would not be otherwise. In cases where a PV and storage system is already economical, valuing resiliency can increase the size of the cost-optimal PV and storage system design. As storage costs decrease, and as outages occur more frequently, PV and storage are likely to play a larger role in building design and management considerations.

What Are Resilient Power Systems?

As severe weather events such as hurricanes and heat waves become common, interest is increasing in resilient electric power systems. For a power system to be resilient, it must be capable of islanding and operating independently from the grid during outages. Installed with additional hardware—including transfer switches, critical load panels, and appropriate controls—these systems can act as self-sufficient microgrids, generating energy and powering critical loads until utility services are restored. Recent natural disasters such as Hurricanes Harvey, Irma, and Maria have reinforced the necessity of reliable power for essential services (such as air conditioning, medical and pharmaceutical needs, and water pumps) and to keep critical businesses operating (such as gas stations and grocery stores).

Solar + Storage Offers Benefits Compared to Diesel

Historically, resilient electric power systems have been powered by diesel generators and other forms of fossil-fueled generation. Recent experiences, however, have highlighted some risks of relying on diesel as the only backup power option.

During a sustained grid outage, diesel supplies can run out. This is particularly true in emergency situations when access to refueling might become strained or impossible. Flooding, downed trees, and damage to roadways might prevent the delivery of fuel to locations where it is needed. In the case of Hurricanes Irma and Maria, for example, resupplying fuel to the Caribbean islands can take days to weeks. Also, there are competing uses for limited supplies of diesel fuel during disasters because fuel is used for transportation too.

Aside from periodic exercises and maintenance, most diesel generators lie idle until an outage occurs. If not properly maintained, they can fail when called upon to support full building loads or operate for extended periods. In the case of widespread outages in the wake of Hurricane Maria, one reporter described the situation in Puerto Rico as "an epidemic of broken generators" (Alvarez 2017).

Unlike traditional generators, PV and battery energy storage systems can operate in grid-connected mode and provide value throughout the year through regular monthly electric bill savings to system owners. In some locations, there is also the potential to generate additional revenue by providing valuable grid services such as frequency regulation or by participating in utility programs such as demand response. Because the systems are used regularly, it is likely they will be operational when called upon in an emergency. Further, although generators require regular maintenance and a constant fuel supply to continue functioning, PV and battery energy storage could provide power for an extended period, assuming there is enough solar resource to continue charging the batteries.

Diesel generators are often viewed as the default solution for providing resilient power, but they might not always be the most reliable or cost-effective solution. Reliance on traditional fuel reduces an energy system's resilience because a disruption or contamination in the fuel supply can cause vulnerabilities. Using solar power to charge on-site energy storage offers unique benefits that traditional diesel-fueled backup power systems cannot. As a result, solar technology combined with energy storage is increasingly being implemented in resilient power system designs.

The Challenge of Valuing Resilience

Unfortunately, although the benefit of having a resilient power system is clear when the electric grid goes down, putting a monetary value on additional resilience investments can be difficult. Each individual business or service provider might have widely varying values of resilience.

Determining the expected utility bill savings and potential for revenue generation associated with an investment in a PV and battery energy storage system can be relatively straightforward; however, assigning a value to the improved resilience associated with a PV and storage system is much more challenging. When solar and energy storage technologies are configured to provide backup power, they create value by allowing businesses to stay open or residents to shelter in place. When powering critical facilities such as hospitals and emergency shelters, resilient power systems might even prevent losses of life.

The study detailed in this paper values resilience in terms of the avoided cost of a grid outage. Essentially, the expected cost of the loss of business or the liability incurred because of the lack of power is used as a proxy for the value of resilience. This study uses values from a compilation of 30 utility customer surveys designed to approximate the cost of outages for various customer types (Sullivan, Schellenberg, and Blundell 2015).[1,2]

With the costs of solar and battery energy storage technologies declining, increasing numbers of developers and building owners are exploring PV and storage as viable options for augmenting or even replacing traditional standby generators.

Method: Determining the Effect of Valuing Resilience on System Design

To quantify the effect of valuing resilience on PV and battery energy storage system design, researchers at the U.S. Department of Energy National Renewable Energy Laboratory (NREL) incorporated the avoided cost of a grid outage into the economics of determining cost-optimal system sizing for buildings in Anaheim, California. For each of the building types analyzed, two scenarios were explored: one that places no value on resilience and one that values resilience in terms of dollars lost per hour of outage.[1]

For each scenario, a solar and energy storage system is designed to maximize economic benefit during an assumed system lifetime of 20 years. The lifetime economic benefit is measured in terms of the net present value (NPV) of the system, which is the net difference between the benefits and the costs of the project, in today's dollars. The project benefits include the bill savings delivered by the PV and storage systems during normal grid-connected operation as well as the additional benefit of surviving a grid outage.[3] The project costs include the capital costs of installing PV and storage, system operating and maintenance expenses, and the cost of any outage period not survived.

> **The study demonstrates that even though a PV and storage system might not appear to be economical under traditional cost-benefit calculations, placing a value on the losses incurred from grid disruptions can make a PV and storage system a fiscally sound investment.**

A project with a negative NPV indicates that it would cost more to install and maintain the system than the savings realized throughout time. A system with a positive NPV indicates that it would be less expensive to build and operate the system than to continue normal operations without it.

Systems costs, benefits, and optimal system sizes for each customer scenario were determined by balancing the cost of the system, the cost of electricity from the utility, and the cost of outages using NREL's modeling program Renewable Energy Optimization (REopt).[4] For scenarios in which resilience is not

1. The outage costs in NREL's study use the "Medium and Large C&I" values from Table ES-1 in Sullivan, Schellenberg, and Blundell (2015).
2. The outage cost values from Sullivan, Schellenberg, and Blundell (2015) are for shorter duration outages, less than 24 hours. Longer duration outages, such as those occurring in disaster scenarios, would be expected to have much higher outage costs and thus higher values of resilience.
3. For this study, critical load is assumed to be 50% of typical building electrical load based on representative load profiles. Actual critical loads vary widely depending on the type of facilities and which services are deemed critical.
4. REopt is a techno-economic, mixed-integer linear program developed at NREL, *https://reopt.nrel.gov/*.

valued by the customer, the cost associated with the outage is assumed to be zero (i.e., no assets were damaged, and no business was disrupted). When resilience is assigned a value, the cost of outages can be reduced by the ability of a resilient power system to survive some part, or all, of anticipated grid disruptions.

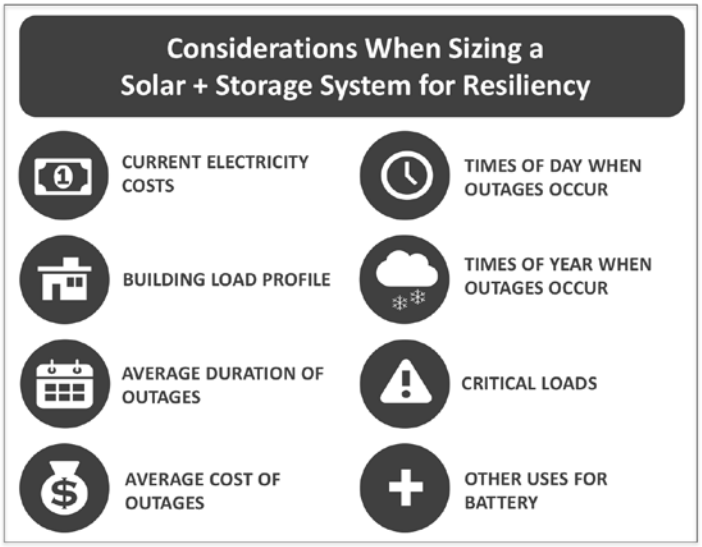

Figure 1. Considerations when sizing a solar and storage system for resiliency

Results: The Impact of Resilience on System Sizing

The number of hours that a given PV and storage system can power critical loads depends on several factors (Figure 1). Some include the amount of energy stored in the battery at the time of the outage, the level of critical loads that must be supported during the outage, and the PV resource availability. To account for these variables, NREL analysts determined the average number of hours that a system could meet 50% of the building's normal electricity load during an outage. This was done by simulating 8,760 different outages (one beginning at each hour of the year). The simulated outages were based on the Customer Average Interruption Duration Index (CAIDI) values reported by utilities, a common reliability index.[5] The modeled outages lasted approximately 2 hours.[2] The average performance of the system among all 8,760 outages modeled for each scenario was used as a measure of the solar and storage system's overall ability to supply the building's critical load during an outage.

For the purposes of the analysis, three types of buildings were selected to illustrate the effects of valuing resilience on the sizing of PV and storage systems: a primary school, a large office building, and a large hotel.[6] Each of these building types has a different combination of optimal PV and battery energy storage capacities when resilience is not valued, and in each case valuing resilience increases both PV and storage sizing.[7] The value of resilience differs among the three building types because it is based on survey data designed to approximate the cost of outages for different customer types.[1]

The analysis considered only electricity needs for the buildings; it did not consider thermal loads, energy efficiency, or other mitigation measures that impact a building's ability to become more resilient.

As shown in Table 1, the results of the analysis indicate that the most cost-effective solution for the primary school is to install PV and a battery energy storage system, even without factoring in the cost of outages. Bill savings through lower energy expenses and reduced demand charges more than offset the lifetime cost of the system. When factoring the value of resilience, the optimal PV system increases by nearly 20%, and the storage system capacity increases more than 13 times compared to the system that was not sized to be resilient. In addition to resilience benefits, the larger system is capable of delivering increased electric bill savings throughout time, more than doubling the net benefit of the system.

Table 1. Valuing Resilience Increases the Economic Solar and Battery System Sizes on a Primary School

Primary School				
Value on Resiliency?	Assigned Value of Resiliency ($/hour)	PV Size (kW)	Battery Capacity (kWh)	Net Present Value ($)
No	$0	113	6	$28,759
Yes	$2,368	134	79	$58,399

5. Typical outage durations are determined based on CAIDI for Southern California Edison, the utility serving Anaheim. CAIDI is a reliability index commonly reported by utilities that represents the ratio of total customer outage durations to total number of customer power disruptions. CAIDI values are derived from the U.S. Energy Information Administration's "Electric power sales, revenue, and energy efficiency Form EIA-861 detailed data files" available at *https://www.eia.gov/electricity/data/eia861/*.

6. The selection of scenarios used for this study was informed by a larger study by the authors that examines the economics of PV and storage for commercial customers in the United States. That study explores 16 building types, 17 locations, and more than 70 utility rates from across the United States. Three scenarios for which PV and storage systems were found to be economical, or nearly economical, were selected as the basis for this study.

7. Note that a much larger portion of the normal operating costs for the large office and large hotel are a result of the utility energy charges compared to the primary school. The utility rates for the office and hotel have relatively high peak energy charges of $0.386/kWh. The higher energy charge coupled with a lower demand charge than the primary school is most likely why a battery is not economical when resilience is not valued for the office and hotel.

For the school building, valuing resilience increased the size of a solar and storage system that was already economical. For a representative large office building, however, solar was cost-effective without valuing resilience but not storage. But when accounting for the cost of outages, the model increased the ideal PV size on the office by 35% and added a 271-kWh battery energy storage system (see Table 2). With the ability to avoid outage losses and deliver increased electric bill savings throughout time, the solar and storage system increases the net benefit for the customer by $178,000 throughout 20 years, a 160% boost in NPV.

Table 2. Valuing Resilience Increases the Optimal PV System Size and Makes the Addition of Storage Economical on a Large Office

Large Office				
Value on Resiliency?	Assigned Value of Resiliency ($/hour)	PV Size (kW)	Battery Capacity (kWh)	Net Present Value ($)
No	$0	961	0	$111,000
Yes	$14,365	1,304	271	$289,060

For the large hotel shown in Table 3, incorporating the value of resilience alters the optimal solution from that of no system at all to a resilient power system with 134 kW of PV and 79 kWh of battery energy storage capacity. In this case, valuing resilience enables PV and storage to become the least-cost solution, whereas neither PV nor storage would be economically viable otherwise.

Table 3. Valuing Resilience Makes Solar and Storage Economical on a Large Hotel

Large Hotel				
Value on Resiliency?	Assigned Value of Resiliency ($/hour)	PV Size (kW)	Battery Capacity (kWh)	Net Present Value ($)
No	$0	0	0	$0
Yes	$5,317	363	60	$50,640

Accounting for the Cost to Island

Islanding a PV system is critical for resilience. PV panels on a rooftop that are grid-connected do not ensure that a building will have power during a grid outage. Any islandable PV and storage system requires additional expenses that are more than the cost of a nonislandable system. These added costs depend on many factors. These might include additional hardware components, such as transfer switches and critical load panels; software components; and electrical design, permitting, and safety considerations. These must be factored when determining whether a resilient system is the most economical solution.

The costs to island can be highly variable and depend on a multitude of site-specific factors. Based on anecdotal experience, the cost to island a system might add incremental expenses ranging from 10% to 50% of the nonislandable PV and storage system cost.

The benefit of any avoided losses during grid outages must be balanced with these added costs of designing a system to meet critical loads. For a resilient power system to result in a net economic benefit for a customer, the cost to island must be no more than the added savings delivered by the system.

The study explores 21 scenarios to determine the maximum allowable cost to island in each case. For the systems analyzed, the maximum cost to island ranged from 3% to 21% of the nonislandable system cost, with an average maximum of 12%.

For example, the primary school in the analysis provides a total economic benefit of $28,759 before valuing resilience. When resilience is valued, the larger system delivers an economic benefit of $58,399—amounting to a $29,640 increase in benefits, representing approximately 15% of the cost of the smaller, nonislandable system. For the islandable system to ultimately benefit the customer, the cost to island must be less than the added value. If the cost to make the system islandable is more than $29,640, it would be more cost-effective to build the smaller system instead.

Note that the system costs used in these analyses do not account for any added costs associated with giving a grid-connected system the ability to island (that is, operate independent of the grid during an outage). These additional costs are beyond the scope of the study, but they should be factored into real-world system design considerations. A grid-connected system with islanding capability can benefit from utility bill reductions and revenue generation during normal operations, and it can continue to provide power to a specified load during a utility grid outage.

Conclusion

Under current technology price assumptions, battery energy storage systems are often only cost-effective in locations that have relatively high utility demand charges or where there is a viable market for the grid services storage can provide. The study demonstrates that even though a PV and storage system might not appear to be economical under traditional cost-benefit calculations, placing a value on the losses incurred from grid disruptions can make a PV and storage system a fiscally sound investment. In most cases, incorporating the value of resilience will increase the optimal sizing of both the PV and battery systems, but the added cost to make a system islandable must also be considered.

Recent major weather events and widespread outages have raised awareness of and interest in the need for localized, resilient power systems as well as the limitations of current solutions such as diesel generators. With technology costs declining and extended outages becoming increasingly common, more businesses and building owners are likely to consider the value of resilience and the viability of PV and storage to avoid outage-related losses.

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