Increasing Resiliency Through Renewable Energy Microgrids

A Technical Paper prepared for SCTE/ISBE by

Kate Anderson, Senior Engineer and Group Manager, National Renewable Energy Laboratory, SCTE/ISBE Member
15013 Denver West Parkway
Golden, CO 80401
Kate.Anderson@nrel.gov
303-384-7453

Nick DiOrio, National Renewable Energy Laboratory

Dylan Cutler, National Renewable Energy Laboratory

Bob Butt, National Renewable Energy Laboratory

Allison Richards

Table of Contents

List of Figures

List of Tables

1. Introduction

This paper describes a methodology to quantify the economic and resiliency benefit provided by renewable energy (RE) in a hybrid RE-storage-diesel microgrid. We present a case study to show how this methodology is applied to a multi-use/ multi-function telecommunications facility in southern California. In the case study, we first identify photovoltaic (PV) and battery energy storage system (BESS) technologies that minimize the lifecycle cost of energy at the site under normal, grid-connected operation. We then evaluate how those technologies could be incorporated alongside existing diesel generators in a microgrid to increase resiliency at the site, where resiliency is quantified in terms of the amount of time that the microgrid can sustain the critical load during a grid outage.

We find that adding PV and BESS to the existing backup diesel generators with a fixed fuel supply extends the amount of time the site could survive an outage by 1.8 days, to 3.5 days for the PV/diesel/BESS hybrid system. Furthermore, even after diesel fuel supplies are exhausted, the site can continue to operate critical loads during daytime hours using just the PV/BESS when there is sufficient solar resource. We find that the site can save approximately $100,000 in energy costs over the 25-year lifecycle while doubling the amount of time they can survive an outage.

The methodology presented here provides a template which may be applied to other sites interested in quantifying the energy, economic, and resiliency benefits of RE..

2. Background

Electricity system resiliency focuses on preventing power disruption and, when an outage does occur, restoring electricity supply as quickly as possible while mitigating the consequences of the outage. Resiliency is a high priority for telecomm facilities, which can experience millions of dollars of losses during outages. Traditionally, diesel generators have been used to provide backup power during outages. Renewable energy is starting to play a role in energy resiliency for two primary reasons.

First, the US has seen an increase in the number of high-impact and high-cost natural disasters - seven of the ten costliest storms in US history have occurred in the last ten years (Ton 2015). These high impact incidences have exposed the fact that existing approaches to energy resiliency are not sufficient in many communities. Numerous weaknesses were exposed during these incidences, including: lack of refueling options for backup diesel generators, unreliable operation of backup generators, interruptions in natural gas and other fuel supplies, and aging infrastructure (Marqusee 2017).

Second, the market is experiencing a significant decrease in the cost of renewable energy (RE) systems, most prominently photovoltaics (Barbose 2016), and battery energy storage systems (BESS) (GTM Research/ESA 2017). These cost decreases have led to a significant increase in the number of deployed RE and storage systems (GTM Research/ SEIA 2017 and GTM Research/ESA 2017).

The combination of fuel supply interruptions in many of the recent natural disasters, and the increased cost-effectiveness of RE and BESS has generated significant interest in using RE technologies both for economic benefit as well as for backup power to sustain critical loads during grid outages. Unlike conventional back-up generation such as diesel gensets, which sit idle most of the time, the combination of BESS, RE, and demand management technologies can be operated for economic gain during the 99% of the time that the grid is functional. The grid-connected benefits of RE and BESS microgrids include offsetting bulk energy purchases, reducing peak demand charges, performing energy arbitrage, and providing ancillary services. With the appropriate inverters and controls these same systems can be islanded to form a microgrid, along with diesel generators, to sustain critical electrical loads for the site/facility during grid outages. A hybrid diesel-RE microgrid system such as this can sustain longer outages for a given amount of diesel fuel by reducing the run-time of the diesel generator, increasing the energy resiliency of the site.

The cable industry has recognized the importance of lowering energy consumption, cutting energy costs, and reducing dependence on the grid. They have formed the Energy 2020 program, a multi-year campaign through the Society of Cable Telecommunications Engineers (SCTE) Energy Management Program, to envision and enable what energy will look like in cable in the year 2020, targeting maximum customer uptime and enabling capacity growth via successful organizational, customer and environmental energy solutions (SCTE 2017). At the time of publication, the goals of the program are to:

- Reduce energy intensity by 15% year on year
- Reduce energy costs by 25% on a unit basis
- Reduce grid dependency by 10%
- Optimize technical facilities and datacenters footprint by 20%

This paper focuses on the role of renewable energy in meeting the first three of these goals: reducing energy consumption, energy cost, and grid dependency of telecomm sites.

3. Methodology

This section describes the methodology for quantifying economic and resiliency benefit provided by RE in microgrids, and summarizes key analysis inputs and assumptions.

3.1. Modeling Approach

3.1.1. The REopt Model

We used NREL's Renewable Energy Optimization (REopt) modeling platform for energy system integration and optimization to evaluate RE and storage technologies to minimize energy costs and increase resiliency (Cutler et al 2017). The REopt model is formulated as a mixed integer linear program that seeks to minimize the life-cycle cost of energy at a site over the analysis period, subject to a variety of constraints. The life-cycle cost of energy includes all of the costs associated with providing energy to the site, including the cost of purchasing energy from the utility grid (in present value), the capital cost of building new technologies, present value of operating and maintenance (O&M) costs, income from utility or state incentive programs, and any tax benefits. The model performs an energy balance at every time step where loads must be met by some combination of renewable and conventional generation, purchased energy from the utility grid, discharges from energy storage, or dispatchable load. This energy balance is solved for the first year and then is assumed to repeat for each of the ensuing years in the analysis period, with recurring costs escalated and then discounted in the cash flow. The output of the REopt model is a set of cost-optimal sizes for each technology in the candidate pool, and the net present value that would be achieved if the technologies in the solution were to be implemented. The optimal dispatch strategy for each technology required to achieve the net present value is also provided.

3.1.2. Quantifying Economic Benefits of RE and Storage

One of the critical elements in comparing resiliency associated with RE (or hybrid) systems to generator-only systems is capturing the grid connected benefits associated with the RE technologies. The REopt model was used to simulate the business-as-usual case, where the site continues to purchase their energy services from their serving utility. During grid outages the critical loads are served by a backup diesel generator. REopt was also used to optimize the hybrid RE/storage case, where the size and operation of the system are optimized by the model. In this case, the RE systems were able to operate for financial benefits during grid-tied operation, and were also able to serve the critical loads during grid outages.

3.1.3. Quantifying Increased Energy Resiliency Due to RE and Storage

Another key element in evaluating hybrid diesel-RE systems in the context of energy resiliency is quantifying the additional energy resiliency provided by the RE portion of the systems. In this section, we describe an approach for quantifying the extended outage survivability associated with an RE system. Using REopt, the RE system is sized for maximum economic gain under grid-connected operation, where the RE system can offset grid purchases of electricity, reduce peak demand charges, and/or engage in energy arbitrage.

Outage survivability is defined as the probability that a site can supply energy to the critical loads for an outage of X hours given a certain set of energy assets. It is defined as a probability because the ability to survive an outage of a given duration depends on when that outage occurs during the day/year (impacting the load during the outage), and – for sites with RE systems – the concurrent RE resources.

With a traditional diesel generator and a fixed amount of fuel onsite the outage survivability varies as a function of the outage duration. For example, at a telecommunications facility the outage survivability, or probability, would typically be 1 (100%) for the first 24 hours of an outage (given sufficient fuel), and tails off quickly as the fuel supply is exhausted. For a hybrid RE/generator system, the outage survivability for longer outages increases due to the ability of the RE systems to offset some of the generator fuel consumption. To determine the increased energy resilience provided by RE, the outage survivability is calculated first with only the existing diesel or gas backup generators and fixed fuel supply. Then, the outage survivability is calculated again with the hybrid RE/storage system included in the simulations (along with any existing diesel or natural gas backup generators), making it possible to quantify the increase in outage survivability attributable to the RE systems.

To calculate the outage survivability as a function of hours, random grid failures are injected into the REopt model. These outages are random in both occurrence and duration, with each variable being sampled independently from a uniform distribution. The outage occurrence can occur in any hour in the year, and the outage duration can take any value between 0 and 336 hours (two weeks). In each simulation the model will either fail to have sufficient resources to meet the critical loads, or it will be able to meet those loads and will dispatch those systems during the outage (as well as during the remainder of the year). For this analysis 1000 optimization simulations were executed. The results were binned by 24-hour blocks, and the outage survivability was calculated for each 24-hour period from 24 to 336 hours (1 to 14 days). Each range has an average of 77 simulated outages.

3.2. Model Inputs

The modeled site is a multi-use/ multi-function facility, which includes administrative offices, a warehouse, a production studio, a technology center for research and development, a customer service center, and a hub site delivering cable services to the surrounding community.

3.2.1. Load and Utility Rate Tariff Data

The site was modeled using actual electrical load data, measured over one year on 15 minute intervals. The average load is approximately 150 kW, ranging from a minimum of 120 kW to a maximum of 250 kW in the summer. Total annual energy consumption is 1,400,000 kWh. We assumed the critical load was a flat 155 kW, based on standby generator ratings and input from the site.

The site is in an unregulated market and is served by Southern California Edison (with rate tariff TOU-GS-3 Option B) for delivery, and Constellation Energy for energy charges. The site's total 2015 electric energy cost was $250,000. The combined SCE and Constellation Energy rate tariff is shown in Table 1 and includes on peak, mid peak, and off-peak summer and winter energy and demand charges.

Table 1 - Current Electric Rate Tariff, Combined SCE Option B and Constellation Energy

All year		
Fixed monthly charge	$453.25/meter	
Facility demand charge	$19.38/kW	
June-September	**Energy Charge ($/kWh)**	**Demand Charge ($/kW)**
Noon-6 p.m., weekdays	0.15856	15.51
8 a.m.-noon, 6 p.m.-11 p.m., weekdays	0.12541	3.05
All other hours	0.10878	0
October-May	**Energy Charge ($/kWh)**	**Demand Charge ($/kW)**
8 a.m.-9 p.m., weekdays	0.12156	0
All other hours	0.1131	0

If the site installs a PV, it will be eligible to switch to SCE TOU-GS-3 Option R. This tariff is favorable for PV because the highest energy charges occur during times of peak PV generation. It is less favorable for BESS because there are no time-of-use demand charges. Table 2 shows the combined SCE TOU-GS-3 Option R and Constellation Energy rate.

Table 2 - Future Electric Rate Tariff, Combined SCE Option R and Constellation Energy

All year		
Fixed monthly charge	$453.25/meter	
Facility demand charge	$12.78/kW	
June-September	**Energy Charge ($/kWh)**	**Demand Charge ($/kW)**
Noon-6 p.m. weekdays	0.35634	0
8 a.m.-Noon, 6 p.m.-11 p.m., weekdays	0.17259	0
All other hours	0.12762	0
October-May	**Energy Charge ($/kWh)**	**Demand Charge ($/kW)**
8 a.m.-9 p.m., weekdays	0.1404	0
All other hours	0.13194	0

3.2.2. *Candidate Technologies*

The following candidate technologies were included in the model for consideration and are further described below: utility grid, PV, BESS, and diesel generators. These technologies were selected for consideration based on expert guidance and recommendations, though other technologies may also play a role now or in the future.

a) Utility Grid: The utility grid is assumed to be able to supply an unlimited amount of electricity up to the transformer rating serving the site. Energy from the grid incurs only the costs specified by the tariff structure; there are no capital or O&M costs.

b) PV: The NREL REopt software utilized hourly capacity factors to model the production of PV during every hour of the year. The hourly capacity factors were obtained from PVWatts (Dobos 2013) for the specific location, assuming fixed open rack, south-facing, standard PV panels with a tilt equal to latitude and using a typical meteorological year 2 (TMY2) weather file for Los Angeles (the closest available TMY2 weather file). We assumed system losses of 14% for soiling, electrical wiring losses and availability; an inverter efficiency of 0.96%; and annual performance degradation of 0.5% per year (Jordan 2010). The annual average solar capacity factor was 18%. An installed cost of $2.13/W and an operating and maintenance cost of $0.02/W-year were estimated based on published market research and input from subject matter experts within NREL (Feldman 2014). The system was expected to last 25 years. Electricity produced by the PV in the model could be used to serve the electrical load, charge the battery, or be exported to the grid.

c) BESS: The battery storage module was based on the characteristics of lithium-ion batteries. The model was able to optimally select and size both the energy capacity of the battery and the power electronics that determine instantaneous power charge and discharge capacity. Battery capacity was assumed to cost $520 per kWh and power electronics $1000 per kW (Anderson 2016). The life expectancy of the battery was assumed to be 10 years, and the present value replacement cost of $200/kWh and $200/kW was included in the model. The battery was modeled with a combined round-trip efficiency of 82.9% and discharge was restricted to ensure that the state of charge never dropped below 20%. The battery can be charged by the PV, grid, or generator (during outages) and discharged to the electric load.

d) Diesel generators: The site has two existing diesel generators rated at 75 kW and 230 kW. We assumed tank capacities of 150 and 400 gallons of fuel, respectively, which would last approximately 24 hours at full load or 44 hours at 50% load. The performance of the existing diesel generators were modeled using a linear fuel consumption rate with slope of 0.6 gallons per kWh and y-intercept of 1.4 gallons per hour, based on fuel consumption data for a 230 kW generator. The minimum turn down ratio was assumed to be 30%. There was no capital cost associated with the generators as they were already in place and would therefore not constitute a new expense. The O&M cost was assumed to be $0.02 per kWh produced, and it was expected that the system would last 25 years. A lumped model of the diesel generator was used, meaning that all of the generating capacity specified by the model was assumed to be in one large generator rather than multiple smaller generators. Spinning reserve and operating reserve were not considered as part of this analysis. The diesel generator could directly serve the electrical load or charge the battery, only during outages.

3.2.3. Economic Assumptions

We assumed that RE technologies would be built immediately and would continue to produce energy for the duration of the analysis period, which was assumed to be 25 years. We assumed that the cost of purchasing energy from the utility grid escalates each year at an escalation rate of 0.1%, and the O&M cost associated with RE and BESS also escalates at a rate of 0.1% (NIST 2015). The utility costs and incurred O&M costs in the out-years were then discounted to the present.

We assumed a third party develops and finances the RE and BESS, and the site (the energy off-taker) purchases energy from the developer. There is no upfront cost to the site, but we assume the developer earns a 10% rate of return before taxes, which is reflected in the energy costs the site would pay to the developer. The site specified a 7% discount rate, which was used to discount all energy purchases to the present (including any potential energy purchases from a third-party developer).

We assume that the system owner has sufficient earned income that any and all available tax incentives are fully monetized. These tax benefits include the 30% investment tax credit (ITC) and 5 year depreciation under the modified accelerated cost recovery system (MACRS) for both PV and storage (DSIRE 2016). A 35% corporate tax rate is assumed to calculate the value of the ITC and MACRS. The capital cost used as the basis for MACRS is decreased by 50% of the value of the ITC. Because the ITC and MACRS are not available upfront, but rather are captured in future years, their values are discounted at the 10% discount rate. We also assumed the BESS would qualify for the California Self Generation Incentive Program (SGIP) which was valued at $0.36/Wh at the time of the analysis. Finally, we assume the site can net meter up to 100% of the annual load and the excess above 100% is credited at the November 2016 net surplus compensation rate of $0.02532/kWh (SCE 2016).

We assumed that the energy produced by the PV system degrades by 0.5% per year. We assumed the BESS lasts ten years based on calendar degradation and the cost of one replacement BESS was included in year ten. The BESS may not last the entire ten years if it experiences an excessive number of deep charge / discharge cycles, so we post-processed the BESS dispatch using the "rain flow" cycle counting algorithm (Downing 1982) to verify the ten-year assumption.

3.3. Assumptions

Key assumptions are summarized in Table 3.

Table 3 - Model Key Inputs

Input	Assumption
Technologies considered	PV, BESS, existing diesel generators
Objective	Minimize lifecycle cost of energy
Analysis period	25 years
Ownership model	Third-party owned
Discount rate for TWC	7%
Developer discount rate	10%
Corporate tax rate	35%
General inflation rate	0.1% per National Institute of Standards and Technology (NIST)
Utility cost escalation rates	0.1% per NIST
Incentives	30% Federal ITC for PV and BESS 5-year MACRS depreciation $0.36/kWh SGIP
Net metering limit	1 MW
Value of electricity exported to grid above net metering limit	$0.02532/kWh
Interconnection Limit	None
PV capital cost	$2.13/kW
PV O&M cost (includes one inverter replacement)	$0.02/W-year
BESS capital cost	$520/kWh plus $1000/kW
BESS replacement cost (year 10)	$200/kWh plus $200/kW
Solar resource	TMY2 solar data
Typical load	15-minute load data provided by the site; average load of 150 kW ranging from a minimum of 120 kW to a maximum of 250 kW. Total annual energy consumption is 1,400,000 kWh.
Critical load	155 kW flat load

4. Results of the Economic and Resiliency Analysis

4.1. Grid-Connected System Optimization

We first evaluated technologies that would minimize the life-cycle cost of energy at the site under normal, grid-connected operation. In this approach, the RE assets in the microgrid are optimally selected and sized for maximum economic gain during normal grid-connected operation; although these assets may increase the duration of outage for which the critical load can be sustained, this is not considered during the optimization process. Once the RE assets are optimally selected and sized, a series of stochastic simulations is completed to analyze how the resulting microgrid, which also includes the existing conventional generation of specified size and fuel reserve, performs during grid outages of random lengths throughout the year. In this way, the contribution of RE toward increasing the resiliency of the site can be quantified, even though improved resiliency was not actually an optimization criteria.

We found that the site can minimize their cost of energy by installing an 845-kW DC PV system and a 16 kW, 32 kWh BESS and switching to the SCE TOU-GS-3 Option R rate. The initial cost (borne by the developer) of the PV system would be approximately $1.8 million, and the cost of the BESS would be approximately $33,000. Site electrical work including a duct bank, manholes, pad-mounted switch, and communications required for medium voltage interconnection would be approximately $400,000. The PV system would generate 91% of the site's energy requirements.

The PV system is sized such that it offsets all energy charges. While it only generates 91% of the site's energy requirements, it generates some of that energy during on-peak hours, and so exported energy is credited at a high rate. The site then purchases utility energy during mid-peak and off-peak hours, when energy costs are lower. Therefore, the site can offset all of their energy costs even though they only generate 91% of their energy consumption. The site still pays demand charges and fixed charges so the net bill is positive. The net present value of the investment is $602,000.

We also evaluated a second scenario in which the model is constrained to build a BESS of at least 155 kW, 155 kWh which would sustain the 155 kW critical load at the site for one hour (as required for the selected microgrid configuration, see section 4.2.1). A BESS with a 155 kW inverter and a slightly larger 172 kWh capacity is the most cost-effective size under this constraint, with a net present value of $519,000. These results are summarized in Table 4.

Table 4 - Cost-Optimal Grid-Connected Results

Scenario Description	Base Case (SCE Option B)	PV/BESS Case (SCE Option R)	PV/BESS Case-Larger Battery (SCE Option R)
PV Size (kW DC)	0	845	845
BESS Size (kW, kWh)	0	16, 32	155, 172
PV Cost (without incentives) [a] ($)	$0	$1,803,644	$1,803,644
PV Cost (with incentives)[b] ($)	$0	$896,822	$896,822
BESS Cost (without incentives) ($)	$0	$32,640	$244,440
BESS Cost (with incentives)[b] ($)	$0	$10,448	$90,313
BESS Replacement Cost (without incentives), Year 10 ($)	$0	$9,600	$65,400
BESS Replacement Cost (with incentives),Year 10 ($)	$0	$7,171	$48,854
Site Electrical Work [c]	$0	$402,500	$402,500
Annual O&M ($/year)	$0	$16,900	$16,900
Average Annual PV Generation (kWh/year)	0	1,299,682	1,299,682
Year 1 Electric Load (kWh)	1,423,513	1,423,513	1,423,513
Year 1 Electric Charges ($)	$169,517	$0	$0
Year 1 Demand Charges ($)	$70,378	$28,668	$25,802
Year 1 Fixed Charges ($)	$5,439	$5,439	$5,439
Year 1 Total Utility Charges ($)	$245,334	$34,107	$31,241
Avoided Utility Costs ($)	$0	$211,227	$214,093
Year 1 Payment to Developer ($)	$0	$161,643	$172,212
Year 1 Savings ($)	$0	$49,584	$41,881
Lifecycle Cost ($)	$2,822,767	$2,220,894	$2,303,702
Net Present Value ($)	$0	$601,873	$519,065

[a] Includes PV, inverter, step-up transformer
[b] Includes present value of ITC, MACRS, and SGIP
[c] Includes duct bank, manholes, pad-mounted switch, and communications required for medium voltage interconnect

Figure 1 shows how the PV and BESS work together (in conjunction with grid purchases) to meet the site load at lowest cost. The site consumes utility electricity during nighttime hours when utility prices are low and PV is not generating. During the day, PV meets the full load, and excess PV is used to charge the BESS or is exported back to the utility. The BESS is strategically discharged between 4-7 p.m., as PV generation is tailing off, to slightly reduce peak demand. Because the BESS is small compared to the site load its impact is small, but it does provide some savings through a small reduction in peak demand.

Figure 2 shows how this operating strategy translates into utility bill savings. By shifting to SCE TOU-GS-3 Option R, the site reduces its demand charges by 59%. The largest savings occur during the summer months when utility peak pricing applies, and smaller savings on the part-peak, off-peak, and facility demand charge are earned year-round.

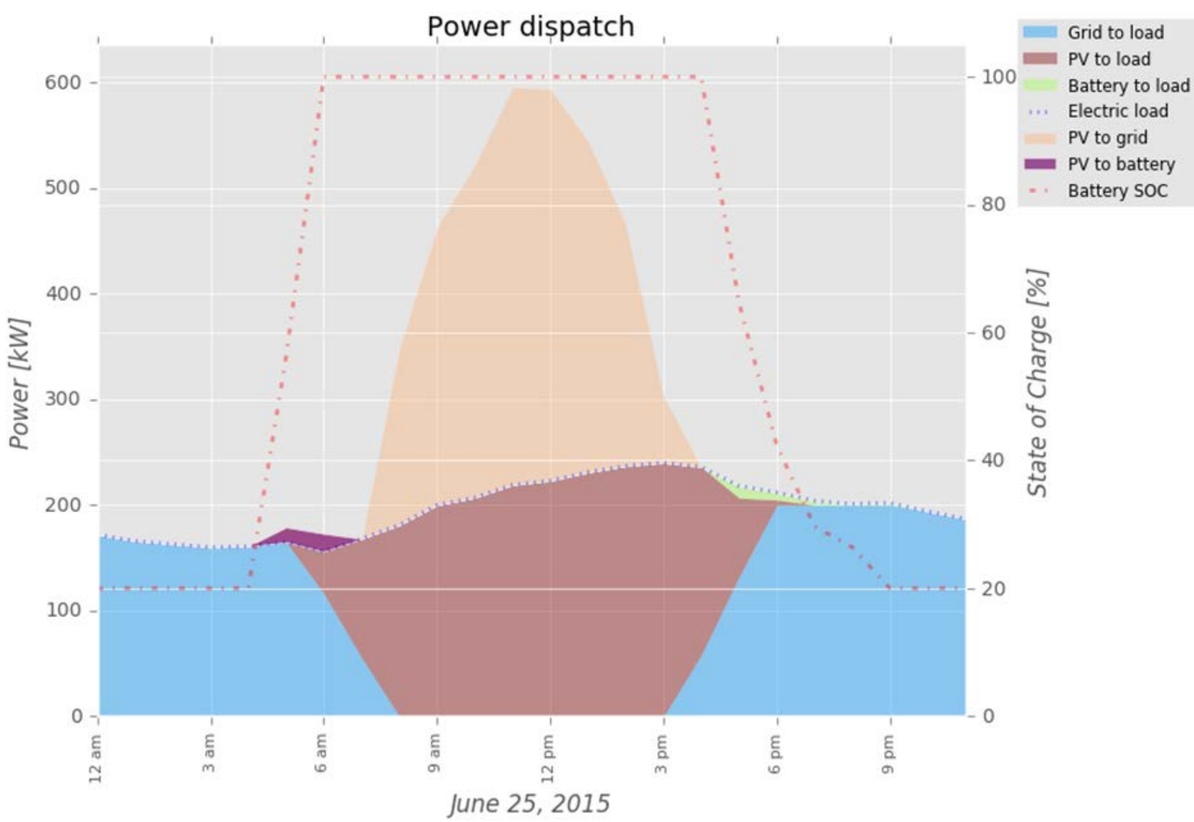

Figure 1 - Dispatch Strategy For One Day In June 2015

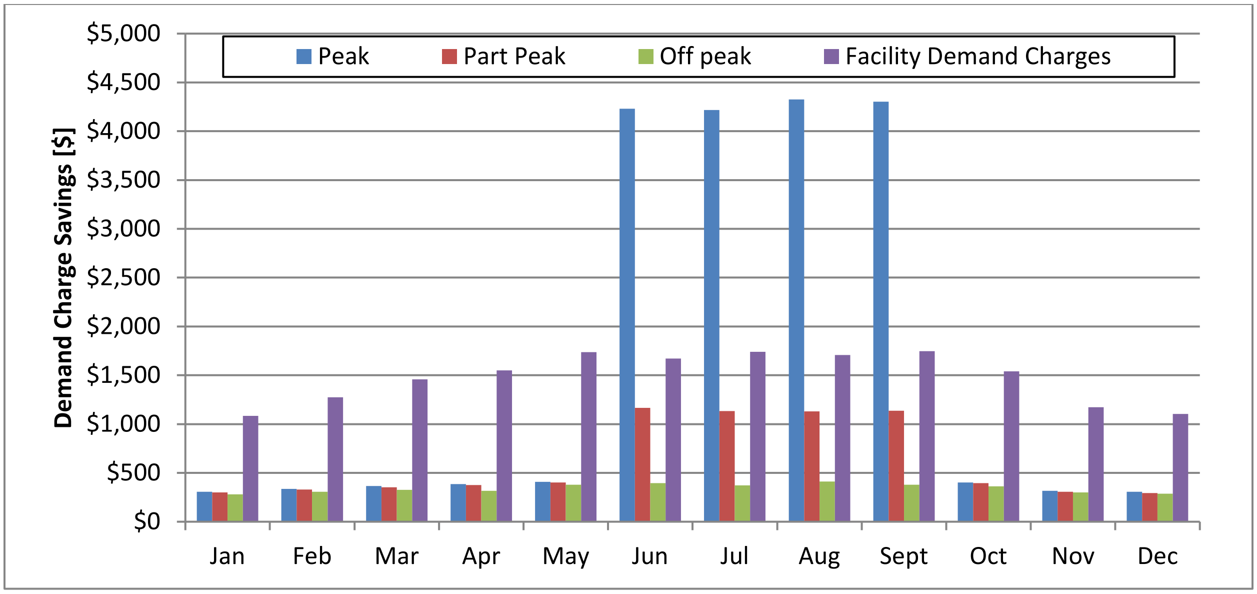

Figure 2 - Monthly Demand Charge Savings

4.2. Resilient System Optimization

4.2.1. Microgrid Configuration

Next, we evaluated microgrid configurations that could be used to integrate PV and BESS alongside existing diesel generators to increase resiliency at the site. We considered two potential microgrid configurations:

1) An independent system where the PV/BESS and generators operate independently, with PV/BESS supplying critical loads for part of the time (generally during the day) and then transferring loads to the standby generators when solar energy and battery state of charge are inadequate (generally at night). Uninterruptible power supply (UPS) equipment carries the critical loads during the transition between energy sources, and power to critical loads is undisturbed. Keeping the existing generators separate from the PV/BESS reduces the complexity of controls and communications, and reduces the overall cost. The BESS is sized to support the full critical load for one hour in this scenario. There will be cloudy periods or early morning/ late afternoon hours when PV generation will not be able to supply the full load. During those times, the BESS needs to carry the load until PV generation supplies the full load or until the battery state of charge reaches a low threshold and the load is transferred to the generators.
2) An integrated system where all energy resources operate in an integrated fashion and are centrally controlled. The PV, BESS, and diesel generation operate together to supply microgrid loads. Because the diesel generators can operate at the same time as the PV, they can carry the load during periods when the PV generation is not able to supply the full load, and so the BESS does not need to be sized for the full load in this scenario. The integration of the PV/BESS with the existing generators requires modifications to existing equipment as well as more complex controls and communications, resulting in higher installation cost.

We evaluated the capital cost and resiliency of each configuration, and selected the independent configuration because it provided the same amount of resiliency as the integrated system, but at lower cost. . Only the independent configuration is presented here.

4.2.2. RE's Impact on Resiliency

We simulated a series of grid outages from 0-14 days in length that occur at random times throughout the year to identify how long the base case system (two diesel generators with a combined size of 305 kW and fuel storage of 550 gallons) could sustain the critical load. We then simulated the same outages for the proposed RE system, where the diesel generator is augmented with the PV and BESS. In order to calculate the probability of surviving an outage, all of the simulated outages were binned into 24 hour periods. Outages between 1 and 24 hours are binned as 1 day, 24-48 hour outages are binned as 2 days, and so on. The proportion of outages that the system can sustain in each bin is reported. For purposes of this analysis, we assume diesel fuel supplies to the site have been compromised and fuel deliveries are not being made during the outage. After diesel fuel supplies are exhausted, the site could continue to operate some loads during daytime hours using just the PV/BESS when the solar resource is adequate.

We found that adding the 845-kW DC PV system and a 155 kW, 172 kWh BESS to the existing 305 kW of diesel generators extended the amount of time the site could survive an outage by 1.8 days (from 1.7 to 3.5) with 90% probability. Figure 3 shows the number of days of outage the base case (generators only, shown in red) can sustain compared to the RE case (generators plus solar and storage, shown in blue). For example, in the base case, the diesel generator can power 86% of simulated outages 1-2 days in length, but only 2% of outages 2-3 days in length. When the generator is combined with the PV and BESS, 98% of outages 2-3 days in length can be sustained.

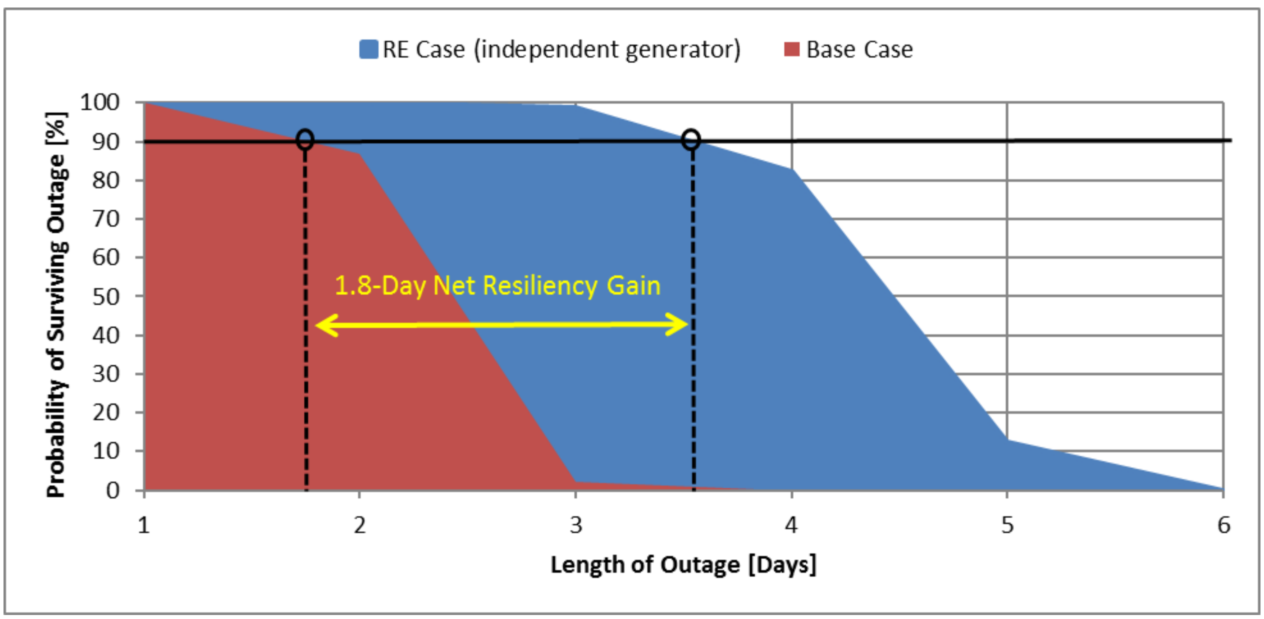

Figure 3 - The PV and BESS Extend Outage Survivability by 1.8 Days at 90% Probability

An example of the microgrid operating strategy is shown for one day in Figure 4. The generators meet the load during the night. In the morning when the sun comes up and the PV starts generating, the PV charges the BESS until the PV generation and the BESS state of charge are high enough that they can meet the load on their own without the generators. The load is then transferred to the PV/BESS system and the generators turn off. The BESS and PV power the load together from 7–8 a.m. when PV generation is not yet high enough to meet the load by itself. At 8 a.m., when PV can fully meet the load, the BESS stops discharging. Excess PV generation is used first to charge the BESS and then remaining excess is curtailed. In the evening, PV generation decreases, until the PV and BESS can no longer meet the full load. Some of the PV generation is curtailed because the BESS is already fully charged. At this point, the generators turn on again and supply the load overnight. By allowing the generators to turn off during daytime hours, the diesel fuel supply is extended, allowing the critical load to be sustained an additional 1.8 days with 90% probability.

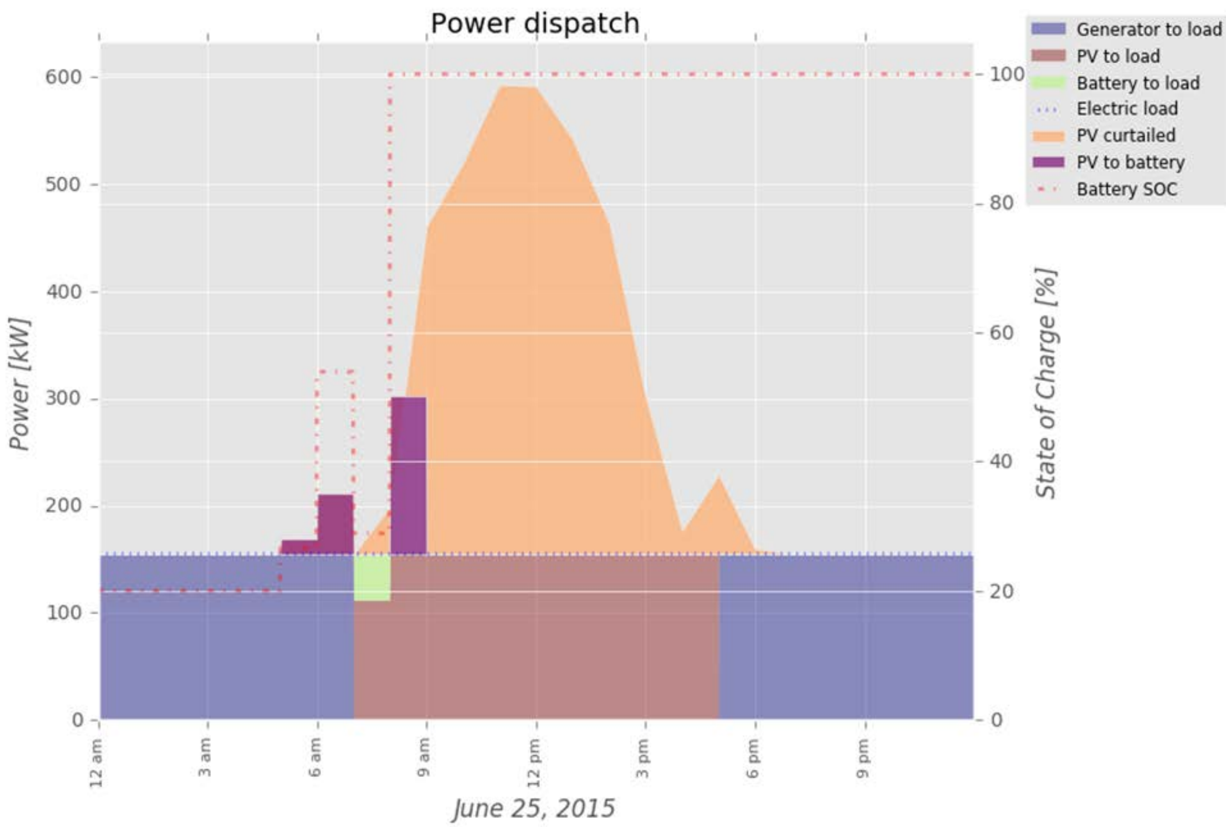

Figure 4 - The Solar Plus Storage System Reduces The Amount Of Time The Generator Is Needed

4.2.3. Microgrid Cost Estimate

We developed a rough order of magnitude cost estimate for the microgrid. SCE may have certain requirements regarding islanded operation and protection for their grid that could require a manual isolation of the microgrid from SCE's network, and/or a permissive signal may be required by the utility before the microgrid can operate. The costs associated with meeting SCE requirements for islanded operation are not included. Both configurations require a trained operator to maintain microgrid operations. We assume this person is already employed at the site, and no additional cost for this person is included.

Table 5 shows the rough order of magnitude costs. By implementing the independent system, the site saves \$104,000 over the lifecycle of the project, and extends the survivability of the site by 1.8 days to a total of 3.5 days. The inclusion of the microgrid costs reduce the total NPV of the PV/BESS system from \$519,065 to \$104,065, but this delivers the added resiliency benefits while still saving \$104,065 for the site over the analysis period.

Table 5 - Microgrid Cost Estimate

Description	Independent
PV and BESS Installation Costs BESS (before incentives) [a]	\$2,450,584
Microgrid Additional Costs [b]	\$415,000
Total PV, BESS, Microgrid Cost	\$2,865,584
Net Present Value (\$)	\$104,065
Added Resiliency (days)	1.8

[a] Includes PV, BESS, and site electrical work
[b] Includes additional rough order of magnitude costs for system integrator, system controller/software upgrades, engineering/design, testing/commissioning, and other contractor costs

5. Conclusions

The results of this analysis indicate that installation of a grid-connected 845-kW DC PV and 16 kW, 32 kWh BESS system, via third-party financing, would save the site \$50,000 per year in energy costs. Over the 25-year lifecycle, after accounting for the upfront investment, the site would save \$602,000 in present dollars. The system would provide 91% of the energy required by the site during normal grid-connected operations.

If the PV and BESS were also integrated into a microgrid, the site would gain an extra 1.8 days of resiliency as compared to the existing diesel back-up system, while saving the site \$104,000 over the 25-year lifecycle. Additionally, if diesel fuel supplies are exhausted during an outage, the site could continue to operate critical loads during daytime hours using just the PV/BESS.

There are additional benefits of an RE microgrid that were not captured in the lifecycle cost analysis. This analysis does not place an economic value on the added survivability. During a grid outage, the business-interruption cost to the site could be significant. This value is not included in the economic analysis, but should be considered in the investment decision.

The electricity load, utility rate tariff, technology installation costs, incentives, and solar resource play a critical role in determining the economic viability RE and storage, and therefore every system must be evaluated on a case-by-case basis. This paper describes a methodology to quantify the economic and resiliency benefit provided by renewable energy (RE) in a hybrid diesel-RE microgrid which may be applied to other sites interested in quantifying the energy, economic, and resiliency benefits of RE.

6. Abbreviations

BESS	battery energy storage system
DC	direct current
ITC	investment tax credit
kW	kilowatt
kWh	kilowatt-hour
MACRS	modified accelerated cost recovery system
NIST	National Institute of Standards and Technology
NREL	National Renewable Energy Laboratory
O&M	operations and maintenance
PV	photovoltaics
RE	renewable energy
REopt	Renewable Energy Optimization
SCE	Southern California Edison
SCTE	Society of Cable Telecommunications Engineers
SGIP	Self Generation Incentive Program
TMY	typical meteorological year
AP	access point
bps	bits per second
FEC	forward error correction
HFC	hybrid fiber-coax
HD	high definition
Hz	hertz
ISBE	International Society of Broadband Experts
SCTE	Society of Cable Telecommunications Engineers

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