

Battery Energy Storage Systems and PV/battery Microgrid Applications for Buildings

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ABSTRACT

As the number of installations of photovoltaic systems (PV) and lithium-ion battery energy storage systems (BESS) combined into microgrids has grown, their application in buildings has only been limited by their improving economics and the imagination of designers developing innovative applications for their use. Although BESS or PV/battery microgrids are still relatively rare and some of the systems described are still in construction, this paper, written by a team that helped develop innovative strategies for net zero energy buildings almost two decades ago, provides innovative new ideas on how PV/battery microgrids can be used in buildings today.

The paper is intended to provide building designers and owners with fresh ideas for using PV and BESS in applications beyond the traditional use for reduction of electrical energy bills. Although, each system described involves a PV/battery microgrid, these systems focus on different very applications that impact their configuration, relative size, controls and peripheral components.

The systems described in this paper include:

- PV/battery microgrids used for avoiding costly power infrastructure upgrades.
- A PV/battery microgrid intended for use during a Public Safety Power Shutoff event during California's fire season.
- A PV/battery microgrid for critical loads designed for resilience from general utility power outages.
- PV/battery microgrids intended to provide energy security.
- PV/battery microgrid concepts for disaster recovery centers.

Introduction

As the volume of lithium-ion battery production continues to ramp up (Li 2021), and the cost of lithium-ion batteries (Penisa et al. 2020) and PV (Feldman et al. 2021) fall, lower cost BESS are providing opportunities to use these technologies in buildings to not only to reduce electricity bills, but to improve system reliability, reduce the size of distribution infrastructure and reduce greenhouse gas emissions to help fight climate change. At grid scale, the average cost of new solar power is about four cents per kilowatt-hour; considerably less expensive than new coal, diesel, nuclear natural gas or fossil fuel generation and the growth of the solar market has averaged over 40% for each of the last 10 years and is expected to continue to grow (Hunter and Pelchen 2022).

The drop in the cost of lithium-ion batteries has started to pique interest in using BESS to reduce electricity bills. Although there are different rate structures for electric utilities across the United States, two major charges found on many electric utility bills are demand charges and time of use (TOU) rate charges.

Figure 1 shows the maximum demand of an example building during a typical day. Demand charges are typically for the maximum kW provided by the utility that occurs during a billing period. As an example, the demand charge that Pacific Gas and Electric (PG&E) - a California utility charges for their commercial B-19 rate for a peak that occurs between 4:00 pm to 9:00 pm during the summer season is \$58.97/kW (Kennedy 2021). It is not uncommon for demand charges to comprise 30 to 70 percent of an electricity bill (Dieziger 2000). BESS can be used in buildings to reduce this charge by storing energy in the battery when demand in the building is low and then releasing it when demand in the building peaks less power is supplied by the utility because the battery supplies it instead, reducing the peak demand (Darghouth et al. 2020).

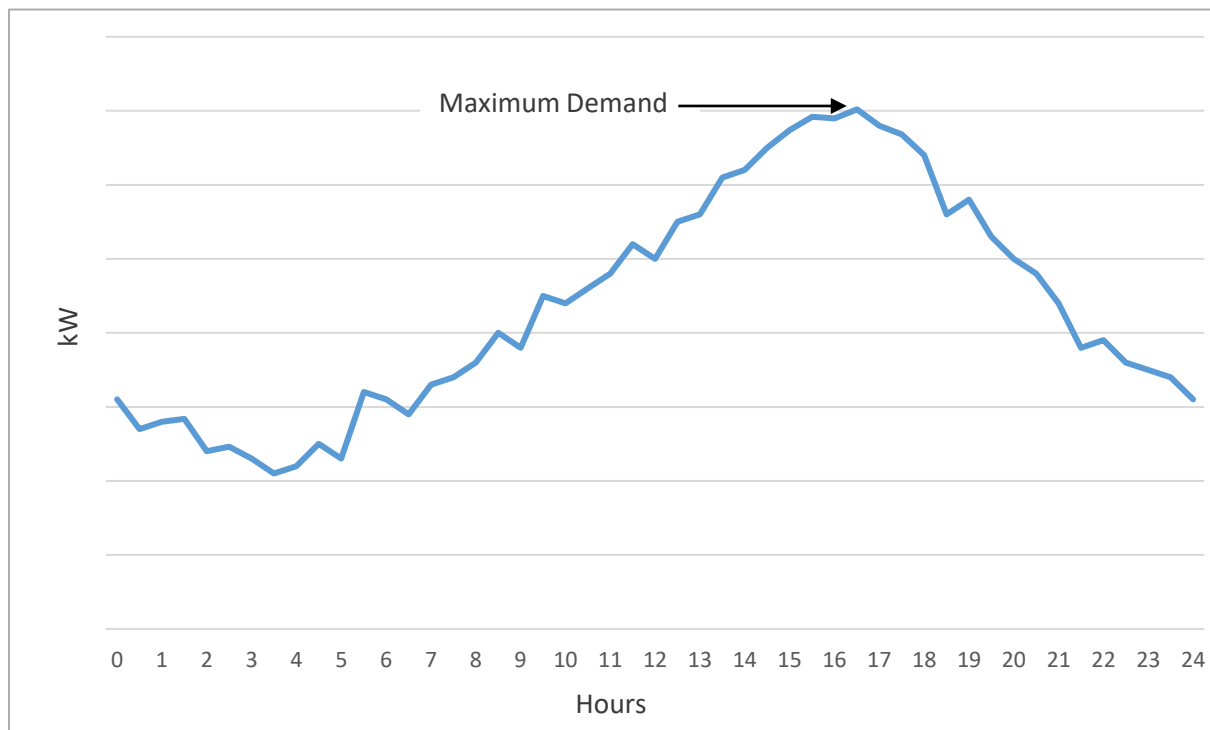


Figure 1. Example showing the maximum demand of a building through the course of a day. *Source:* IDEAs Consulting, Inc.

The other major charge on electrical bills is the energy charge. This is for the electric energy used during a billing period. In many cases, the rate varies depending on the time of day that the energy was used. These varying rates are termed “time of use” (TOU) rates. Figure 2 shows an example of the TOU rates from the same PG&E B-19 rate during the summer season. The rates vary between a peak rate of \$0.19598/kWh to an off-peak rate of \$0.07872/kWh (Kennedy 2021). BESS provide energy arbitrage to reduce this charge by simply storing energy when the rates are low and discharging it when the rates are high. This increases the amount of

low cost energy the building uses, but compensates by reducing the amount of high cost energy it uses (Renewableenergyworldcontentteam 2020).

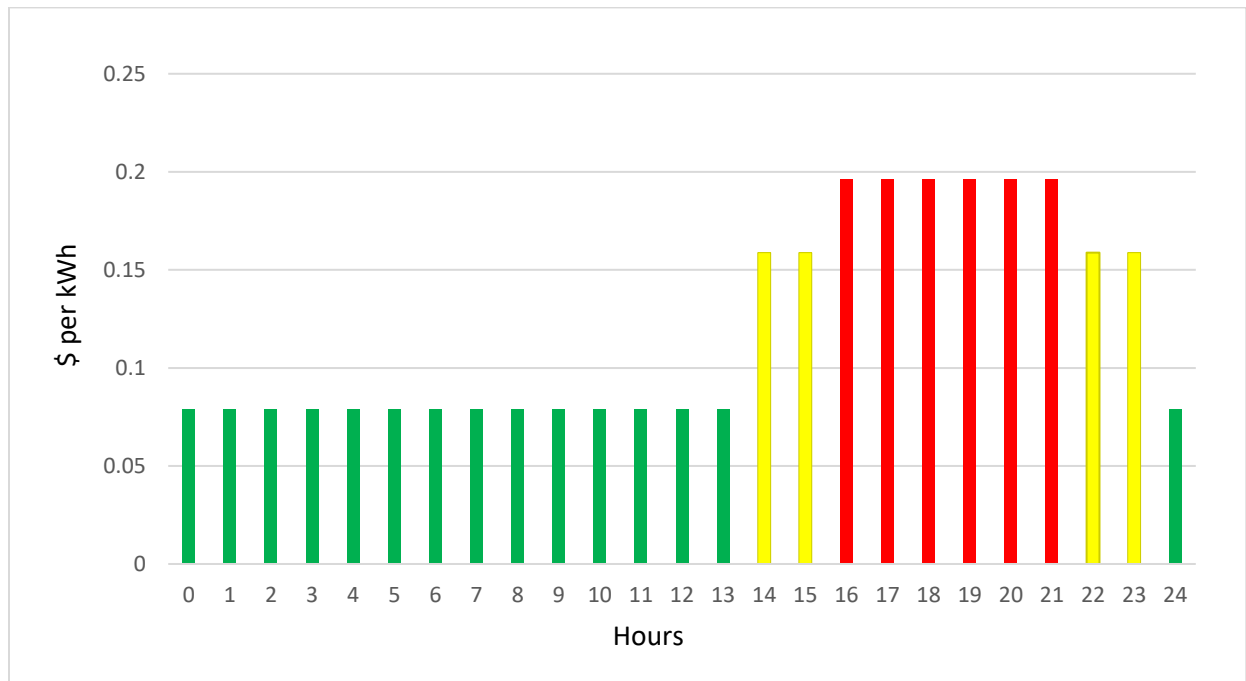


Figure 2. Example showing varying “time of use” (TOU) rates of an electric utility through the course of a day. Source: IDeAs Consulting, Inc.

Supporting these trends, President Biden issued Executive Order 14057 on December 8, 2021, encouraging Federal Agencies to facilitate new carbon pollution-free electricity generation and energy storage capacity by authorizing use of their real property assets for the development of new carbon pollution-free electricity generation and energy storage. It also announced goals that include: using 100% carbon pollution-free electricity on a net annual basis by 2030 for Federal facilities and setting a target to reach a net-zero emissions economy nationwide by 2050. (Biden 2021). This Executive Order aligns the use of BESS and PV with reducing climate change. Although electricity bill savings is a key factor in most decisions to install PV and a BESS on a site, those same systems can also provide “carbon pollution-free electricity generation and energy storage” as mentioned in Executive Order 14057, so both save money and fight climate change. In addition, once a decision is made to provide both PV and a BESS on a site there is the opportunity to combine these systems to create a PV/battery microgrid that is able to independently generate energy and provide power even when the grid is unavailable and provide additional services both to the owner and grid.

Although PV/battery microgrids are still relatively rare, their applications are limited only by the improving economics, the ability of control systems to manage the often complex operation and overlapping goals of a microgrid and the imagination of the teams designing them. This paper provides descriptions of several innovative applications of PV/battery microgrids illustrating how they can provide some of these additional services. The intent is to provide innovative ideas for how a microgrid might provide benefits beyond the traditional demand charge and energy arbitrage reduction applications and encourage designers to develop

additional applications. Although each project involved PV and BESS, the different applications required different sizes, configurations, controls and peripheral components.

Avoiding Infrastructure Upgrades

Just as utilities are starting to use BESS in conjunction with variable renewable energy sources to support their grid networks (IRENA 2019), BESS can be used within a site distribution system to deliver energy locally when power demand is high and then recharge later from the grid when demand is lower allowing the site to increase its load without needing to increase the size of its main electrical service, main switchboard or the feeders to local panels. This can save on upgrade costs when major loads need to be added to an existing site. PV/battery microgrids can go one step better by generating energy on site and storing it in the same battery until it is needed, further reducing the impact on the grid and the owner's electrical bills and distribution system.

Example

In the summer of 2015, Hawaii suffered a record breaking heatwave. In August, when the Hawaii Department of Education's (HIDOE) schools restarted, temperatures in some classrooms exceeded 90°F and in some cases students and school staff were showing signs of heat exhaustion (Simpliphi 2021). This was especially noticeable in poorly insulated portable buildings.

Because of the mild weather that Hawaii has historically enjoyed, the many public school classrooms in Hawaii are naturally ventilated, with operable windows and neither heated nor air conditioned. Electrical power distribution systems in those schools were not designed with the capacity to add air conditioning systems (A/C).

The challenge that the Hawaii Department of Education (HIDOE) faced was the high cost to convert schools to A/C. Adding A/C would have required upgrading the incoming electrical service, the main switchboard and parts of the campus electrical distribution system on most campuses. The cost to do district wide A/C was estimated at \$1.7 billion dollars, and there was also concern that the air conditioning would increase energy bills dramatically, straining the HIDOE's budget (Simpliphi 2021). In 2016 the state legislature allocated \$100 million to cool 1000 of Hawaii's classrooms, but the funding came with the stipulation that A/C implementation would not increase electricity costs (Governor of the State of Hawaii 2017).

IDeAs Consulting, Inc. worked as part of a group of building design teams that the HIDOE convened to discuss strategies for improving comfort on a budget. The solution developed was to install individual A/C units backed by PV/battery microgrids incorporating solar plus storage. The microgrids were designed to provide all of the power required to run the A/C systems. PV systems were sized to offset the energy required to run the A/C systems and batteries were used to store excess PV energy for later use if the A/C system did not need it immediately or augment the PV if the A/C system required additional energy. These microgrids allowed the HIDOE to provide A/C with practically no impact on the campus electrical distribution systems, main switchboard and incoming service since both the A/C and energy to run it was provided adjacent to the classrooms.

In the unlikely event that a PV array did not generate enough power to run both the A/C and keep the associated microgrid battery charged, a timer circuit was used as a back up to

recharge the batteries at night when school was not in session and the demand on the campus electrical system at its lowest, again avoiding the need to upgrade any existing campus power distribution systems.

Benefits

Electrical system upgrade avoidance. This novel approach allowed the HIDOE to provide air conditioning to their overheated classrooms, without impacting the size of their campus's existing electrical distribution systems. By avoiding costly electrical system upgrades, the capital cost of implementing these microgrid systems was kept substantially lower than the cost would have been to install traditional central A/C systems and upgrade the campus electrical distribution systems. To date, over 1,200 classrooms have been retrofitted using PV/battery microgrids A/C and the HIDOE has also reduced their energy costs (Simpliphi 2021).

Environmental benefits. Despite adding air conditioning to over 1200 classrooms, no net additional power is required from Hawaii's utility companies to run these systems. The Energy Information Administration estimates that Hawaii uses fossil fuels for generating over 77% of its electricity (Simon 2022), so students and teachers benefitted from improved classroom conditions without increasing the use of fossil fuel.

Other Applications. This concept is one of several strategies being studied in California where thousands of existing buildings need to be converted from dual fuel (natural gas/electric) to all-electric to meet California's carbon emission reduction goals. Similar to the HIDOE, in many cases, existing electrical infrastructure is inadequate to provide power to the electrical equipment that needs to be added such as induction cooktops, heat pump water heaters and electric dryers in residences. One potential solution is to use BESS as described above to provide additional energy to offset increases in demand and allow a homeowner to upgrade to an all-electric home without having to upgrade the existing utility service. Also, if installed with PV similar to the HIDOE example the system could offset increased demand and increased energy bills.

Planned Utility Fire Safety Shutdowns

California, Oregon, Washington, and other western states are experiencing an increase in wildfire risk and a longer wildfire season (PG&E 2022). Heat, drought conditions and high winds can cause energized lines to spark or sag or tree branches to contact the lines and start a wildfire. In November of 2018, California experienced their deadliest wildfire in history, known as the Camp Fire which killed 85 people. At \$16.65 billion, it was the costliest natural disaster in the world in 2018 and destroyed 18,804 buildings (Mann 2021). It was caused by sparking utility power lines which was blamed on poor maintenance and caused PG&E the utility company responsible for the faulty power line to file for bankruptcy (Romo 2020).

When those weather conditions occur, utilities now turn off power to reduce the risk of wildfires. These events are called a Public Safety Power Shutoff (PSPS) (PG&E 2022). During a PSPS event, utility companies proactively disconnect power based on expected or actual wind conditions. More states are starting to adopt similar safety power shut offs due to wildfire risk. California has seen an increasing number of PSPS events as utility companies try to reduce the risk of forest fires caused by their power lines. From 2013-2016, there was an average of just one

PSPS event per year, but in 2017 that number jumped to 5, then 7 in 2018, 15 in 2019 and 20 in 2020. Over 70% of PSPS events have occurred during September and October, the peak months of fire season and the median length of a PSPS event was 42-44 hours with 10% lasting more than 3.8 days. This has resulted in millions of dollars lost for businesses as productivity within commercial buildings is minimal or nonexistent if power is unavailable (Murphy 2021).

Key features of PSPS events are that they nearly always happen on sunny days which makes the weather almost ideal for a PV/battery microgrid, utility companies typically provide warning that a PSPS event is imminent so batteries can be fully charged when the event starts and they last much longer than a normal power outage (which averages 1½ hours). If a building has a PV/battery microgrid that includes a PV system sized to be net zero energy, coupled to a battery sized to run the building for 24 hours, this research team calculated a high performance building in Northern California could run at full output for over 72 hours during fire season and under ideal conditions even longer. A second option is to install a smaller BESS and PV system use building controls to balance stored energy plus PV production to building energy use to allow systems to continue running at partial load for the duration of a PSPS event.

In addition to responding to a PSPS event, microgrid owners can also use their BESS when there is no imminent PSPS event to capture utility bill savings by offsetting utility energy and demand charges as described in the introduction.

Example

Point Energy Innovations and IDEAs Consulting collaborated on a project within the San Francisco Bay Area for a confidential tech client that wanted to address potential PSPS events. The project consisted of two buildings totaling 300,000 sf of occupiable space with a 1,340 kW of PV system and a 2,500 kW / 5,000 kWh BESS integrated into a microgrid. The system will provide resiliency in the event of a normal power outage and electric bill savings when no PSPS event is imminent, in addition to addressing a PSPS event.

During normal operation, the system will limit its minimum charge level to 25%. This allows the system to supply power independent of the grid to the entire complex in the event of an unplanned power outage of up to 1 hour. Since the average non-PSPS utility outage in this area lasts 1½ hours, if the battery charge is below 40% when the outage occurs the system will automatically go into load shed mode to reduce energy consumption and increase the life of the battery. The expected minimum runtimes for the buildings from the battery with no load shedding are as follows:

- Battery state of charge 100%: 6 hours
- Battery state of charge 40%: 2 hours
- Battery state of charge 25%: 1 hour

The PV system is designed to provide about 60% of the annual energy use of the buildings. The amount of solar generated and energy provided by a fully charged battery was not enough to meet the 2+ day runtime desired to operate both buildings off grid during a PSPS event. Analysis was done to determine what percentage of the buildings could be kept online for the duration of a PSPS event. The analysis compared predicted hourly energy use of the buildings to the PV production and battery discharge capacity at various times throughout the fire season. A key step in the process was working closely with the building owner to match the

system capabilities with desired outcomes and prioritize which systems would be backed by the microgrid, then designing the electrical and mechanical equipment control infrastructure so that the systems could shed loads to produce desired results by providing the ability to reduce the building's energy usage to extend battery life. After understanding the capabilities and constraints of the microgrid, the owner opted for a system that would use the BESS to reduce utility bills, keep both buildings operational for the duration of an unplanned power outage and keep half of one of the two buildings operational during a multiday PSPS event.

Having a control system that can manage building energy usage is crucial for a microgrid if the intent is to outlast a PSPS event. The control system monitors building energy usage, battery state of charge, and anticipated PV generation and automatically makes adjustments to prolong system runtimes.

The analysis concluded that the microgrid system can keep 25% of the occupiable area or approximately one floor operational for the duration of a typical multiday PSPS event during fire season. Figure 3 shows a calculation for energy performance of the microgrid system including the building loads, the PV energy generation and the amount of battery storage available. Understanding the interplay of these three key factors and developing strategies to adjust the building energy usage is key to understanding whether a microgrid can outlast a PSPS event.

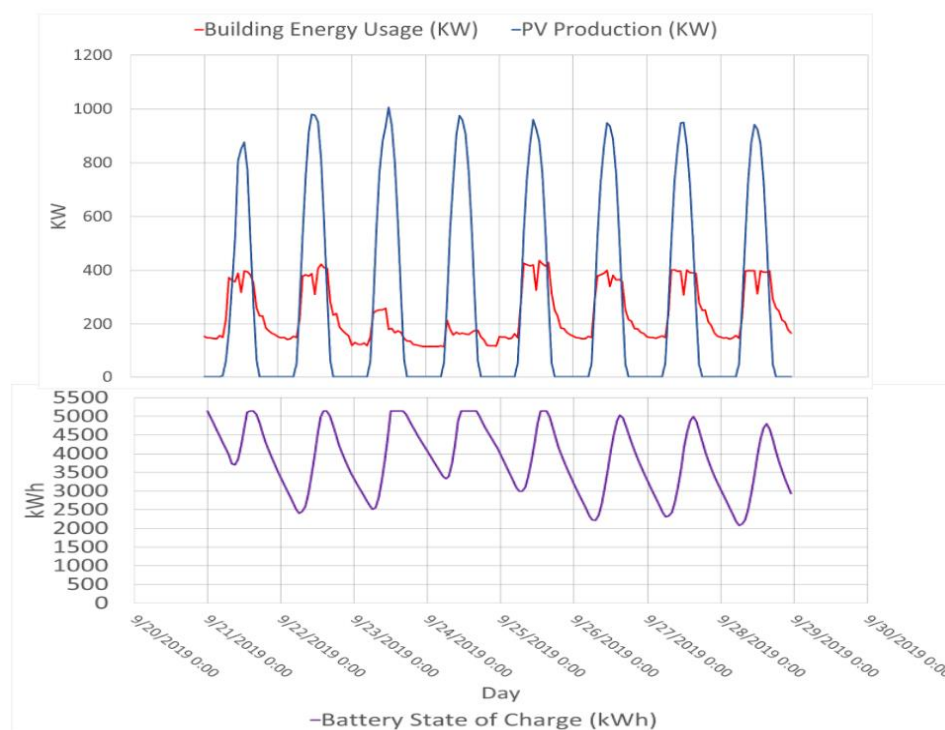


Figure 3 Modelled operation of building energy use, PV production and battery state of charge of a building in microgrid mode. Source: Point Energy Innovations

Benefits

Resilience. PV/battery microgrid can island and provide standby power both for unplanned outages and during a multiday PSPS event. Taking advantage of the fact that PSPS events occur on sunny days, allowed the project team to increase the run time of the system, so occupants can

continue to use the facility without the need for a standby diesel generator. One major tech company estimates profits per person at \$300/person/hour, so a two day PSPS shutdown of a facility that houses 1000 employees can potentially cause a loss of about \$4.8M.

Cost savings in normal operation. Since utility companies provide warning prior to PSPS events, there is time to fully charge the battery prior to an event, allowing the owner to use the system to provide typical financial benefits through reduced demand charges and energy arbitrage, similar to a typical BESS systems when no PSPS events are imminent.

Standby Power for Non Emergency Critical Loads in lieu of Generators

Although generators are normally used for backup power, building owners are increasingly investigating PV/battery microgrids for standby power. PV/battery microgrids offer key advantages in standby power applications. For example during sunny weather, PV/battery microgrids can potentially extend backup power duration for days, whereas diesel generators depend on fuel being delivered to the site. Microgrids also have few moving parts and are not subject to the mechanical stresses and high temperatures that internal combustion engines see, resulting in less downtime and significantly lower maintenance and operation costs.

The PV system for this application was sized to offset 100% of the annual energy usage of the loads supported by the microgrid. The battery systems are sized to provide a minimum runtime (defined by the owner of the project) so in the worst case load and solar production conditions, the system is able to provide power in the event of the perfect storm of low solar energy availability and a power outage. As shown in figure 4, average PV energy production in the fall, spring and summer seasons are significantly higher than winter, so excess energy production and battery system capacity during those seasons can be used for functions such as electricity bill reduction.

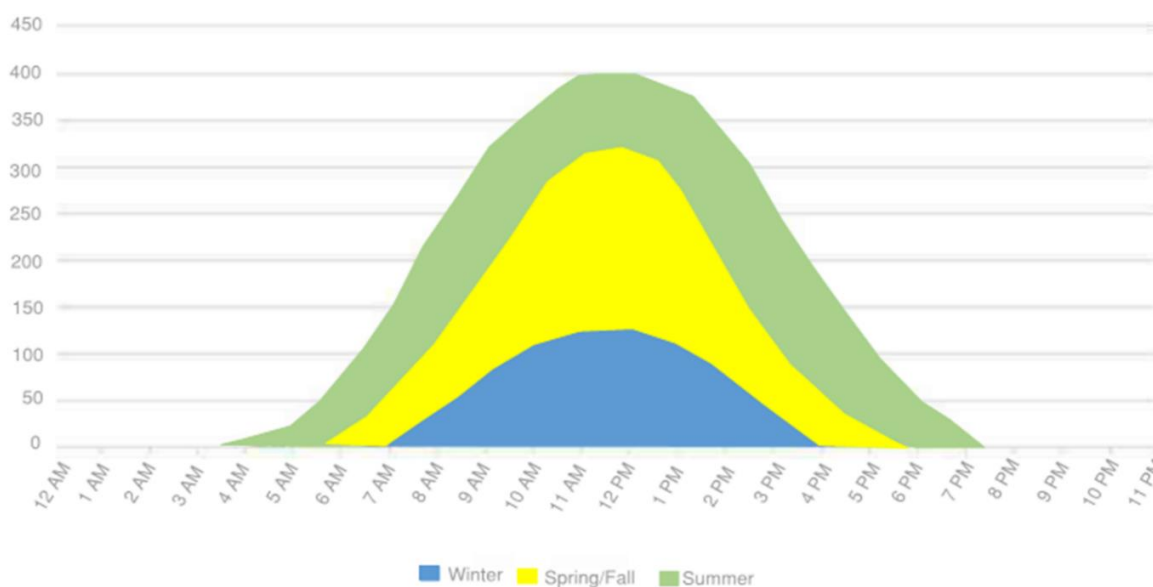


Figure 4 Typical PV system average daily power generation calculation for different seasons. *Source:* IDEAs Consulting.

Standby power from PV/battery microgrids require a “critical load” panel within the electrical system for the loads connected to the microgrid. This panel needs to have the ability to island itself from the utility grid either through an islanding contactor or an electronically controlled main circuit breaker interfaced to the microgrid control system, so modifications to the distribution system are required. It also needs to have the PV and BESS connected directly to it. If the system is designed to support the entire site, the main switchboard needs to be islandable using an electronically controllable main circuit breaker.

Example

A school district wanted to investigate using a PV/battery microgrid to provide standby power to the entire campus for all four of its schools. The district required at least 24 hours of backup power. Based on utility data, Table 1 shows the PV/battery microgrid sizes the team selected.

Table 1. School District Microgrid Sizes

Site	PV Array Size	Battery Energy Storage System
A Middle School	400 kW	500 kW / 750 kWh
B Elementary School	218 kW	350 kW / 500 kWh
C Elementary School	245 kW	350 kW / 500 kWh
D Elementary School	204 kW	275 kW / 375 kWh

Figure 5 compares the payback of PV/battery microgrid to a diesel generator at one of the campuses. The simple payback was estimated to be less than 6 years, plus the microgrid provided additional opportunities for demand charge reduction savings for portions of the year.

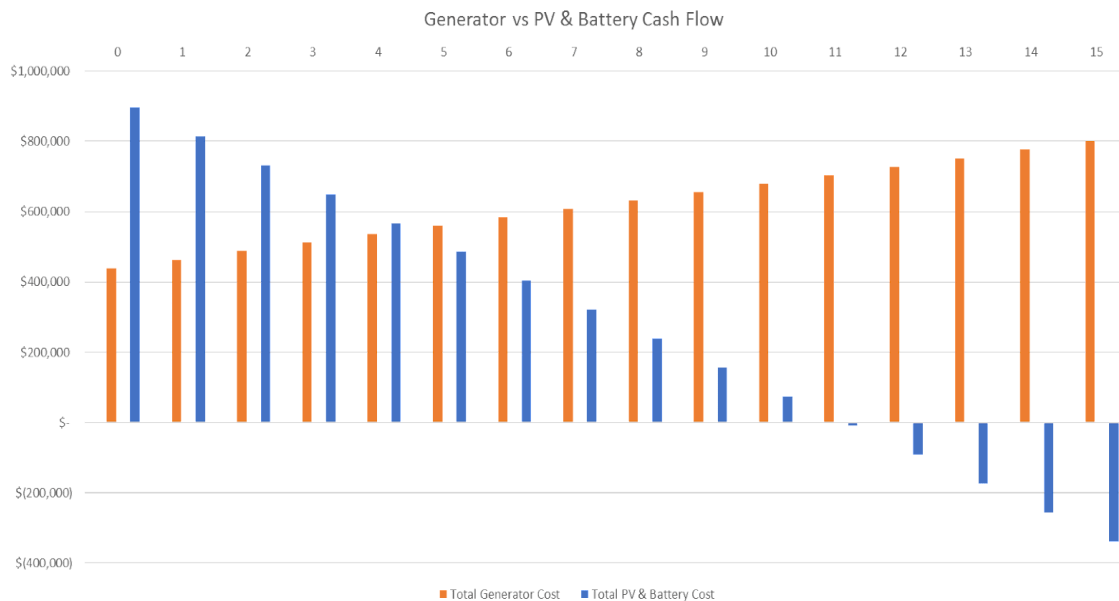


Figure 5 Sample diesel generator vs. PV & battery system simple payback calculation. *Source:* IDeAs Consulting

The PV/battery microgrids on the four campuses were able to provide both the required runtime for the campuses and up to \$308,000 in utility bill savings each year. The school district would also be eligible for up to \$637,500 in Self Generation Incentive Program (SGIP) incentives from the State of California for the PV and Battery systems.

Benefits

Elimination of diesel fuel combustion. Increasingly schools in California are looking to eliminate the use of diesel engines in the form of backup generators and school buses, over growing concern about air pollution and greenhouse gas emissions. The PV/battery microgrids use solar energy as their fuel source making their operation are emissions free. Microgrids are also practically noise free, while generators contribute to noise pollution which is problematic on a school campus and are often placed in acoustical enclosures adding cost to the system.

PV increases required available energy. The battery was sized so that when 100% charged, the microgrid is capable of providing 24 hours of backup power even in winter. Since the school district was only targeting 24 hours of standby power, further analysis was done to estimate the runtime and amount of battery capacity that could be diverted for other uses. With additional power from the PV system the estimated runtimes for one campus were as follows:

- Winter: up to 24 hours
- Spring: 3.5 days to over a month
- Summer: over a month
- Fall: 3 days to over a month

Table 2 shows excess battery capacity available each month. The microgrid is able to divert some of the energy storage for demand charge reduction and energy arbitrage functions from March through October while still providing 24 hours of standby power, an unintended but welcome consequence.

Table 2. Microgrid battery capacity available for demand charge reduction of energy arbitrage

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Battery Capacity	0%	0%	50%	66%	66%	66%	66%	66%	60%	50%	0%	0%

Lower operating costs. Once installed, diesel generators require regular maintenance and need to be exercised monthly to ensure reliability, burning fossil fuel and using maintenance staff time. In addition, the cost of diesel fuel and natural gas is expected to continue to rise and there is a growing movement to ban the use of natural gas and internal combustion engines in California, which may in the long term drive the cost of natural gas or diesel up further or reduce the availability of either as a fuel source. Once installed, PV/battery microgrids get their energy

from the sun and have few moving parts, so operation and maintenance costs are lower and systems more reliable.

Energy Security

Energy security is a critical concern to many organizations including government bodies, utilities and critical service providers. Energy security has long been a concern in United States military operations. (Warner and Singer 2016). In addition, Navigant Research estimates that the military could save \$8-\$20 billion over the next 20 years by shifting from a reliance on backup diesel generators to large-scale microgrids (Wood 2019). A paper titled “More Fight - Less Fuel” published in 2008 found that critical National Security and Homeland Defense missions were at an unacceptably high risk of extended outage from failure of the grid. It recommended that the US Department of Defense (DoD) “reduce the risk to critical missions at fixed installations from loss of commercial power and other critical national infrastructure” and “invest in energy efficient and alternative energy technologies to a level commensurate with their operational and financial value” including “increasing investments in energy storage technologies to enable storage of electricity generated by renewable sources at forward operating bases” (Defense Science Board 2008).

The DoD’s mission is to provide the military forces needed to deter war and protect the security of the United States. To successfully execute this mission, the US Military Services must have the energy, land, air, and water resources necessary to train and operate, today and in the future. The DoD implements energy resilience and energy security measures in support of advancing readiness and mission assurance objectives. Aligning facility energy requirements directly to mission and readiness requirements, agnostic of specific technologies or practices, is the DoD’s key opportunity to improve energy resilience (United States Department of Defense 2020). Microgrids can provide a critical backup power source and can function independently from the grid, enhancing the physical security and cybersecurity of US military bases (Van Beek 2022).

The focus of microgrids installed for the purpose of energy security is to provide energy with high reliability, including in the event of equipment failure, natural disaster or an attack on the energy supply.

To achieve this the DOD historically relied on stand-alone generators with short-term fuel stockpiles to provide emergency backup power for individual buildings housing critical loads. For the highest priority loads, two stand-alone backup generators could be deployed to provide a backup to the backup (Marqusee 2020). However, Figure 6 shows the sheer number of independent generator systems on a large military base increases the chance of a failure of a backup power supply to a critical load somewhere in the system. A small base was defined as having two buildings and a large base was defined as having or more 40 buildings with high priority loads. Building-tied systems had two generators per building.

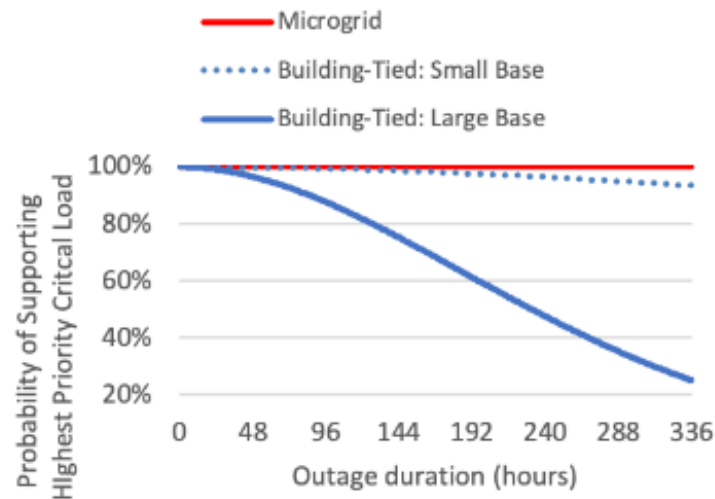


Figure 6. Probability of building-tied generators meeting 25% of highest priority critical load for small and large bases compared to a microgrid. *Source:* Marqusee 2020

Key features of microgrids recently installed at military facilities include: minimizing life cycle external energy needs and fuel costs, providing redundant sources of energy, providing onsite energy sources, ensuring high reliability, reducing the use of greenhouse gas producing fossil fuels and reducing vulnerability to sabotage of energy sources.

Examples

The US military has installed a number of microgrids featuring energy storage, islanding capabilities, renewable energy, and multiple onsite power sources to provide enhanced energy security over traditional individual backup diesel generators on a number of its bases. Two examples include:

Otis Air National Guard Base, Cape Cod, MA. This military base contains an islandable microgrid incorporating a 1.5 MW wind turbine, a 1.6 MW diesel back-up generator, a 1.6 MW/1.2 MWh lead-acid BESS. It includes enough wind power and battery storage to meet 100% of the facility's power needs 24x7 and is also backed by redundant diesel generators. In addition to supplying the Air Base, this system benefits the community by taking part in the utility's demand response program (Wood 2019).

US Marine Corps Recruit Depot, Parris Island, SC, features a microgrid to provide power on the 121 building, 8000-acre base with that trains 20,000 recruits per year. In addition to energy efficiency upgrades, the system deploys a natural gas fueled 3.5 MW combined heat and power plant, 6.7 MW of photovoltaics and a 4 MW/8.1MWh lithium ion BESS all controlled by an automated high speed, intelligent microgrid control system, capable of fast load shedding and

dispatch of generators, BESS, and PV to optimize both on and off grid operation. The base is expected to reduce utility energy demand by 75% and save \$6.9M annually (Ameresco 2020).

Benefits

Increased reliability. Both military bases have added hybrid microgrid systems, incorporating an additional layer of power supply to increase system reliability, which is a critical component of their national defense mission. Power can now be supplied by the local utility, a PV/battery microgrid (Parris Island) or wind turbine/battery microgrid (Otis Air Base) or a fossil fuel based generation source. They are able to run in an islanded microgrid mode and only use traditional standby generators as backup to the microgrid adding an additional layer of reliability.

Reduced carbon emissions. Both military bases also incorporate significant amounts of onsite or adjacent renewable energy sources, reducing greenhouse gas emissions. Otis Air Base runs on 100% renewable energy with diesel generation purely as a back up and Parris Island has an islandable microgrid with significant amounts of PV generation. Both use energy storage to increase energy security.

Economic Benefits. Although not designed primarily for cost savings, both military bases expect to save money through their use of renewable energy/battery microgrids. Otis Air Base expects a payback of five years or less on its microgrid. Parris Island is expected to save \$6.9M annually.

Natural Disaster Resilience

As PV/battery microgrids have become more common, community service providers such as counties, cities, local utilities and emergency service providers are considering incorporating PV/battery microgrids into building electrical systems to provide resilience in the event of a natural disaster. Natural disasters can come in many forms including snow or ice storms, tornados, earthquakes, wildfires, floods, heatwaves, hurricanes, a tidal wave or even volcanic eruptions, so the design criteria for buildings intended to support operations during a natural disaster can vary significantly depending on the location and type of disaster anticipated.

This team has developed concept designs for multiple projects considering natural disaster recovery including earthquakes, flooding, wildfire, wind, and snow and ice storms. Each disaster scenario comes with its own set of unique challenges, however some concerns include:

- Loss of site or even regional utility services including electricity, natural gas, water and/or sewage potentially for multiple days.
- Inability to get fuel deliveries fuel to run standby generators.
- Extreme weather such as heat, cold, wind, rain, snow, hail or sleet.
- Hazardous air quality or ash fallout.
- Damage to on site infrastructure.
- Requirement for temporary onsite command centers for emergency services personnel housing or housing for displaced residents.
- Fresh water and food preparation capabilities.
- Sanitary facilities such as showers and toilets.

Although many of those concerns go well beyond BESS and PV/battery microgrids, having the capability to provide energy independent of local utilities is a unifying factor. This calls for an independent onsite energy source and preferably multiple sources similar to the energy security microgrids mentioned above. In all cases, the minimum level of redundancy was the utility, a PV/battery microgrid, and some kind redundant generation capacity.

In the lowest budget case, a generator connection box and a manual transfer switch was provided so the owner could procure and connect a mobile diesel generator in the event of a power outage that ran so long that the microgrid was running out of power. This saved the owner from having to own, maintain, fuel and exercise a diesel generator, but creates a risk sourcing a generator when needed. In this case, the city involved plans to contract with a local mobile generator supplier to get top priority as an emergency services provider in the event of a disaster.

A more reliable scenario is have keep a traditional a backup diesel generator on site and in one case currently in design, a dual fuel natural gas/diesel generator is part of the design so if the utility grid fails, the PV/battery microgrid runs low on charge and roads become impassable for diesel delivery, there is still the possibility to use natural gas as the fuel source.

Benefits

Source of energy of last resort. Similar to a energy security microgrid, in a disaster recover scenario, ensuring a source of power is a critical first step and trumps greenhouse gas emissions or running costs. Using a PV/battery microgrid as a component of the power system provides a source of energy that may be the only one available when all others fail. PV/battery microgrids are the only solution that have the potential to provide ongoing power to a facility if all utilities fail and fuel deliveries are impossible.

Conclusion

This paper outlines five different applications for PV/battery microgrids that go beyond the basic commercial PV and battery system meant to reduce electric bills. As can be seen from the descriptions, they provide many different specialized functions for their owners, from providing a source of reliable power to avoid upgrading undersized electrical systems. They also provide the additional benefit of allowing buildings to shift the times when they use energy from the grid. This can result in less net carbon emissions and as the world moves to combat climate change by minimizing greenhouse gas emissions and make energy supplies to greenhouse gas free, renewable sources such as wind and solar energy and energy storage will play key roles. Increasingly, utilities and their customers will need to match the demand for energy for buildings and transportation to the availability of clean renewable energy. This major change is already taking place and is impacting government policies, utility investment and rates, energy codes and equipment manufacturing and sales.

Building designers can help accelerate this move to a carbon free economy by incorporating PV, BESS and PV/battery microgrids into their designs to help drive acceptance of these technologies, match renewably generated carbon free energy with the energy needs of buildings and lower the cost of these systems by making them common place.

References

Ameresco, 2020 “Project Highlight U.S. Marine Corps Recruit Depot Parris Island, SC” CS-6273-00-2/20-07

Biden, J. 2021. “Executive Order on Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability”. *Presidential Actions*. www.whitehouse.gov/briefing-room/presidential-actions/2021/12/08/executive-order-on-catalyzing-clean-energy-industries-and-jobs-through-federal-sustainability/

Darghouth, N., G. Barbose, J. Zuboy, P. Gagnon, A. Mills, and L. Bird. 2020 “Demand charge savings from solar PV and energy storage” *Energy Policy* 146 (2020) 111766
reader.elsevier.com/reader/sd/pii/S0301421520304882?token=D41E3D7F94BDD59249B3CDD5FD7C031D66AD006DAF7A4692E307AFB50E0B09E958AB48BDDC65C144ED8D8A7E7B0E55F2&originRegion=us-east-1&originCreation=20220701224655

Defense Science Board, 2008 “Report of the Defense Science Board Task Force on DoD Energy Strategy “More Fight – Less Fuel”, *Office of the Under Secretary of Defense, For Acquisition, Technology, and Logistics* apps.dtic.mil/sti/pdfs/ADA477619.pdf

Dieziger, D., 2020 “Saving Money by Understanding Demand Charges on Your Electric Bill” *United States Department of Agriculture T&D Publications, Engineering Tech Tips* 7100 Engineering 0071-2373-MTDC www.fs.fed.us/t-d/pubs/htmlpubs/htm00712373/index.htm#:~:text=Demand%E2%80%93related%20charges%20usually%20represent,most%20commercial%20customers'%20electric%20bills.

Feldman, D., V. Ramasamy, R. Fu, A. Ramdas, J. Desai, and R. Margolis. 2021. “U.S. Solar Photovoltaic System Cost Benchmark: Q1 2020.” Golden, CO: *National Renewable Energy Laboratory*. NREL/TP-6A20-77324. www.nrel.gov/docs/fy21osti/77324.pdf

Governor of the State of Hawaii, 2017 “DOE On Track to Reach Goal of Cooling 1000 Classrooms”, Capitol Connection, Featured. governor.hawaii.gov/featured/doe-on-track-to-reach-goal-of-cooling-1000-classrooms/

Hunter, S., and L. Pelchen. 2022. “Here Are Some Awesome Facts About Solar Energy That May Surprise You” *Forbes Advisor*. www.forbes.com/advisor/home-improvement/solar-energy-facts/

IRENA, 2019 “Innovation landscape brief: Utility-scale batteries”, *International Renewable Energy Agency*, Abu Dhabi. www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Utility-scale-batteries_2019.pdf

Kennedy, R., 2021 “Electric Schedule B19, Medium General Demand-Metered TOU Service” *Pacific Gas and Electric Company Cal. P.U.C. Sheet No. 49020-E* www.pge.com/tariffs/assets/pdf/tariffbook/ELEC_SCHEDS_B-19.pdf

Li, D. 2021. Electric Vehicles to Drive Massive Battery Demand: *BNEF Chart* news.bloomberglaw.com/environment-and-energy/electric-vehicles-to-drive-massive-battery-demand-bnef-chart

Mann, R., 2021 “In 2018, this fire was the most expensive natural disaster in the world”, *The Weather Network*. www.theweathernetwork.com/ca/news/article/tdiwh-november-21-2018-california-camp-fire

Marqusee, J., 2020 “Emergency Diesel Generator Backup Power Systems for Military Bases”, *NREL ESTCP ESNREL/FS-5C00-76600* www.nrel.gov/docs/fy20osti/76600.pdf

Murphy, P., 2021 “Preventing Wildfires with Power Outages: the Growing Impacts of California’s Public Safety Power Shutoffs”, *PSE Blog*, Energy and Environment Program, March 19, 2021 www.psehealthyenergy.org/news/blog/preventing-wildfires-with-power-outages-2/#ref

Penisa, X., M. Castro, J. Pascasio, E. Esparcia Jr., O. Schmidt, and J. Ocon. 2020. "Projecting the Price of Lithium-Ion NMC Battery Packs Using a Multifactor Learning Curve Model" *Energies* 13, no. 20: 5276. doi.org/10.3390/en13205276

PG&E, 2022 “Why PSPS Events Occur”. PG&E. www.pge.com/en_US/residential/outages/public-safety-power-shutoff/why-psps-events-occur.page

Renewableenergyworldcontentteam. 2020. “What Time Of Use rate makes sense for residential energy arbitrage?” *Renewable Energy World*. www.renewableenergyworld.com/storage/what-time-of-use-rate-makes-sense-for-residential-energy-arbitrage/#gref

Simon, J., 2022 “Climate: Biden's climate agenda is stalled in Congress. In Hawaii, one key part is going ahead”. *NPR Weekend Edition*, NPR KQED, January 15, 2022 www.npr.org/2022/01/15/1066578157/bidens-climate-agenda-is-stalled-in-congress-in-hawaii-one-key-part-is-going-ahe

United States Department of Defense, 2020 “Department of Defense Sustainability Report & Implementation Plan 2020” www.sustainability.gov/pdfs/dod-2020-sustainability-plan.pdf

Warner, J., P. Singer, 2016 “Fueling the “Balance” A Defense Energy Strategy Primer”, *Foreign Policy at Brookings* www.brookings.edu/wp-content/uploads/2016/06/08_defense_strategy_singer.pdf

Wood, E., 2019 “Military Microgrids: Four Examples of Innovation”, *Microgrid Knowledge* microgridknowledge.com/military-microgrids-four-examples/