EVALUATING FACILITY ENERGY EFFICIENCY AND RESILIENCE OPPORTUNITIES WITH FEDS AND MCOR

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ABSTRACT

The threat of natural or human-caused disruptions to the electrical grid has made energy resilience increasingly important for critical building infrastructure. Energy efficiency can increase resilience by reducing critical loads and lowering the cost of supplying alternative power. This paper highlights two tools that are well-suited for analyzing building energy efficiency and resilience opportunities and presents a case study for their combined application. The Facility Energy Decision System (FEDS) and Microgrid Component Optimization for Resilience (MCOR) tools can be used together to simulate building systems, identify energy efficiency measures, and evaluate resilience options for powering a site during an outage.

INTRODUCTION

The importance of energy resilience for critical building infrastructure has become increasingly recognized in recent years in response to actual and potential disruptions to energy supplies and the electrical grid from threats ranging from natural disasters and extreme weather events to malicious human activities (Ton and Wang 2015). Energy efficiency can reduce the magnitude of critical loads and therefore lower the cost of supplying alternative power. Greater efficiency also allows available energy supplies to last longer with suitable storage. As such, improving the energy efficiency of a building or campus should be considered a key step for cost-effective resilience planning.

In anticipation of emerging challenges and threats, government agencies are exploring viable options to identify and secure critical loads (Van Broekhoven et al. 2013). They are developing energy resilience plans to allow sites to withstand, respond to, and recover from utility disruptions while ensuring mission continuity.

Pacific Northwest National Laboratory (PNNL) has developed numerous analysis tools and processes to support agencies in meeting their goals related to energy use, sustainability, security, and other needs. Together, two of these tools have demonstrated capabilities for assisting agencies in improving facility energy efficiency and site resilience. The Facility Energy Decision System (FEDS), an established energy efficiency analysis tool, and the Microgrid Component Optimization for Resilience (MCOR), a recently developed microgrid planning tool are discussed in the context of identifying cost-effective energy efficiency measures (EEMs) and evaluating microgrid configurations suitable for meeting the resilience requirements of a building or campus. The Army Reserve Installation Management Directorate has supported PNNL in developing and applying these tools to assist with energy and water resilience assessments. A case study highlighting the application of the capabilities to an Army Reserve site is presented to illustrate how these analysis tools can be coupled to maximize impact and inform a more cost-effective resilience solution. The tools are not intended for the detailed design of such solutions, nor to solve or minimize the sometimes complex development, deployment, and operational challenges associated with the implementation of such projects, but rather to help guide the identification and evaluation of suitable resource and technology options for a given site.

BUILDING ENERGY EFFICIENCY AND LOAD SIMULATION

Facility Energy Decision System

FEDS is a user-friendly, Windows-based building energy simulation and analysis tool developed at PNNL (Dahowski, 2020). It offers energy and economic modeling and decision capabilities suited to both single buildings and multi-building campuses. Designed for both accuracy and ease of use, it is intended for facility energy managers, operators, and engineers to perform a variety of analyses focused on building energy use, operation, and identification of savings opportunities.

FEDS provides a combination of scalability and flexibility to meet a range of analysis goals, from high-level screening and prioritization to detailed project identification and development support. The number of required inputs is minimal, which facilitates preliminary screening assessments when data is limited and allows modelers to begin the simulation and analysis of building systems more quickly to assess potential impact before collecting more complete information. An inference engine automatically fills in more detailed input parameters which can be reviewed and overridden.

More robust ASHRAE level 2 assessments can be performed with closer attention to detail and specification of building parameters. FEDS integrates a number of features to facilitate the modeling of building and campus energy use, evaluate EEMs that maximize life-cycle savings, and report investment costs and savings potential. FEDS has proven to be a useful tool to support government agencies (e.g., Fisher 2014, Woodward and Dahowski, 2017) as well private organizations in pursuing their energy savings and resilience goals. Experience in modeling thousands of sites and buildings has demonstrated a suitable accuracy of FEDS models for these analyses, typically within ten percent of metered energy use for preliminary models or screening assessments, and within a few percent for more detailed models with reasonable quality assurance (QA) and calibration.

Analysis Approach

With flexible input requirements, users can quickly develop building system models for a broad range of building types, locations, use types, occupancies, construction characteristics, and energy systems. FEDS' simulation engine calculates hourly loads and energy use over a year based on specified weather information, covering lighting, heating, cooling, ventilation, water heating, motors, and miscellaneous equipment. Central energy plants and associated thermal distribution loops may also be defined, if present. Details on location and energy rates translate energy use into operational costs, and flexible project financing options can be evaluated.

EEM Identification

Upon developing the building model(s) and performing QA and calibration, EEMs can be evaluated automatically. FEDS contains an internal database of thousands of EEMs including building envelope improvements, lighting upgrades and controls, HVAC equipment and controls, energy efficient motors, improved water heating equipment, and water reducing devices. In addition to performance parameters, each measure includes estimated materials cost and labor hour requirements. When coupled with user-input or inferred labor rates, materials cost factors and contracting and overhead rates for the location, an estimate of total installed cost is computed for each measure. Individual project costs are evaluated against savings resulting from lower energy, demand, and maintenance expenses to determine the cost-effectiveness of each possible measure and combination of selected EEMs.

A comprehensive iterative EEM review and selection process is performed to consider each viable upgrade option. Interactive effects among systems within each building are captured, along with the impact on the cumulative peak electric billing demand for the site to accurately value net savings. As desired, users can impact the process by prioritizing which buildings to evaluate (e.g., by mission-critical function), bypassing EEMs that may not be feasible, or identifying equipment that has reached the end of its useful life and must be replaced. The resulting identified measures represent the package of improvements offering the greatest savings, on a life-cycle cost basis, to the modeled site. Reports detail the selected EEMs, with estimated project implementation costs, energy, demand, and emissions reduction, and energy, demand, and maintenance cost savings.

Load Simulation

The latest FEDS release (8.0) offers the option to output the hourly load profiles generated by the simulation. The resulting load profiles for both the baseline and post-retrofit scenarios are available, for electricity and each of the other fuels that may be used by the site. For buildings lacking reliable interval meter data, the baseline load profile from the simulation can provide a valuable representation of the existing building and site energy use throughout the year. The post-retrofit profiles allow for the understanding and review of the building and site energy loads following the implementation of the recommended EEMs.

RESILIENCE EVALUATION AND PLANNING

Microgrid Component Optimization for Resilience

While there is an increasing demand to design and deploy microgrids to meet resilience needs, most existing microgrid evaluation tools are focused on optimizing these systems to meet economic goals (e.g., Lilienthal 2004, Simpkins et al. 2014) and provide analysis on resilience as a secondary benefit if at all. Designing a system that can support critical loads during extreme weather events also requires quantifying risk and understanding how the system will perform under a large range of conditions, yet many of these tools simulate solar and wind resource availability based on typical meteorological year (TMY) data that are intended to depict weather under average conditions. Finally, existing microgrid tools are not capable of determining critical loads for a site, and this must be modeled separately.

To meet the need for resilience-focused microgrid tools, PNNL developed the MCOR tool (Newman et al. 2020) to streamline the assessment of microgrids intended specifically for resilience services. In the use case described in this paper, MCOR is used together with FEDS to calculate the critical loads for buildings on a site and evaluate microgrid configurations that can meet those loads during an outage.

The MCOR tool simulates microgrid performance under a large range of outage conditions and returns several potential system configurations that all meet a site's critical loads for a specified outage duration. These configurations can be filtered or sorted by varying constraints according to the needs of a particular site. The available generation resources for a system include photovoltaics (PV), battery storage, and diesel-powered generators. These are each sized to ensure that all load is met during an outage and provide a range in the generation resource mix to give multiple viable options with varying benefits. To ensure that load is met under a large range in potential outage conditions, the tool generates hundreds of outage scenarios using probabilistic modeling of historical weather data.

MCOR produces high-level sizing estimates for viable microgrid configurations and does not perform detailed power electronics modeling. It considers a single electrical node (bucket of energy analysis), with no constraints in the distribution system that would prevent any generation source from delivering energy to any node, and no calculated distribution losses. Transient electrical effects, such as equipment switching on and off, and details regarding instantaneous energy flexibility will need to be modeled separately for configurations that proceed to design. Finally, the tool currently models hourly time steps, although sub-hourly modeling may be added in the future.

Outage Scenarios

To create the outage scenarios, the MCOR tool uses 20 years of modeled historical solar resource and temperature data from the National Renewable Energy Laboratory's National Solar Radiation Database (NSRDB)[1] and creates a set of outage profiles that specify the hourly temperature and solar resources for an outage period, including global horizontal irradiance, direct normal irradiance, and cloud cover. Using these profiles ensures that the microgrid operation under an emergency situation is simulated under a large range of conditions (including the time an outage begins, the load that corresponds with that time, and variability in weather over seasons as well as years), enabling a system designer to have a better understanding of risk and more confidence in the system's ability to meet load during an outage.

For each outage scenario, the MCOR tool calculates the AC power produced from a 1kW PV array using the pvlib-python library[2], a publicly available and well-documented library developed at Sandia National Laboratories as part of the PV Performance Modeling Collaborative[3]. PV power is calculated using user-specified system parameters, such as panel tilt, orientation, racking type, and tracking capabilities. Batteries are modeled using a simple time-step state-of-charge model with user-specified efficiency and -charge limits.

System Configurations

At the beginning of an MCOR run, a suite of PV and battery component sizes are determined based on either user-specified sizes and/or the available solar resources and the user-supplied annual critical load profile. The largest PV and battery sizes are intended to represent net-zero performance, wherein the total power generated by the PV system is equivalent to the total annual load plus efficiency losses from charging and discharging the batteries. The batteries are sized to be able to meet all energy requirements during the longest night of the year.

In addition to the net-zero size, several smaller configurations are also included to provide a range of options. For each combination of PV and battery sizes and each outage scenario, a rules-based dispatch simulation is run to determine the generator capacity required to meet all load during the outage period. In this simulation, load is first served by PV generation, when available, and then batteries are discharged to meet the load at a relatively constant rate in order to reach the minimum state of charge at the end of each night. Any remaining load shortfall is met by the diesel generator. Battery performance is determined using a fixed efficiency factor (i.e. it does not vary with state of charge). The outage scenarios for a given PV and battery size are then aggregated to determine the average and largest capacity generator required to meet unserved load (see Figure 1). Potential generator capacities are selected from a common diesel-generator supplier, along with their fuel efficiency curves (as a function of loading level) and installation costs.

[1] https://nsrdb.nrel.gov/

[2] https://pvlib-python.readthedocs.io/en/stable/

[3] https://pvpmc.sandia.gov/

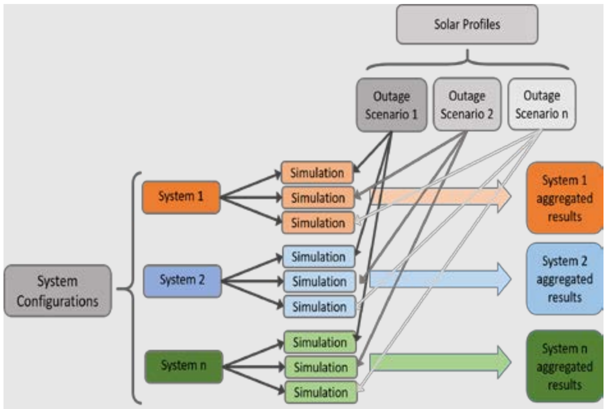

Figure 1. MCOR simulation workflow

The MCOR tool returns several metrics that can be used to weigh possible system configurations against each other, including capital and maintenance costs, fuel requirements under typical and worst-case scenario conditions, breakdowns of how different resources are meeting the site's electrical load, and typical net-metering revenue. The tool allows for several different types of net-metering restrictions to be specified, including sizing the battery to be capable of storing all excess PV generation in case there is no net-metering allowed for a site. Sample MCOR output is shown in the next section for a case study site.

By modeling system operation under a large range of outage conditions and selecting a generator capacity that can meet all load not served by the PV and battery systems of each configuration, MCOR ensures that all system configurations supplied to a user have adequate capacity to serve all critical loads in an outage. As previously mentioned, any detailed power systems modeling to ensure instantaneous viability will need to be performed within the subsequent design phase.

EVALUATION CASE STUDY

Site Description and Drivers

The Army Reserve is utilizing FEDS and MCOR to analyze load resiliency scenarios as part of their installation energy and water management planning process. An example case study was selected to highlight the application of these tools in support of a site resilience assessment, as represented by Figure 2. The selected Reserve site, located in California, has five buildings, three of which are considered mission critical and thus serve as the focus of the assessment. There are several natural hazards that can produce widespread power outages and impact the operations at this campus.

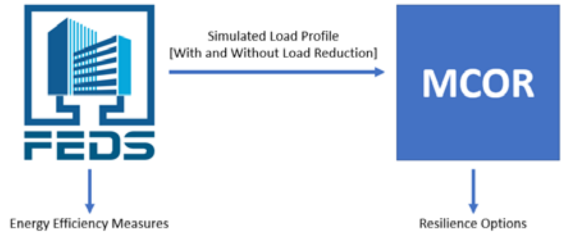

Figure 2. Application of FEDS and MCOR for resilience planning

These include strong winds, seismic activity, wildfires, and flooding. Historical natural hazards that impacted the overall region were gathered from disaster declarations and the National Oceanic and Atmospheric Administration (NOAA) Storm Events Database[4].

The driver for the assessment was to support agency goals of achieving increased resilience and mission assurance in the face of a range of possible disruptions to energy and water supplies. This case study focuses on the application of FEDS and MCOR capabilities towards identifying and evaluating energy resilience options at this site to maintain essential operations for a disruption lasting up to 14 days. Results and recommendations from the analysis are presented to the agency for consideration and further evaluation towards implementation. Next steps would often include a detailed design, cost, and operational assessment, plus coordination with the local utility and other stakeholders, and examination of legal and financial risks and considerations that may impact project development and deployment.

Building Characteristics

The three buildings included in the assessment have a combined floor area of 270,000 ft^2, and each is approximately ten years old. As shown in Table 1, the largest is an administration building, followed by a storage facility and a maintenance shop. There are approximately 350 full-time staff, with frequent occupancy on weekends, and expected 24-hour emergency center operations during emergency response scenarios.

Table 1. Buildings evaluated

BUILDING	SQ. FT.	VINTAGE
Administration	180,000	2011
Storage	65,000	2010
Maintenance	25,000	2010

[4] https://www.ncdc.noaa.gov/stormevents/

Energy Use and Rates

The site is served by both electricity and natural gas. Electric rates include both seasonal and time-of-use components for energy and demand. Appropriate marginal rates were determined by season and rate period and applied by both FEDS and MCOR to properly value the savings from EEMs and the electricity generated by the PV systems, respectively. Recent typical annual energy consumption for the three mission-critical buildings was approximately 2.5 million kWh of electricity and 34,000 therms of natural gas. The administration building is responsible for more than 80% of this electricity use.

Building Modeling and Energy Simulation

FEDS models for the three mission-critical buildings were developed based on information collected during a site assessment, design drawings provided by facility personnel, and a comprehensive energy and water evaluation performed by PNNL four years prior. Conditions and system characteristics were reviewed for each building and entered into the models. These included marginal energy and demand rates, building age, use type, occupancy patterns, geometry, envelope, HVAC and controls, lighting systems, domestic hot water, plug loads, and motors. Known parameters were specified, and inferred parameters reviewed and updated as warranted. Monthly and interval electricity data from the utility guided an iterative calibration process focused on adjusting uncertain elements of the modeling assumptions within feasible bounds. This was accomplished while adjusting the input weather to reflect that of the base year. As a result, the simulated annual energy use of the baseline administration model was less than two percent from actual consumption.

EEMs

The calibrated building models were used to identify EEMs and simulate various emergency operation scenarios. For the three mission-critical building models, FEDS identified light emitting diode (LED) lighting as a viable measure for all fixtures, both interior and exterior. As highlighted in Table 2, the energy savings were estimated at 1,130 MMBtu/yr., representing approximately $83,300/yr. savings with an overall savings-to-investment ratio (SIR) of 1.3. The calculated energy savings were based on traditional operations and did not include any increase in operating hours during an assumed emergency response scenario.

Improvements to the building control system for the administration building were also identified. These measures represent 1,370 MMBtu/yr. in energy savings representing approximately $59,200/yr. in cost savings with an SIR of 4.0. The capital investment required to implement these EEMs totals $1.1M and will reduce the energy use at the three buildings by 21% (approximately a 16% reduction in the site's overall energy use). These measures will reduce the risk to the critical facilities by minimizing energy requirements, in terms of both consumption and demand.

Table 2. Identified EEMs

	LED LIGHTING	**HVAC OPTIMIZATION**
Electricity Savings (kWh/yr.)	340,000	290,000
Peak Electric Demand Reduction (kW)	64	-
Natural Gas Savings (therms/yr.)	-270	3,680
Cost Savings ($/yr.)	$83,300	$59,200
Project Cost ($)	$1,106,000	$28,000
Simple Payback	13.3	0.5
SIR	1.3	4.0
% Savings	7%	9%

Energy Loads

Once viable EEMs were identified, a post-retrofit model was developed for the site. Hourly simulations of both the baseline and post-retrofit models created hourly energy load profiles for each mission-critical building. Figure 3 shows the pre- and post-retrofit critical electric load profiles that illustrate the savings realized with the implementation of the LED lighting EEM.

The post-retrofit FEDS energy model was adjusted to simulate the higher 24-hour operation of the emergency center, located in the administration building, during wildfire and flooding seasons. The resulting simulated load profile for this operation-adjusted FEDS model exhibits a higher energy demand and consumption when compared to the post-retrofit energy model (Figure 4).

This aggregate critical load profile was fed into the MCOR tool, which calculates solar PV, battery, and generator capacities for use in a microgrid. The goal of the MCOR tool is to provide several viable microgrid configurations that can meet a site's resilience goals without any power supply from the electrical grid.

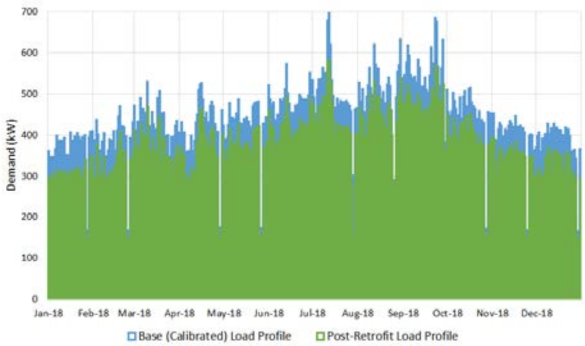

Figure 3. Calibrated and post-retrofit load profiles (three critical buildings)

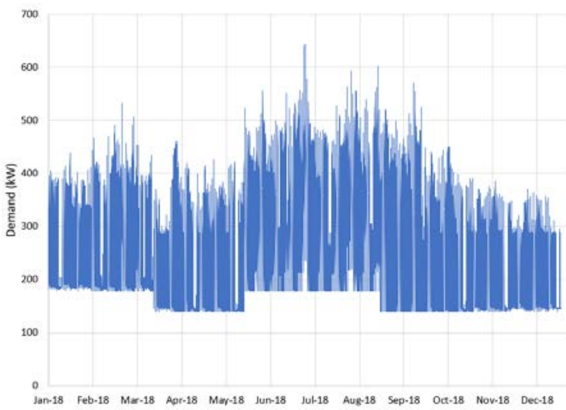

Figure 4. Emergency operations load profile (administration building)

Microgrid for Resilience of Administrative Functions and Emergency Response

MCOR was first run using the simulated emergency load profile for the administration building to determine a microgrid configuration sufficient to meet all of that building's load in an emergency. The selected configuration (see Table 3) includes 750 kW of PV, a 750-kW/750-kWh battery, and an 800-kW generator.

The administration building contains the emergency center and also has the highest electric load. Cost savings are based on (1) PV generation directly offsetting grid purchases, (2) energy stored in a battery offsetting grid purchases during non-generation hours, (3) energy sold back to the utility under a net-metering arrangement, and (4) loss of staff productivity for employees who are not able to work during outages.

Table 3. Selected resilience configuration

	ADMINISTRATION-ONLY MICROGRID
PV Capacity (kW)	750
Battery Capacity (kWh)	750
Battery Power (kW)	750
Generator Power (kW)	800
14-Day Fuel Use (gallons)	3,200
Capital Cost ($)	$9.7M
Annual Savings ($)	$356,000
Simple Payback (yr.)	27

Dispatch plots of the microgrid are shown in Figures 5 and 6 for the 14-day outage scenario with maximum PV production and for the scenario with minimum PV production, respectively. Reduction in diesel consumption by generators during average solar conditions is approximately 45% due to the installation and operation of this microgrid as compared with only using the generator to meet critical load during an outage.

Microgrids for Campus Resilience

Microgrids were also sized to meet the critical loads of all three facilities during an outage. Table 4 shows two candidate microgrid configurations which resulted from this analysis. The results highlight that the benefit of using a larger battery does not outweigh the additional cost, as demonstrated by the longer payback.

The fuel consumption required for the diesel generators to support campus loads during the 14-day utility disruption is shown in Figure 7. This plot shows that as PV capacity increases, the amount of fuel needed to run the generators decreases. Increased battery capacity does not have much impact on fuel consumption unless the PV system is large enough to generate excess energy for storage and overnight use. The options shown in the figure assume a load equivalent to all three mission-critical buildings.

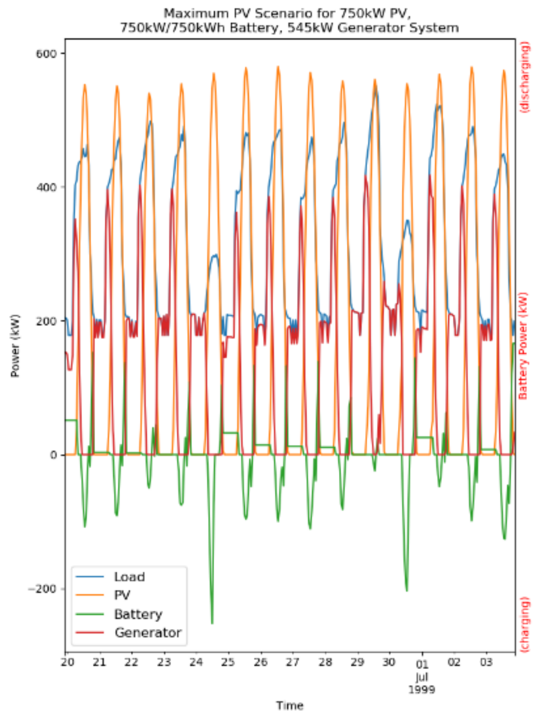

Figure 5. Dispatch of recommended microgrid configuration during summer

Table 4. Microgrid expansion options for all mission-critical buildings

	MICROGRID WITH SOLAR PV AND SMALL BATTERY	MICROGRID WITH SOLAR PV AND LARGE BATTERY
PV Capacity (kW)	1,350	1,350
Battery Capacity (kWh)	1,700	3,400
Battery Power (kW)	425	850
Generator Power (kW)	550	550
14-Day Fuel Use (gallons)	2,800	2,200
Capital Cost ($)	$12.7M	$14.3M
Annual Savings ($)	$468,000	$472,000
Simple Payback (yr.)	27	30

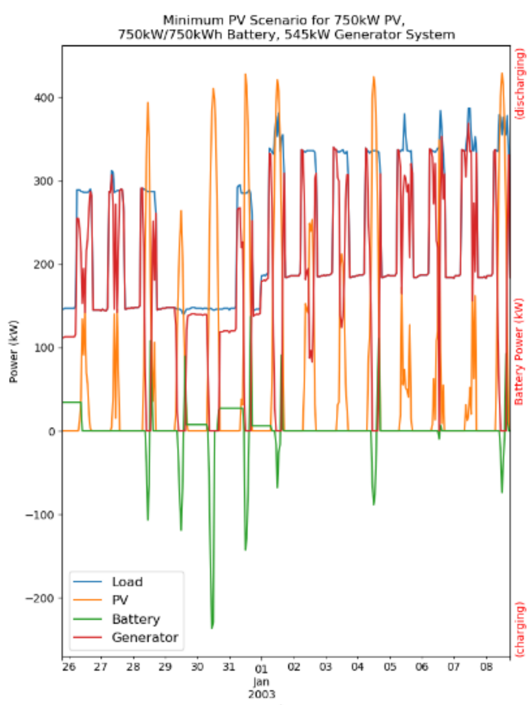

Figure 6. Dispatch of recommended microgrid configuration during winter

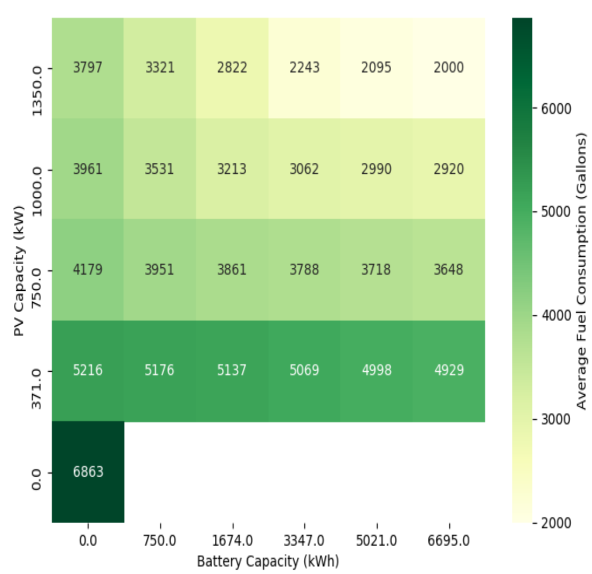

Figure 7. Generator fuel consumption during a 14-day outage for various PV and battery capacities

The recommended microgrid solution for the administration building, described in the previous section, includes the scope of work and capital costs required to perform electric service upgrades necessary for integrating the storage and maintenance buildings in the future. As a result, this configuration provides the most flexibility to the Army Reserve, meeting near-term needs while also allowing for growth. Future expansion of the administration-only microgrid was proposed in phases. The first phase would connect the storage and maintenance buildings to the PV, generator, and battery components. Next, the PV array and battery capacities would be increased to reduce reliance on the generator in serving the additional loads.

CONCLUSION

As the demand for resilience planning continues to increase, government agencies as well as commercial entities and consultants need tools to perform objective and reliable evaluations. The capabilities presented here offer a proven option for systematically assessing energy efficiency and resilience options for individual buildings as well as campuses to maintain mission assurance under potential outage scenarios.

FEDS is designed as a robust and easy-to-use tool for simulating existing building conditions, identifying cost-effective EEMs, and generating corresponding load profiles that form the basis of understanding mission-critical loads to be met during an emergency or other outage. MCOR uses the resulting building loads to evaluate a number of PV, generator, and energy storage microgrid configurations, under a large range of potential solar resource conditions. The results offer the site a comprehensive comparison of options and benefits, from which more detailed design and implementation planning can begin.

Currently, the tools remain separate, with load profiles reflecting baseline and post-retrofit conditions passed from FEDS to MCOR. However, there is interest in more closely integrating some of the capabilities of these tools to facilitate more comprehensive and automated evaluations. When used together, this pairing provides valuable recommendations, including load reduction as a first and most cost-effective step towards resilience. In the case study example presented, not only will the identified EEMs pay for themselves in utility cost savings under normal operation, they have enabled an enhanced (i.e., smaller-sized and lower-cost) resilience solution that better meets the needs of the site.

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