Combined Use of EV Batteries and PV Systems for Improving Building Resilience to Blackouts

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***Abstract*—Californian residencies face increased risk of blackout. The state depends more on imported electricity that may not always be available to fill the gap between renewable generation and demand. For buildings with PV panels, storing the surplus solar power to support the load during a blackout can be achieved with a large energy storage system (ESS). The electric vehicle (EV) provides potential solutions as it can expand the energy capacity of the residential ESS with its battery. In this paper, a reference house in California was modeled in EnergyPlus. The building resilience for a house with different load percentages were studied, for both with, and without EV scenarios.**

***Index Terms* –** Electric Vehicle (EV), Vehicle-to-Home (V2H), Home Energy Management (HEM), Battery Energy Storage System (BESS), Blackout, Resilience.

I. Introduction

California residences are facing increasing power loss threats from generated power volatility as they move forward rapidly with green energy initiatives. The Golden State has ambitious goals for the development of net zero energy (NZE) buildings, including requirements for all new residences to be NZE by 2020 [1]. As California implements more residential PV generation, the most difficult time of day for utilities to consistently meet power demand is gradually shifting from the typical power demand peak in the afternoon into the early evening as PV generation fades with the falling sun. If California utilities fail to import power to meet the demand gap left by varying renewable generation, which can be as large as 8,000 MW, rolling blackouts are likely to occur.

Another major threat to California's power system stability is uncontrolled wildfires, which devastate swaths of California more and more each year. In 2020 alone, there were 8,112 wildfires reported resulting in 1,443,152 acres of burned land, as compared with 5,856 and 446,960 respectively for the 5-year average during the same time interval [2]. Rooftop PV panels can generate electricity during a blackout, but the reliability is limited due to their intermittent nature. The battery energy storage system (BESS) can mitigate this problem but also requires a hefty initial investment and proper home energy management (HEM) to operate optimally.

The market share data from [3] shows the spreading trend of EV. A study based on the national household travel survey (NHTS 2017) found that most EVs travel around 20 miles every day, maintaining a state of charge (SOC) of 90% by the time they return home [4]. These same EVs are also parked 95% of the time, providing a large amount of idle battery power storage that could be used during a blackout. Connecting and using EV battery packs to the home can potentially boost the capacity of the residential energy storage system (ESS).

Table I
Basic specifications of residential load modeling

Parameters	Value
Conditioned area	2,401 ft^2
House type	4-bedroom, 3.5-bathroom
Climate zone	Burbank, CA
PV rating/annual generation	7.2kW/11,316kWh
Annual Elec. usage w/o EWH	13,628kWh
Annual Elec. usage for EWH	4,233kWh
EWH rated power	5kW
BESS rating	11kWh/5kW
Initial BESS SOC	100%
EV battery rating	20kWh/10kW
EV initial SOC	90%
Minimum BESS/EV SOC	20%

II. Electrical energy and power modeling for the reference house

The reference house's characteristics, whose model was based on a EnergyPlus Input Data File (IDF) released by Pacific Northwest National Laboratory (PNNL) in [5], is summarized in Table I. This area's weather data is publicly available on the EnergyPlus website as typical meteorological year (TMY) [6].

The reference house's EV has a battery rated for 20kWh and is considered to have a typical schedule where the EV should be ready to leave at 6am and returns home at 6pm. Since the typical daily travel distance is less than 20 miles, the EV is assumed to return home with an SOC of 90% [4]. The minimum SOC for the EV battery is considered to be 20%, a typical SOC discharge limit for batteries. In this study, the house's load percentage without electric water heater (EWH) is varied to represent different user behavior. The rating of other components, including PV, BESS and EV are fixed.

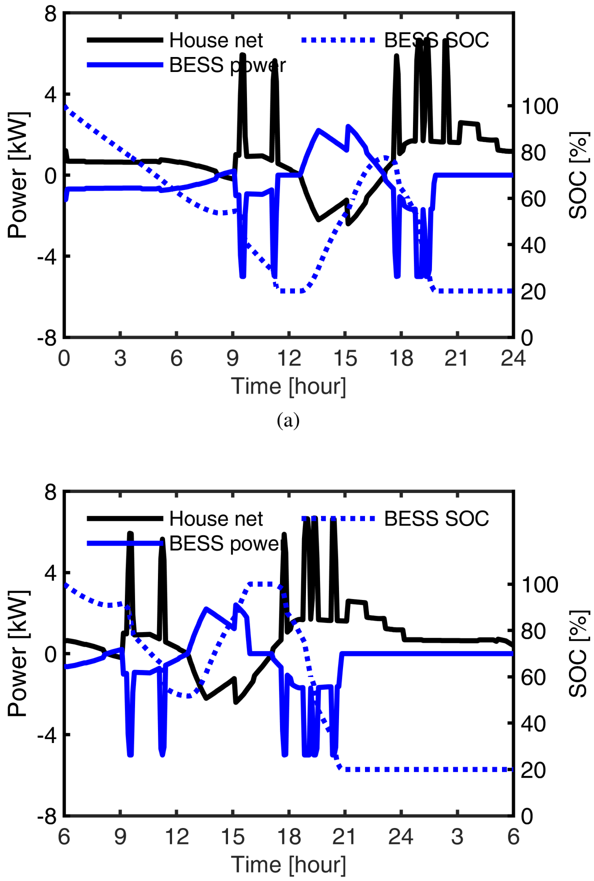


Figure 1. The blackout's timing has a large impact on the self-sustainment duration for the house. Shown is an example case on the 172th day for the reference house when the blackout occurred at (a) midnight, (b) 6 am.

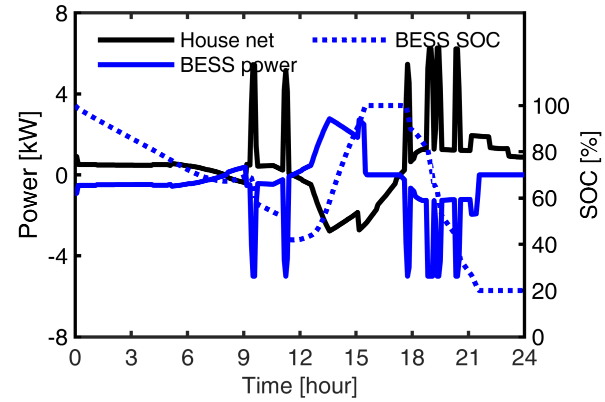


Figure 2. Example case on the 172th day when the blackout occurs at midnight but with 75% of load. The self-sustainment duration increased to around 21 hours.

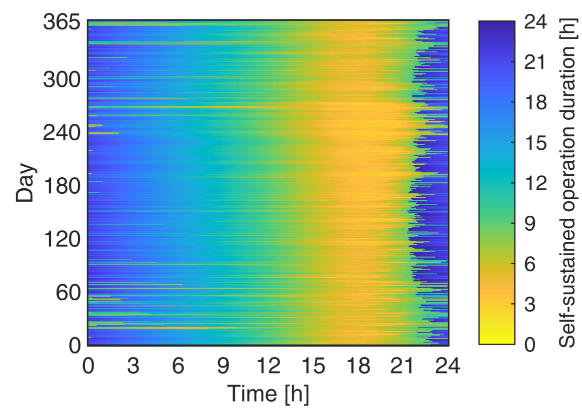


Figure 3. Self-sustained operation duration of the reference house for blackouts occurring for 24 hour periods evaluated at 5-min time steps. Evaluating 5 minute time steps across each day in the example year resulted in 105,120 evaluated instances.

III. Building Resilience for House with Different Load Percentages

For this study, the total energy supplied by the BESS since the blackout occurred is defined as:

$$E_{B,i} = \sum_{i=1}^{t} P_{B,i}\Delta t, \quad P_{B,i} = -P_{H,i}, \tag{1}$$

where i is the simulated time step; $P_{B,i}$, the power of BESS; $P_{H,i}$, the net power of the residence. In an ideal situation, the BESS would self-sustain the house by supplying the house's total demand to achieve building resilience during a blackout.

The house self-sustainment duration T is defined as:

$$\exists i = T : E_{B,T} \leq E_C \wedge E_{B,T+1} \geq E_{C,T}, \quad E_{C,T} = \eta_B E_{C,B}, \tag{2}$$

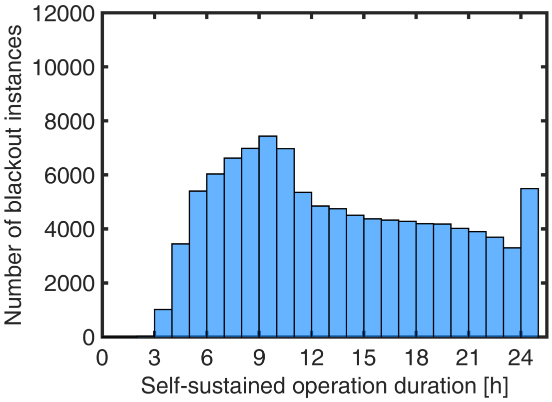
where $E_{C,T}$, is the total available energy of the residential ESS; η_B,is the maximum range of the SOC of the BESS; and $E_{C,B}$, is the rated capacity of the BESS.

Blackouts could occur at any time on any day throughout the entire year. Within this study, the BESS was considered to initially be at 100% SOC when the blackout occurred. Immediately after the blackout, the building self-sustained until the BESS SOC fell to 20%.

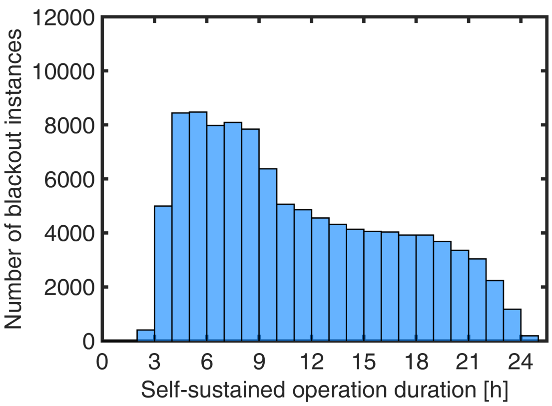
Simulation results in Fig. 1 show that the time of day the blackout occurred greatly impacted time duration that the reference house could self-sustain using the BESS. Self-sustainment duration is longer when the blackout occurs at night because the BESS can be charged in the following morning and midday via renewable energy production. Reducing the percentage of the house's total load prolonged the self-sustained operation duration, as shown in Fig. 2.

Using a simulation time step of 5-min, there are $12 \times 24 \times 365 = 105,120$ instances throughout the year when a blackout could occur. For each time step, the following 24 hours were simulated to find the self-sustainment duration, and the results are represented in Fig. 3. Each cell in this heatmap indicates a 5-minute increment, and the color shows the self-sustainment duration when the blackout occurred at this time step.

The impacts of different load percentages were studied and are presented in Fig. 4. Higher load percentage generally resulted in shorter self-sustained operation duration. The cumulative distribution for self-sustained operation duration was calculated and presented in Fig. 5. The probability to self-sustain for more than 3 hours is almost 100% for all three example load percentages and reducing the load percentage



(a)



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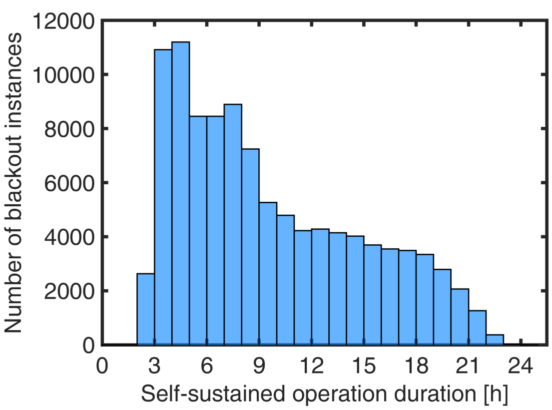


(c)

Figure 4. The distributions of self-sustained operation duration for the house during blackout with different load percentages clustered by hour intervals: a) 75%, b) 100%, c) 125%.

increased the probability of self-sustaining for a longer duration.

IV. Building Resilience with connected EV

After a blackout occurs, the EV can stay home and supplement the residential load through its battery energy. With an incorporated EV battery, the total energ capacity of the residential ESS, which is defined in (2), becomes:

$$E_{C,T} = \eta_B E_{C,B} + \eta_E E_{C,E}, \tag{3}$$

where η_E is the maximum range of the SOC of EV battery; and $E_{C,E}$ is the energy capacity of the EV battery.

An EV battery could significantly increase the total residential ESS capacity so all instances evaluated in this section were examined for the following 72 hours rather than 24. The simulation results based on the reference house for all 105,120 instances throughout the entire year confirmed that the ESS incorporating the EV battery resulted in longer periods of self-sustainment, as shown in Fig. 6.

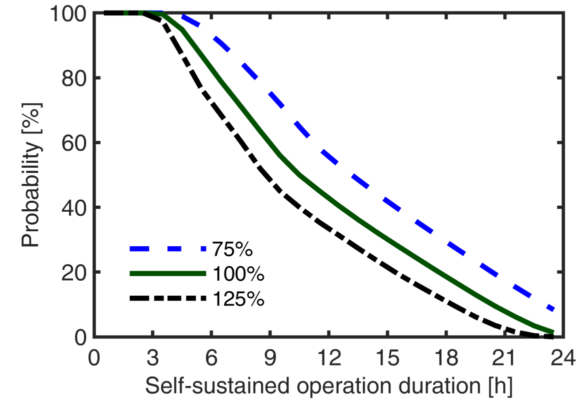


Figure 5. The cumulative distribution for self-sustained operation duration of the house for varying load percentages. Reducing the load percentage increased the likelihood of self-sustaining for a longer duration. In all three shown examples, if the blackout occurs anytime throughout the year, the house is highly likely to self-sustain for more than 3 hours.

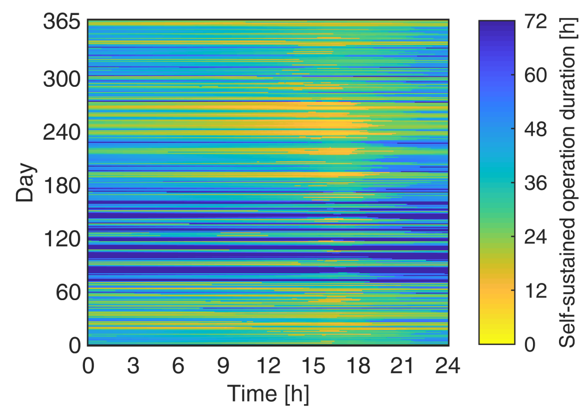
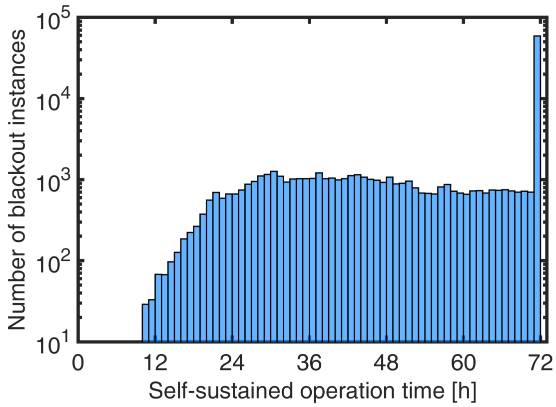


Figure 6. The self-sustained operation duration of the reference house for blackouts occurring at different times. The EV battery was incorporated into the residential ESS to improve the building's resilience and ESS capacity. Self-sustained operation duration was verified for 72 hours from a time step of 5 minutes. 105,120 instances were evaluated through the example year.

The self-sustained operation duration was presented with a 1-hour interval in Fig. 7 for different load percentages. Overall building resilience was improved significantly with an interconnected EV, as compared with the cases shown in Fig. 4. The house with a high load percentage self-sustained for a shorter time than other interconnected EV cases but performed



(a)

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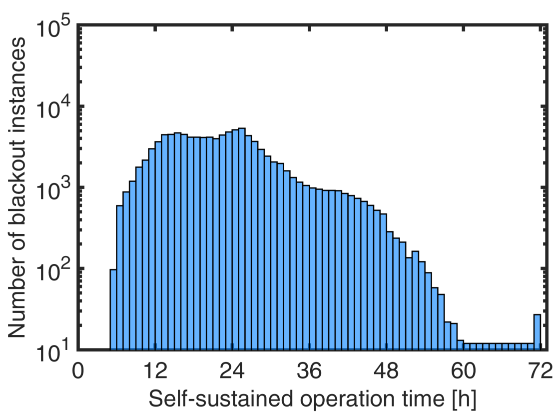

(c)

Figure 7. The distributions of self-sustained operation duration for the house connected to an EV during a blackout with different load percentages clustered by hour intervals: a) 75%, b) 100%, c) 125%.

better than operation without the connected EV.

The cumulative probability curve for self-sustainment duration with different load percentages and an interconnected EV is shown in Fig. 8. With the EV battery of 20kWh connected to supply the residential load, house with the three examples load percentages could self-sustain at least 12 hours. The simulation results show that reducing the load percentage improved the building's resilience significantly, especially when the expected self-sustained operation duration was long. For example, when the self-sustained operation duration was 36 hours, reducing the load percentage from 125% to 75% increased the probability of continuing to self-sustain from approximately 10% to 90%.

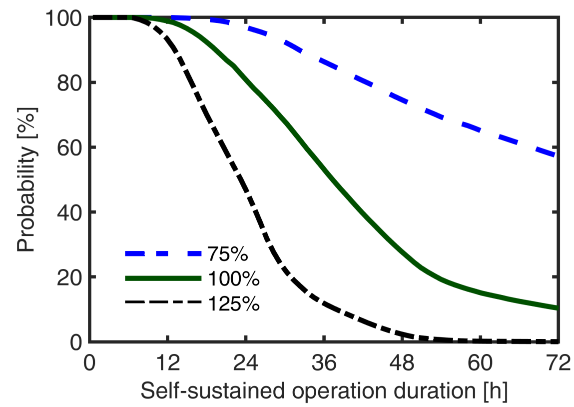

Figure 8. The cumulative distribution for self-sustained operation duration of the house for different load percentages. The EV battery of 20kWh was incorporated into the residential energy storage system. The building resilience of the house was improved for all load percentages.

V. Conclusion

This paper defines the building resilience by examining the self-sustainment operation duration of a house with an energy storage system (ESS) during a blackout. Different load percentages were studied and results show that reducing the power demand during a blackout could improve building resilience. This paper further explores the possibility of incorporating an EV battery into the residential ESS, demonstrating that when the EV battery is incorporated in the residential ESS, the house's resilience increased significantly.

VI. Acknowledgment

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