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Can solar+storage keep the lights on? Assessing solar+storage for backup power during long-duration power interruptions in the US

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Abstract — **Recent market trends reveal rapid growth in the adoption of paired behind-the-meter (BTM) solar photovoltaic and energy storage systems (PVESS). Those trends have been driven in part by customer concerns over electric system reliability and demand for backup power, which are likely to become even more pronounced as wildfire, hurricane, and other climate-driven risks rise over the coming decades. But what can customers expect, and what can installers promise, in terms of how well these systems might actually perform in providing backup power during long-duration power interruptions? The presentation will highlight key findings from Berkeley Lab's examination of BTM PVESS in backup power applications. The analysis is based on simulating PVESS backup performance during both a set of synthetic power interruption events as well as a set of 10 historical long-duration power interruption events. The analysis evaluates performance across a wide range of outage conditions and across thousands of individual building models, capturing both different building types and variations in the existing building stock. The results show how even a relatively small PVESS can provide backup power to a basic set of critical loads, while also highlighting some of the key considerations and constraints in providing backup to electric heating and cooling loads. The analysis illustrates both the challenges and opportunities associated with electrification, in terms of PVESS backup power capabilities.**

I. INTRODUCTION

Paired behind-the-meter (BTM) solar photovoltaic and energy storage systems (PVESS) is a minority application in most regions, representing 10% of all United States BTM residential solar systems installed in 2021 [1]. Industry observers note that early adoption of PVESS has been driven, to a significant degree, by customer concerns over electric system reliability and resilience [2]. As wildfire, hurricane, and other climate-driven risks to electric grids become more pronounced, those concerns are expected to grow [3]. But, the technical resilience benefits of BTM PVESS are poorly understood, owing to lack of data and methodological challenges. Some customer adoption studies assume PVESS can provide full backup during power interruptions, and do not consider heterogeneity across geographies, customer-types, interruption durations, and PVESS system sizes [4].

Past research on the resilience impacts of BTM technologies generally focused either on: (1) development of new optimization and operation methods of PVESS systems, assessing their viability within individual case studies [5-7] or (2) resilience impacts of PVESS within the distribution system from the perspective of a utility or distribution system operator [8-9]. Neither of these two approaches lend themselves to significant geographic and building-type heterogeneity, limiting a comprehensive understanding of the scale of applications for BTM PVESS to mitigate power interruptions and correspondingly assess future customer adoption trends.

This presentation fills a literature gap by providing new information about the conditions PVESS technologies can be relied on to serve load during long-duration power interruptions. The breadth of the results enables public decision-makers at the state and federal level to design, target, and deploy policies that internalize the resilience benefits of PVESS. Finally, the information produced for this presentation is useful to both researchers and industry practitioners forecasting future adoption of BTM PVESS systems as well as those evaluating the relative merits of utility-scale and BTM PVESS applications.

II. METHODS

A. Data

The research approach requires three hourly timeseries data: (1) disaggregated end-use load profiles, (2) solar production profiles, and (3) power interruption profiles.

For load profiles, we use a foundational dataset of more than 500,000 residential building models generated by the National Renewable Energy Laboratory's ResStock simulation tool [10]. These building models use a wide range of empirical data to inform statistical representations of the United States building stock, covering a variety of residential building types, end-uses, and characteristics. For solar profiles, we apply the same weather data that are used in the underlying ResStock simulations to ensure geospatial and temporal alignment [11]. We use the System Advisor Model (SAM), which outputs AC solar production profiles. For these simulations, we use default system losses of 14% and an inverter efficiency of 96% and assume a 1.2 inverter loading ratio, 180 azimuth, fixed-roof system with tilt equal to the latitude of the weather station location.

Finally, we develop two distinct approaches to simulating power interruption profiles: (1) synthetic profiles and (2) historical profiles. The synthetic profiles are simulated as interruption events that occur in every month at a pre-determined start date and start time. To complement the synthetic profiles, we identify 10 historical, wide-spread, weather-driven power outages and develop historical interruption profiles that align with the empirical experience of outages during those events. We focus on 4 event types: (1) Hurricanes (Harvey (2017), Irma (2017), Florence (2018), Michael (2018), and Isaias (2020)); (2) wildfires (California (2019)); (3) winter storms (Washington state (2019) and Oklahoma (2020)); and (4) thunderstorm (Iowa (2020) and Texas (2020)).

B. Dispatch Algorithm

Since we aim to understand the technical capability of a PVESS to provide backup, we limit the operation of the system to solely provide backup during interruption events. The algorithm follows a decision-tree like structure where each hour of the analysis is evaluated sequentially to determine whether solar production or the battery can meet the specific load in that timestep. We assume a 92% one-way battery efficiency and a 2 hour duration battery. We apply constraints on the discharge and charge rates of the battery such that they do not exceed the kW capacity of the battery within the hour, which is determined by dividing the kWh energy limit of the battery by the 2 hour duration. We assume an AC coupled system such that the maximum power of the PVESS is the PV's AC capacity plus the battery power constraints mentioned above.

In order to describe and compare the performance of the PVESS system across all modeled scenarios, we focus on a simple customer centric metric: percent load met (adjusting for load scenario of interest). This metric is defined by the below equation where, P is percent load met (%), E_s is load served during interruption (kWh) and E_o = load demanded during interruption (kWh).

$$P = \frac{E_S}{E_O} \qquad (1)$$

C. Scenarios

Our baseline scenario is bolded in Table 1 and involves the single family detached building model, a 3-day synthetic interruption event that starts at 12am on the 50 percentile net-load day, a solar system sized to meet 100% of annual load, and 10 kWh (5 kW) battery size with a 100% beginning battery state of charge.

III. RESULTS

In majority of counties, PVESS with 10 kWh of storage can provide full power for a minimum set of critical loads that ignore heating/cooling demand (i.e. include refrigeration, limited interior lighting, computer / internet, and well-pumps). With our largest PV sizing assumption, the entire set of limited critical loads are met in 93% of counties. Figure 1 shows that the base PVESS configuration cannot provide power for the majority of U.S. counties once HVAC are included (left maps).

TABLE I
SUMMARY OF SCNEARIO ANALYSIS

Scenario	**Assumption**
Building types	**Single family**; mobile home; multifamily
Interruption length (days)	1; **3**; 7
Load scenario	Critical load (no HVAC); **critical load (with HVAC)**; full load
Beginning SoC (% of total kwh of battery)	0%; 50%; **100%**
Interruption start time	**12am**; 6am; 12pm; 6pm
Interruption start day	Worst; **median**; best
Solar sizing	Solar generation is 50%; **100% of annual load**; Roof area constraint
Battery sizing	**10 kWh**; 30 kWh

In this scenario, a PVESS with 10 kWh of battery could supply 100% of annual power demand to just 6% of counties. In our whole-home backup scenario (right maps), this drops to 0% of counties. There are clear seasonal and regional trends, where performance in summer months is lowest in regions with high cooling loads (i.e. southwest and southeast) while performance in winter months is lowest in regions with electric heating (southeast and northwest, especially in rural counties).

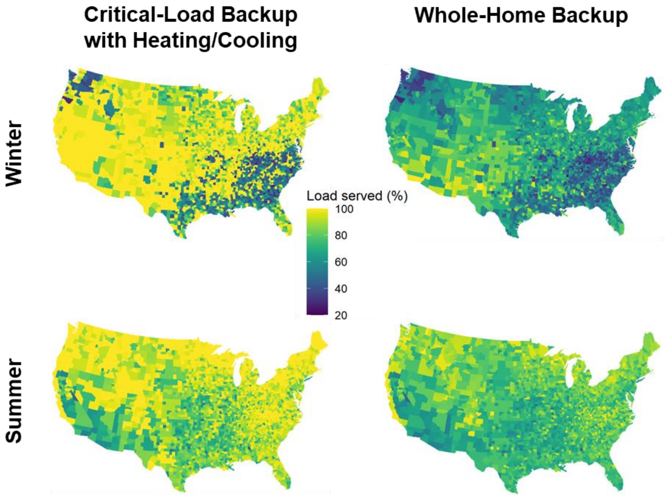

Fig. 1. Average percent of total load served during 3-day interruptions, aggregated to winter and summer seasons.

For a subset of high-population counties, we simulate our results for all single-family detached ResStock building models. Figure 2 shows two counties with particularly high backup performance variability (Phoenix and Houston). In these two counties, backup performance declines the greater the amount of critical load to serve, given fixed battery sizing. Scatter around those trends reflects differences in customer load profile shapes. Differences in critical load levels reflect a number of fundamental drivers: (1) Building size, (2) Heating and cooling equipment type (especially electric vs. gas heating), (3) Efficiency levels, and (4) Occupant/behavioral factors (e.g., set points).

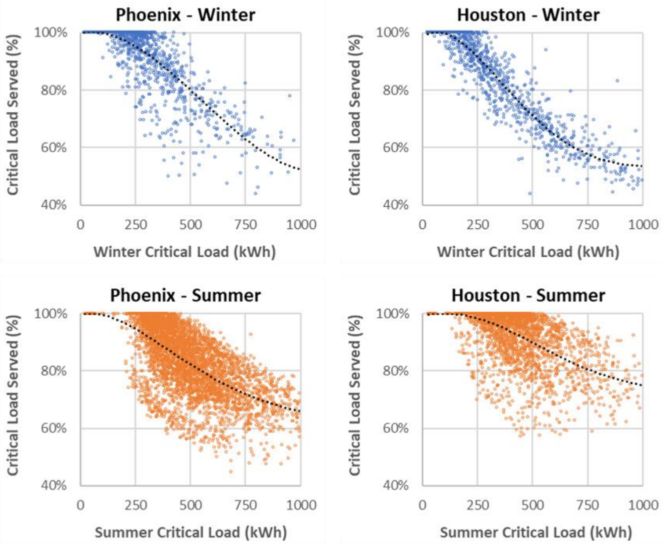

Fig. 2. Percentage of critical load served by amount of critical load

For historical events, we find that the base system size would have supplied full backup for the majority of building models in the Thunderstorm (TX), PSPS (CA), Derecho (IA), and Hurricane Michael events. The worst distributions of load served occur for the two winter storm events and Hurricane Florence. The relatively poor performance represented by Hurricane Florence is driven by the lack of solar production in the first three days of the ~8-day outage event.

IV. DISCUSSION AND CONLCUSIONS

The above results establish a baseline understanding of the capabilities of PVESS to provide backup power across a range of geographies and building stock conditions and have important implications for researchers, analysts, and/or electric system planners trying to forecast the adoption of PVESS for backup. First, assuming that PVESS can fully backup a customer experiencing long-duration interruptions is incorrect and geographically correlated. Second, we show that the specific electric end-use requirements demanded of a PVESS backup power system will drive the resiliency capability of the system. Across all of our scenarios, PVESS could provide power to refrigeration, nighttime lighting, internet / computer loads, and well-pumps without any shed load. However, heating and cooling demand are much more difficult to backup with a PVESS system and oftentimes cannot be fully served during interruption conditions under typical operating conditions. Last, we find that PVESS could mitigate interruptions for a significant fraction of the building stock during prominent wide-spread interruption events over the last 5 years, but customers who adopt PVESS do take on weather risk if the sun is not available during the event, as shown in Hurricane Florence.

Our results relied on load profiles which are statistically representative of the current United States building stock. However, deep decarbonization policy goals suggest that the building stock will electrify beyond levels observed in our study. Though we did find signs of how electrification might pose difficulties for PVESS in providing reliable services to end-customers, future research should more precisely consider load profiles which incorporate more electrification. Such electrification might certainly pose challenges to home back-up via increasing electricity demand; however, other electrification trends could support customer resiliency. Such work could incorporate estimates of the value of lost load to provide estimates of the resiliency value of PVESS across long-duration interruption events.

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