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Backup Power Performance of Solar-plus-Storage Systems during Routine Power Interruptions

A Case Study Application of Berkeley Lab's PRESTO Model

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Introduction

Customer interest in onsite solar photovoltaic and energy storage systems (PVESS) is being driven in part by customer demand for backup power. While that demand may be fueled by increasing frequency and severity of long, multi-day power interruptions, most power interruptions are relatively short duration, typically lasting minutes to hours. They are also unpredictable, and the ability of a PVESS to provide backup power during any particular interruption event partly depends on how fully charged the battery happens to be at the beginning of the event.

This technical brief estimates the expected performance of a PVESS for providing backup power during short-duration power interruption events, accounting for the unpredictable nature of those events.[1] The analysis relies on the Power Reliability Event Simulation TOol (PRESTO), a publicly available model developed by Berkeley Lab to simulate the occurrence of short-duration power interruption events at the county-level. A separate storage dispatch model is then used to simulate PVESS operation and backup performance for each of the large number of interruption events produced by PRESTO. In performing this simulation, the analysis accounts for how the customer operates its battery on a day-to-day basis—in this case, we assume the battery is cycled each day in response to time-of-use rates—and how that, in turn, impacts the battery's state of charge at the beginning of each interruption event.[2]

The analysis presented here is intended to demonstrate an application of the PRESTO model as well as to illustrate some of the key determinants of PVESS backup power performance during short-duration power interruption events. The analysis focuses initially on a typical single-family home in Maricopa County, Arizona, and includes a limited set of scenarios related to system sizing, backup power configuration, and whether the customer charges its battery storage system from the grid during normal operating conditions. The analysis also presents comparative results for two other counties, in Massachusetts (Middlesex) and California (Los Angeles), illustrating how regional differences in climate, interruption patterns, and retail rate structures can affect PVESS performance as a backup power source. In the conclusions, we highlight a number of other important considerations for evaluating PVESS backup power capabilities.[3]

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[1] Berkeley Lab has published separate studies evaluating PVESS backup power performance during long-duration power interruption events. See, for example, Gorman et al. 2022.

[2] Additional methodological details for this technical brief are provided in the accompanying Supplementary Information file.

[3] A full set of results for Middlesex and Los Angeles counties are provided in the accompanying Supplementary Information file.

The Power Reliability Event Simulation TOol (PRESTO)

PRESTO simulates the occurrence of customer-level power interruption events for any given county in the continental United States. The simulations are based on probabilistic functions developed from hourly historical interruption data for each county obtained from PowerOutage.US. Those probabilistic functions estimate the likelihood that an individual customer in a given county would experience an interruption during any given hour of the year, thereby capturing historical patterns in both the timing (e.g., seasonal and diurnal) and duration of interruption events at the county-level.[4] PRESTO uses those relationships to stochastically generate interruption events over a large number (1,000-20,000) of simulation years, allowing a user to develop probabilistic assessments of the impacts of these interruptions.

For the analysis presented here, we used PRESTO to simulate power interruptions over 1,000 simulation years for three U.S. counties. For Maricopa County, the model generated 1,520 interruption events, equivalent to an average interruption frequency of 1.52 events per year. As shown in the left-hand panel of Figure 1, most of those interruption events were relatively short-duration, with a median of 1.8 hours and a mean of 2.2 hours. As shown in the panel on the right, most of those interruptions occurred in July and August, during early morning hours.

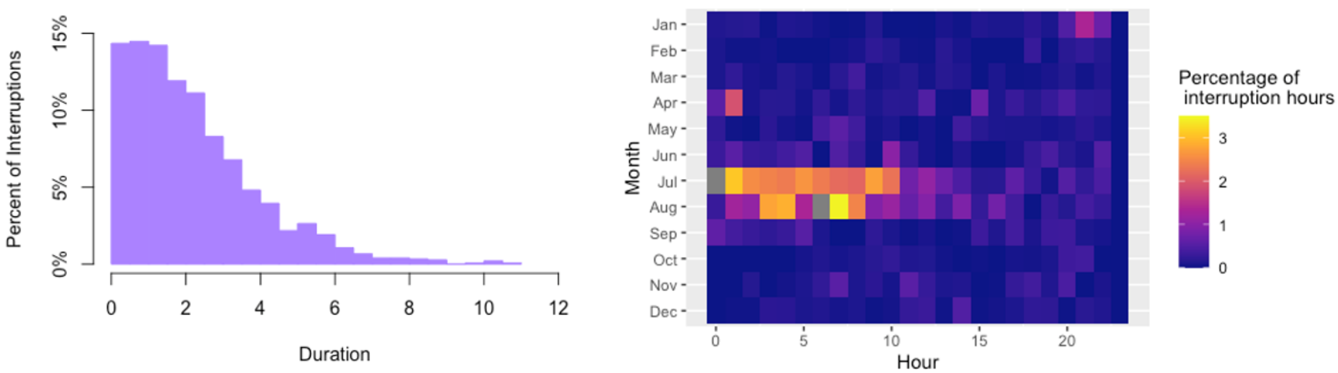

Figure 1. Histogram of interruption duration for the set of simulated interruption events in Maricopa County, Arizona (left) and heatmap showing the timing of those events (right).

Results

We initially consider a PVESS comprised of a PV system sized to meet the customer's annual electricity consumption combined with a 10-kWh battery. A battery of this size is at the smaller end of the spectrum of what is typically observed in the market today.[5] We assume that the customer charges the battery only from solar generation (i.e., no grid charging)[6], but otherwise schedules charging and discharging each day to minimize the electricity bill under the local utility's existing time-of-use rate and does not retain any battery capacity in reserve for possible power interruptions beyond a minimum 5% state of charge. Later results consider several variations on this set-up.

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[4] Further details on the historical interruption data and the model structure are provided in the PRESTO model documentation.
[5] This corresponds to a single LG Chem RESU10H, one of the more common residential batteries, while a Tesla PowerWall has a somewhat larger storage capacity of 13.5 kWh.
[6] The assumption of no grid-charging is partially meant to reflect limitations previously imposed by the federal investment tax credit, which was available to battery storage only if charged primarily from solar (or other renewables), as well as limitations on grid charging that may be imposed by the utility, the battery software, or third-party owners of the system.

Customers often configure their PVESS to provide backup power to designated loads on specific critical load circuits. Here we consider three such configurations: a *limited critical load* case, where the PVESS provides backup power only to refrigeration, nighttime lighting, and 70 Watts of plug loads (e.g., for internet and cell-charging); a *critical load* case, where backup is also provided to heating and cooling equipment, along with the aforementioned end-uses; and a *whole-home* backup case.

Figure 2 shows the distribution in backup performance across all 1,520 simulated power interruption events in Maricopa County, for each of the three critical load configurations described above. As shown, the system meets *less than* 100% of backup load in 16% of interruptions for limited critical load backup, 48% for full critical load backup, and 57% for whole-home backup. To be sure, these results reflect a conservative set of assumptions and thus represent something of a lower bound. In practice, higher levels of backup performance may be achieved by reducing energy consumption during interruption events (e.g., by adjusting thermostat set-point), by programming the battery to retain additional charge in reserve in case of power interruption, or by charging the battery from the grid during off-peak hours. Later results examine that latter approach, as well as results for systems with a larger battery.

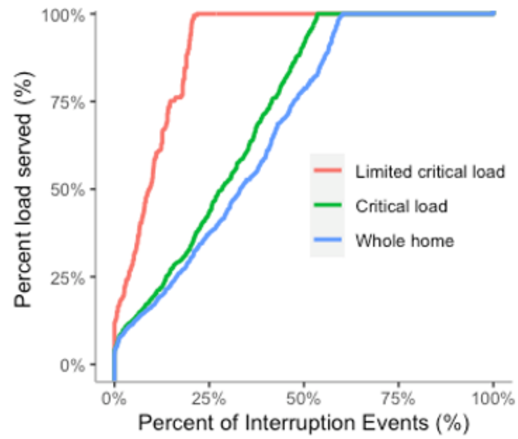

Figure 2. PVESS backup performance for three backup load configurations.

The ability of PVESS to provide backup power during short-duration interruption events may depend on when and for how long the interruption occurs. Figure 3 shows that backup performance generally declines with longer events (albeit with an upturn after 6 hours). However, even for events less than an hour, the PVESS modeled here serves only around 75% of critical load, on average. The scenario shown here is based on the case where backup loads include heating and cooling, and thus an inability to provide complete backup in some cases may reflect the combination a relatively large amount of air-conditioning load and a low state of charge on the battery at the beginning of the event.

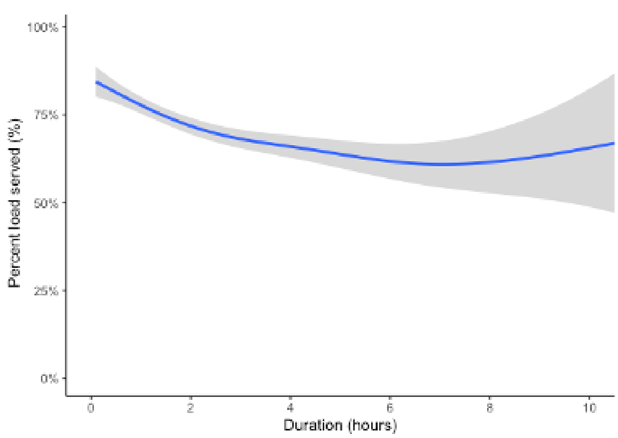

Figure 3. Fitted trendline and confidence interval showing how backup power performance varies with interruption duration (critical load backup with heating and cooling)

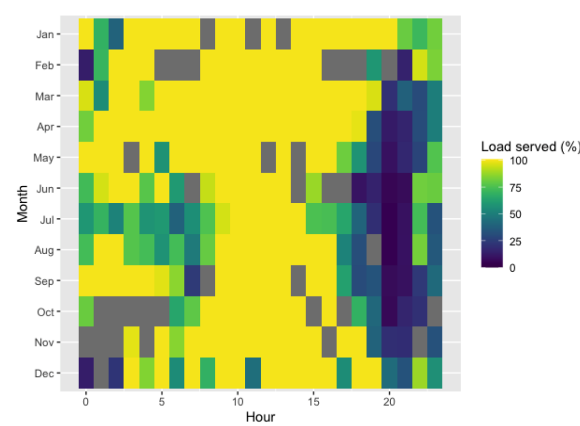

Figure 4. Heatmap showing percent of load served based on the timing of the interruption (critical load backup with heating and cooling). Grey boxes signify no interruptions.

Figure 4 shows how backup performance may also be impacted by the timing of the interruption event. As indicated, performance is lowest for interruptions during early evening hours in warm-weather months. This is driven in part by the utility's TOU schedule, which incentivizes battery discharge from 3-8 pm, meaning that little charge will remain for interruptions starting in the early evening hours after the sun has set, which is further compounded by the fact that air-conditioning load is often still substantial during those hours. However, as noted earlier, most interruptions in Maricopa County occur during early morning hours. As Figure 4 shows, backup performance during those hours typically hovers around 75% of load served, as the battery has limited charge during those hours, before sunrise.

A number of strategies may be employed to improve backup performance; here we consider two. Customers may, of course, install larger batteries, and we consider a PVESS system with 30 kWh of battery storage—at the larger end of the spectrum of typical residential systems today. We also consider a case where the customer charges the battery from the grid, rather than doing so exclusively with PV generation. Depending on a utility's net metering or interconnection rules, and on whether/when the customer received a federal tax investment credit for the battery, this may or may not be permitted. As shown in Figure 5, both strategies substantially improve performance. Notably, the grid charging case outperforms the larger battery. In neither case, however, is the PVESS able to provide complete backup to heating and cooling loads in all interruptions.[7] Additional strategies for improving backup performance, which are not explored here, include: (i) holding some portion of battery capacity in reserve for possible power interruptions and (ii) adjusting thermostat set-points or otherwise reducing loads during interruption events.

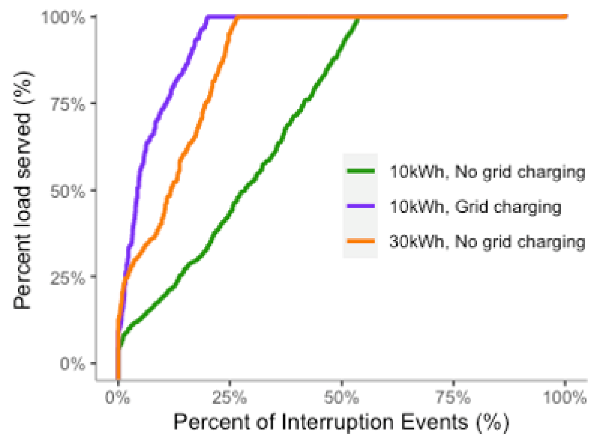

Figure 5. PVESS backup performance for scenarios with a larger battery or with grid charging (critical load backup with heating and cooling)

Finally, Figure 6 illustrates how PVESS backup performance during short-duration power interruptions can vary regionally, comparing results across typical single-family homes in three counties: Los Angeles (California), Maricopa (Arizona), and Middlesex (Massachusetts). The results here are based on a PVESS with 10 kWh of storage and no grid charging, and for backup of critical loads that include heating and cooling. Not surprisingly, backup performance is higher in Los Angeles and Middlesex counties, compared to Maricopa, given the considerably lower cooling loads. None of the homes analyzed here have electric heating, though the home in Middlesex county has higher heating loads than the other two

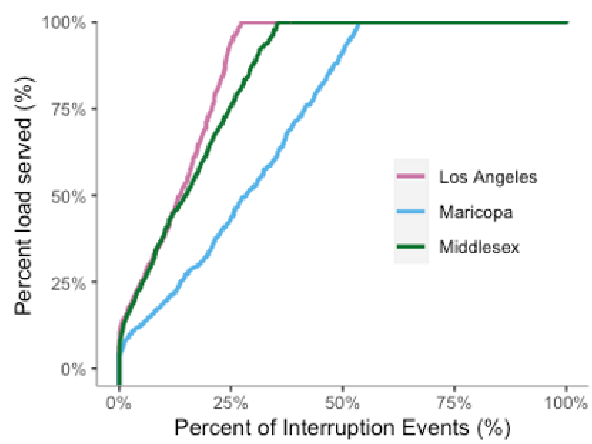

Figure 6. PVESS backup performance for three counties (critical load backup with heating and cooling)

[7] As shown in the Supplementary Information file, the 30-kWh battery does provide complete backup across all interruptions for the limited critical load scenario, where heating and cooling are excluded from the critical load.

counties, related to furnace fan usage.

Results also differ across counties as a result of interruption patterns. In both Los Angeles and Middlesex counties, power interruptions occur with relatively equal probability across hours of the day (as shown in Figures A3 and A4 in the Supplementary Information file), and thus the average state of charge on the battery at the beginning of the interruption is higher than in Maricopa, where the interruptions are more concentrated in early morning hours, when the battery state of charge tends to be lowest. Lastly, TOU rate structures also differ across these counties, which can impact the battery state-of-charge when interruptions occur. In particular, the TOU rate applicable in Middlesex county has a broad peak period from 8 am to 9 pm, which leads to more diffuse charging and discharging patterns, compared to the TOU structures in the other two counties, where peak period rates are concentrated in a much smaller number of hours.

Conclusions

Berkeley Lab's PRESTO model is a novel tool for simulating the occurrence of random short-duration power interruption events. As a demonstration of PRESTO's capabilities, this technical brief explores the potential for onsite PVESS as a backup power source. The analysis focuses on a typical single-family home in Maricopa County, Arizona. Under a conservative case involving a relatively small (10 kWh) battery, and where the customer charges the battery only from solar and does not hold any battery capacity in reserve for possible power interruptions, the system only partially meets backup load in 43-84% of interruptions, depending on the set of loads included for backup. Performance improves significantly for a 30-kWh PVESS or when grid charging is allowed, but the system still does not consistently meet 100% of backup load when heating and cooling end-uses are included. Comparisons to counties in California and Massachusetts illustrate how backup performance can vary regionally based on differences in climate (particularly if backup is provided to heating and cooling loads), the typical timing and duration of power interruptions, and retail rate structures.

While this case study analysis illustrates a number of key considerations for PVESS backup power applications, it by no means provides a comprehensive treatment. To do so would require both a broader geographic scope and a more robust scenario design. Among other things, future analyses should consider additional strategies and combinations thereof—including load controls to reduce consumption during interruption events and more advanced battery management strategies that retain varying quantities of battery capacity in reserve in case of possible power interruption. Any analysis of the latter would need to consider economic tradeoffs between reduced customer power interruptions (potentially monetized using the value of lost load) and reduced bill savings or revenues from participating in demand response or virtual power plant programs.

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