Hawaiʻi Natural Energy Institute Research Highlights

Energy Policy & Analysis

Curtailment and Grid Services with High Penetration Solar + Storage

OBJECTIVE AND SIGNIFICANCE: The Hawaiian Electric Company (HECO), with approval from the Hawaiʻi Public Utilities Commission (PUC), is negotiating power purchase agreements (PPA) for substantial amounts of utility-scale solar + storage assets in Hawaiʻi. The design and operation of these resources is expected to impact the ability to integrate these new resources into the grid, their ability to provide grid services, and on grid reliability. The objective of this study was to assess the impact of PPA structures and plant configurations on curtailment when large amounts of solar + storage are added to the grid and to identify how these solar + storage resources could be leveraged to increase value and flexibility.

KEY RESULTS: HECO is completing PPA negotiations that will add large amounts of utility scale PV, with the typical project having four hours of storage, based on plant nameplate capacity. The addition of storage to these future PV deployments significantly reduces but does not eliminate curtailment. Mitigations, such as the retirement of AES and cycling of select steam units, that provide additional "space" on the grid for variable renewables was found to significantly reduce the risk of curtailment. It was also found that curtailment likely occurred due to lack of load in the evening and nighttime hours, not a result of insufficient storage.

In addition, the current DC-connected systems and PPA structures that limit charging from the grid to achieve full tax credits may miss significant reliability benefits. Infrequent charging from the grid during rare events increases benefits to the system. Additional analysis is being conducted to quantify these potential benefits.

BACKGROUND: At the end of 2018, the Hawaiʻi PUC approved eight utility-scale solar + storage projects collectively referred to as "Stage 1." These projects, totaling 275 MWac of solar and 1,100 MWh of battery storage, are expected to be operational by the end of 2022. Of this total, 140 MW of solar with 558 MWh of storage is proposed for construction on Oʻahu. In a second solicitation, referred to as "Stage 2," HECO selected an additional seven solar + storage projects, totaling approximately 500 MW solar and 2,150 MWh of storage statewide that includes up to 287 MWac solar and 1,275 MWh of storage on Oʻahu. In addition to these projects, HECO is currently soliciting proposals for up to 235 MW of solar under their Community Based Renewable Energy (CBRE) efforts that are likely to include additional battery energy storage.

These changes are taking place against the backdrop of other significant changes to the grid, notably the retirement of the AES coal plant, the largest fossil generator on the Oʻahu grid. As a result, it is important to understand how the proposed solar + storage projects can be optimally utilized to ensure efficient grid operations in the future.

The primary use case of the proposed solar + storage projects is to mitigate potential oversupply of solar resources in the middle of the day and to shift energy into evening peak and overnight periods. This decreases the need for oil units to cycle on and off, reduces peak load, offsets more expensive oil-fired generation used during overnight periods, and minimizes curtailment. Details of the battery charging will depend on utility requirements and in some cases, restrictions in the PPA agreements, but in general, the optimal dispatch that minimizes total generation costs shows that battery charges to near full capacity during the day, then discharges during evening peak and overnight hours. The battery then discharges more during the morning load ramp and is near minimum state-of-charge by the beginning of the next daytime period.

Optimal economic dispatch shows that a significant fraction of the solar energy goes directly onto the grid. This is because any solar energy that cycles through the battery will incur additional round-trip efficiency losses of approximately 10 to 15%. As a result, if there is available room on the grid for more PV, the PV will flow directly to the grid, displacing oil-fired generation at the time the solar is produced. Additional constraints such as minimum state-of-charge and use of the battery for grid services will also impact the battery charging.

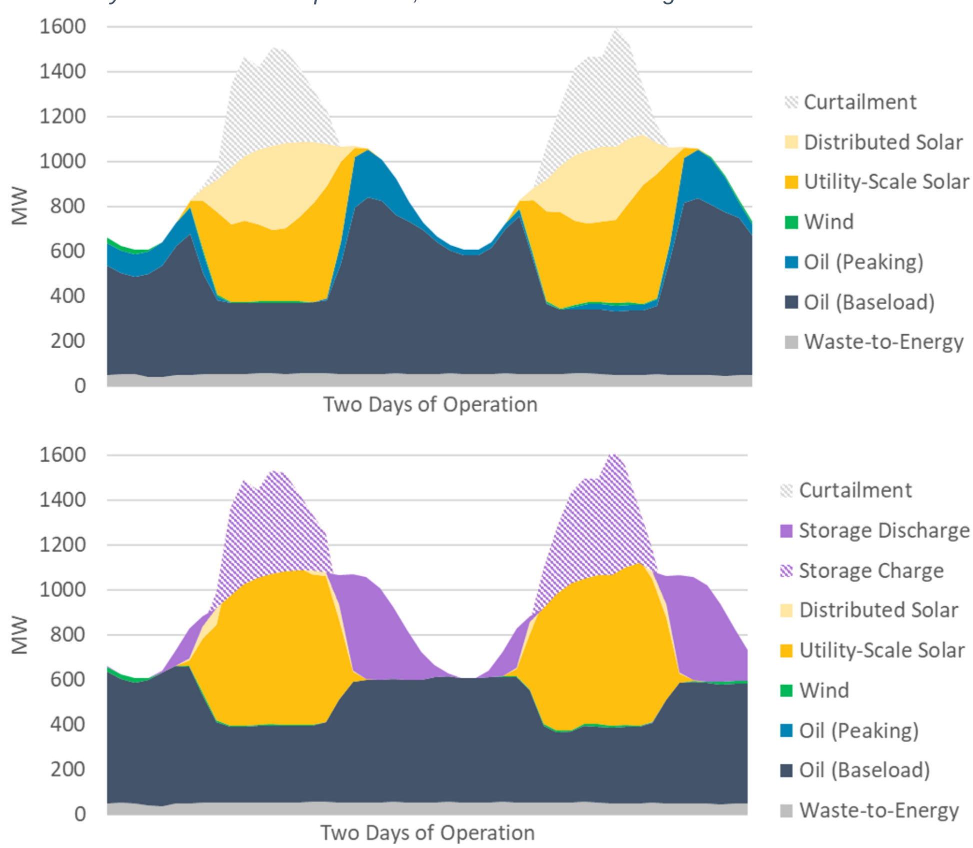
The figure on the following page illustrates the potential operations of the Oʻahu grid over a two-day period for two scenarios of solar deployment. The top chart shows representative grid operations with the addition of 800 MWac without storage while the bottom chart shows the same two days with 3200

MWh of storage included. In this example, all the energy that is curtailed without storage can be accommodated on the grid when storage is added. At higher penetrations, this is not the situation.

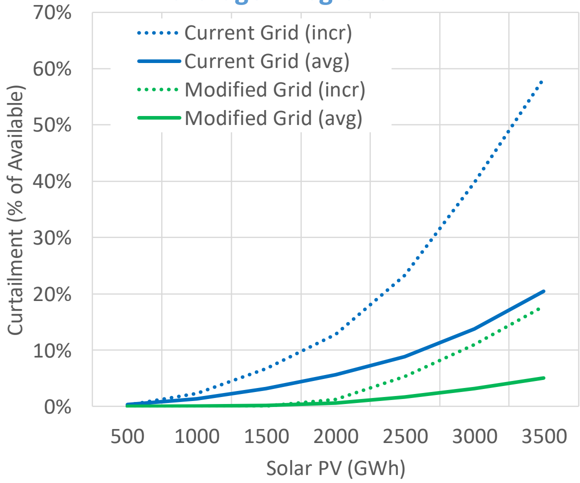
<u>PROJECT STATUS/RESULTS</u>: To understand the utilization of solar + storage at very high penetrations, a series of grid simulations were conducted with increasing blocks of solar capacity. Each block comprised 200 MWac of PV (500 GWh annually), with 800MWh of storage. Each block represents approximately 6.5% of O‘ahu’s annual energy needs. Blocks were added up to an additional 3500 GWh, which, when combined with existing renewables represented a 70% renewable share (~80% RPS).
The optimizations were conducted for two grid configurations, representing different thermal generation resource mixes. The first represents the “Current O‘ahu Grid,” and includes all fossil generating units currently in operation and must-run operations for the baseload steam oil units. The second represents a “Modified O‘ahu Grid,” in which the AES coal plant is assumed to be retired and the steam units can cycle on and off, providing increased grid flexibility and more “room” for accepting variable renewable energy onto the grid.

While storage will delay PV curtailments, it will not eliminate them. As shown in the figure on the following page, solar integration with AES still operational results in significant curtailment even when storage is included. With 1500 GWh of additional solar, overall curtailment reaches 3.2%. This curtailment increases to 20% of the total solar generation when 3500 GWh are added. More importantly, incremental curtailment of the last solar added rises quickly from 7% for the third 500 GWh block to just under 60% for the last block. With the retirement of the AES coal plant and ability for the baseload steam oil units to cycle offline or turn down to lower loading levels, curtailment is greatly reduced but not eliminated. Additional constraints may change these results when reliability and grid services are considered. The “**<u>Grid Reliability with AES Retirement</u>**” project summary discusses in detail potential reliability issues when AES is retired.

Two Days of Future Grid Operations, with and without Storage

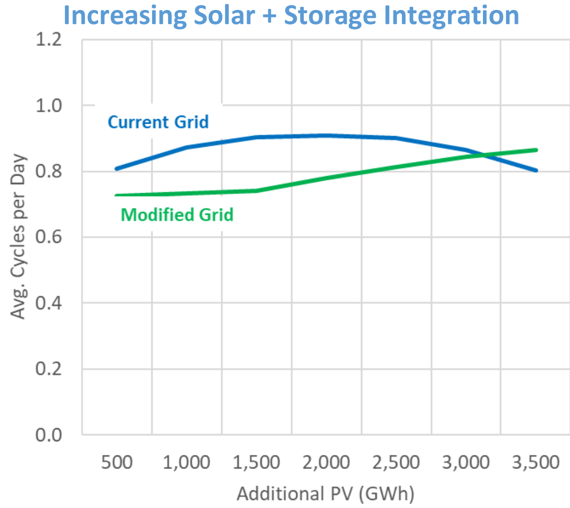


Solar Curtailment with Increasing Solar + Storage Integration



As shown below, batteries on average cycle less than one time per day under optimal operations, indicating that curtailment is not, in general, driven by the lack of available storage capacity but rather by "space" on the grid to discharge during evening and overnight periods. At a certain point, there is not enough load in the evening to adequately discharge before the solar generation starts again the next day. This may be alleviated by cycling select steam units or with further retirements, but this requires a more detailed evaluation including a careful analysis of grid service needs.

Average Daily Storage Cycles with Increasing Solar + Storage Integration

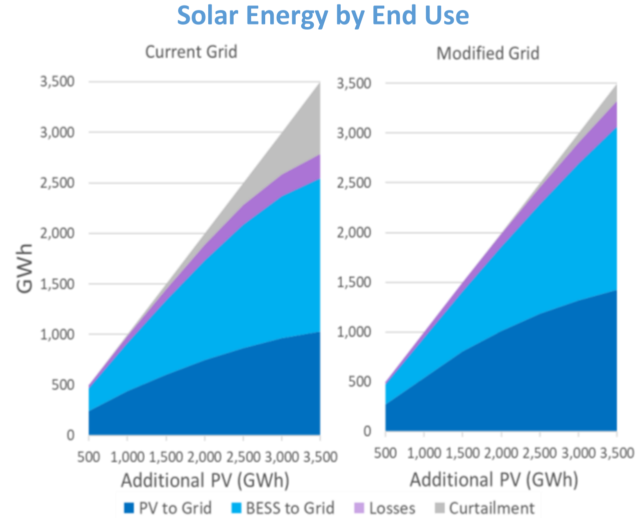


As noted previously, this analysis does not support adding additional storage as a means to mitigate curtailment. In fact, as shown in the previous figure, the daily average cycles per day is less than one for both grid configurations and for all additional blocks of solar + storage. In this analysis, a battery cycle is measured as the amount of round-trip *energy* that is charged and discharged relative to the capacity rating of the storage.

Under Current Grid assumptions, cycling duty of the storage increases as PV increases through 2,000 GWh of installed PV, but then decreases. This is attributed to a lack of evening load to fully discharge before the next day begins. While still averaging less than one cycle per day with the AES retirement, battery usage increases with increasing PV penetration. In this case, the additional "space" on the grid resulting from the AES retirement and steam-cycling allows more PV to go directly to the grid and more efficiently uses the available storage. Changes to load or load profiles as may occur with the addition of electric vehicles (EV) would likely modify this behavior.

The figure below, shows this from another perspective. This figure shows the fraction of the solar energy (aggregated for the year) that goes directly to the grid, goes to the grid via the storage, as losses in the system, and the amount that is curtailed. As noted above, the additional "space" on the grid resulting from the retirement of AES allows a larger fraction of solar-generated energy to go directly to the grid, reducing the fraction required to be stored for evening with a substantial reduction in curtailment.

Solar Energy by End Use



In Hawai‘i, most battery installations will not be standalone, but instead will be coupled with an adjacent solar PV system with shared plant and transmission infrastructure similar to the trend seen throughout the country. There are several other reasons for this trend:

- Investment Tax Credit: As long as storage is charged 75% from renewable energy it qualifies for the ITC, which can offset up to 30% of the initial capital cost;
- Shared infrastructure: Hybrid projects share the same transmission infrastructure across both solar and storage systems;
- Simplified procurement: Hybrid projects allow utilities to bundle the procurement into a single PPA and purchase the renewable energy and storage services on a simple $/MWh basis, streamlining the regulatory approval process; and

While the hybrid configurations bring many advantages, including those listed above, they can also introduce both technical and contractual restrictions that result in additional operating constraints. Across North America, the majority of solar + storage projects are developed in a DC-coupled configuration because it captures additional energy due to "clipping losses" attributed to high DC:AC ratios and shared transmission interconnection infrastructure. However, with Hawai'i's small, low inertia grids, there may be additional benefits to AC coupling (see figure below). Specifically, AC-coupled solar + storage projects afford more flexibility for system operators as both the battery storage and solar portions of the plant can be used in parallel, effectively doubling the capacity of the resource during critical time periods. This could, for example, negate the need for additional standalone storage.

Fast frequency response has the potential to be especially valuable on the island's grids. Preliminary model results indicate that AC-coupling can provide up to two times more reserve capability during mid-day hours when system inertia is lowest and increase the total reserve availability by up to 30% over the year. HNEI is conducting additional analysis to assess benefits that may accrue from alternative solar + storage configurations as well as possible benefits that may accrue if direct charge from the grid is also implemented.

Based these results, it is clear that hybrid solar + storage additions can provide significant value to Hawai'i's grids, both with the ability to shift solar energy to evening and overnight periods and to provide grid services.

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Contact: Richard Rocheleau, rochelea@hawaii.edu

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